



Differential Response of Soybean Genotypes to Photoperiod and Temperature

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ABSTRACT

Background: Soybean is a short-day crop whose growth, development and productivity are significantly influenced by photoperiod and temperature. Hence, the crop is restricted to rainy season cultivation in India.

Methods: The study included fifteen soybean genotypes assessed for physiological, phenological, yield and quality traits grown under three distinct photoperiod and seasons (*kharif*, *rabi* and *summer*). The variation was assessed for different traits in all the three seasons.

Result: Significant genetic variability was observed for all the phenological, physiological, yield and yield traits across the different seasons. Across genotypes, the oil content increased in *rabi* due to reduced photoperiod (11 h 20 min). There was increased SPAD chlorophyll meter reading during *rabi* over *kharif*. During summer, highest per cent increase was exhibited by chlorophyll 'b' followed by days to initiation of flowering, days to 50 per cent flowering, SPAD Chlorophyll Meter Reading (SCMR) and total chlorophyll when compared to *kharif* season. The increase in chlorophyll content could be attributed to higher temperature during summer (33.8°C) over *kharif* (28.3°C) due to increase in enzyme activity up to a certain level of raise in temperature (35°C) in soybean. A marked reduction in seed yield was recorded during *rabi* (up to 57.2%) and summer (up to 76%) compared to *kharif*, the usual growing season in India, primarily due to reduced photoperiod and elevated temperatures that shortened the growth cycle and adversely affected pod number, plant height and seed weight. Notably, MACS 330 showed photoperiod insensitivity for days to maturity while, DSb 34 exhibited yield stability with less seasonal reduction for different traits, suggesting their potential for cultivation under variable environments.

Key words: Genotype × Season interaction, Photoperiod, Soybean, Temperature, Yield stability.

INTRODUCTION

Soybean [*Glycine max* (L.) Merrill], a major legume crop, is valued for its high protein (30-45%) and moderate oil (15-24%) content. In addition to being a source of essential amino acids, vitamins and nutraceutical compounds, soybean contributes to sustainable agriculture through nitrogen fixation and adaptability to diverse cropping systems. Globally, soybean was cultivated on 130 million hectares with a production of 372 million tonnes during 2021-22. Brazil, USA, Argentina, China and India are the top producers, with India contributing 3% of global production. In India, Maharashtra and Madhya Pradesh states dominate soybean production.

Soybean growth is highly sensitive to environmental factors, particularly photoperiod and temperature. As a quantitative short-day plant, soybean's flowering, morphology and yield are influenced by day length and thermal regimes, which vary with season and location (Han *et al.*, 2006). Soybean crop growth is restricted to particular season especially rainy season in India due to this photo-thermo sensitiveness. To overcome these environmental barriers and extend adaptability, identifying specific genetic traits that modulate flowering time under varying day lengths are important in legume breeding (Sapey *et al.*, 2021). Due to high protein content and good quality oil, there is ever increasing demand for soybean. This can be achieved

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by increasing the crop area in the main season of its cultivation, or extending its cultivation to non-traditional areas. Both these are not practically achievable and hence

the better alternative will be extending its cultivation to non-traditional seasons *i.e.*, *rabi* and summer in Indian context. Genotypes differ in their response to different environmental factors existing in different growing seasons (Deshmukh *et al.*, 2019; Mattos *et al.*, 2020), making genotype selection for photoperiod and temperature adaptability essential for stable performance across diverse environments (Tiwari *et al.*, 2016).

The global demand for vegetable oils is increasing with limited arable land, expanding soybean cultivation into new regions and seasons are critical. This requires identifying genotypes with stable yield across diverse environments without much effect on the protein and oil content. This study aims to evaluate the response of diverse soybean genotypes to varying photoperiod and temperature conditions grown under three different seasons for phenological, physiological, yield, yield components and quality traits. Further the study helps in identification of soybean genotype(s) with superior adaptability and yield stability across seasons.

MATERIALS AND METHODS

The study consisted fifteen soybean genotypes, including MACS 330 (photoperiod-insensitive; Singh *et al.*, 2008), obtained from Agharkar Research Institute, Pune, while the remaining genotypes (Local black soybean, JS 335, JS 93-05, DSb 21, DSb 23, DSb 28, DSb 33, DSb 34, DSb 39, DSb 40, DLSb 1, DLSb 3, DLSb 5 and DLSb 6) were sourced from All India Coordinated Research Project on Soybean, University of Agricultural Sciences (UAS), Dharwad. The experiment was conducted at the Main Agricultural Research Station, University of Agricultural Sciences, Dharwad, during *kharif* 2022, *rabi* 2022-23 and summer 2023. Meteorological data (Rainfall, temperature, humidity) were recorded at the station and day length data was obtained from NASA-GISS.

Experimental design and crop management

A randomized complete block design with three replications was used. Each plot measured 4 m × 1.2 m, consisting of four rows of 4 meter length per genotype, with spacing of 30 cm and 10 cm between rows and plants, respectively. During *kharif*, genotypes were sown on 17th June 2022 while, during *rabi*, the sowing was taken up on 29th October 2022 and during summer, sowing was on 11th January, 2023. Recommended agronomic practices were followed to raise good crop. Irrigation was given both under *rabi* and summer seasons while during *kharif* season only protective irrigation was provided.

Physiological traits

SPAD chlorophyll meter reading (SCMR) was measured at 45 DAS using SPAD-502 Plus on third trifoliate leaf from top and mean of five plants was considered for analysis. Chlorophyll a, b and total were estimated adopting DMSO method at 45 DAS using Arnon (1949) method. Growing degree days (GDD) was calculated at flowering

and maturity stages using the following formula given by Monteith (1984).

$$GDD = \frac{\sum (T_{max} + T_{min})}{2 - T_{base}}$$

Where,

$T_{base} = 10^{\circ}\text{C}$.

Phenological and morphological traits

Days to initiation and fifty per cent flowering was recorded as days from sowing to first flowering and flowering in 50% of plants in the plot. Days to Maturity was taken as days from sowing to 90% pod maturity. Plant height in cm was measured at maturity in five tagged plants per replication.

Quality parameters

Seed Protein Content was estimated *via* Kjeldahl method wherein the nitrogen content was multiplied by 6.25. Seed oil content was measured in each genotype using NMR (MCQ+) at University of Agricultural Sciences Raichur, Karnataka.

Yield and yield components

Branches per plant, pods per plant were taken at maturity in five randomly tagged plants. Seeds per pod was counted in 10 pods from five tagged plants. 100-seed weight (g) was measured from each replication taking random 100 seeds. Seed yield (kg/ha) was recorded from plot yield converting with suitable conversion factor and expressed in kg/ha.

Statistical analysis

The data on various traits was analyzed season-wise using R software and mean performance of each soybean genotype was compared among the three seasons with assessment of reduction in *rabi* and summer season over *kharif* season.

RESULTS AND DISCUSSION

Fifteen soybean genotypes were evaluated to assess their response to different photoperiods and temperature regimes (*kharif* 2022, *rabi* 2022-23 and summer 2023). The choice of the experimental time frame was based on the analysis of day length during the crop period for Dharwad location which indicated that *kharif* (17th June-2nd October) had highest day length (12 h 33 minutes) followed by summer (11th January-2nd May, 11 h 56 minutes) and *rabi* (29th October-7th February, 11 h 20 minutes). The variation in the photoperiods during *kharif* 2022, *rabi* 2022-23 and summer 2023 has been depicted in the Fig 1. The maximum temperature in the location also varied during *kharif* (28.3°C), *rabi* (30.1°C) and summer (33.8°C, Table 1). This is a pre-requisite to assess the role of vartyping photoperiod and temperature on the soybean growth and reproductive traits.

Significant mean sum of squares attributable to genotypes was observed for physiological traits (SPAD

Table 1: Mean sum of squares of different traits in soybean for *kharif* 2022, *rabi* 2022-23 and summer 2023.

A) Physiological traits													
Source of variation	df	SCMR			CHA			CHB			CHT		
		K	R	S	K	R	S	K	R	S	K	R	S
Replication	2	1.48	0.42	1.60	0.0001	0.002	0.004	0.0006	0.002	0.003	0.002	0.001	0.01
Genotypes	14	19.52**	13.02**	21.29**	0.04**	0.05**	0.04**	0.04**	0.03**	0.58**	0.06**	0.12**	0.92**
Error	28	1.31	0.39	1.63	0.0004	0.001	0.002	0.0004	0.001	0.004	0.001	0.001	0.01
Total	44	22.31	13.83	24.52	0.0405	0.053	0.046	0.041	0.033	0.587	0.063	0.122	0.94
B) Phenological traits													
Source of variation	df	DIF			DFF			DM			PH		
		K	R	S	K	R	S	K	R	S	K	R	S
Replication	2	0.29	0.07	0.87	0.02	0.09	1.69	0.47	1.09	0.03	1.67	0.09	2.93
Genotypes	14	40.13**	28.61**	78.57**	41.42**	12.88**	76.64**	238.32**	99.12**	200.96**	310.11**	80.23**	500.16**
Error	28	0.29	0.30	1.01	0.24	0.23	0.98	0.35	0.57	0.18	2.29	0.54	3.93
Total	44	40.71	28.98	80.45	41.68	13.2	79.31	239.14	100.78	201.17	314.07	80.86	507.02
C) Yield components, yield and quality traits													
Source of variation	df	NBP			NPP			NSP			HSW		
		K	R	S	K	R	S	K	R	S	K	R	S
Replication	2	0.07	0.09	0.02	1.76	0.20	0.09	0.02	0.02	0.02	0.02	0.001	0.02
Genotypes	14	0.77**	0.88**	1.36**	202.85**	122.76**	128.68**	0.52**	0.50**	0.41**	2.35**	6.84**	2.96**
Error	28	0.07	0.09	0.03	2.45	0.11	1.87	0.02	0.07	0.02	0.04	0.023	0.01
Total	44	0.91	1.06	1.41	207.06	123.07	130.64	0.56	0.59	0.45	2.41	6.864	2.99
Source of variation	df	SY			PC			OC			OC		
		K	R	S	K	R	S	K	R	S	K	R	S
Replication	2	45388	9565	8131	0.02	0.06	0.02	0.06	0.08	0.03	0.07	0.07	0.14
Genotypes	14	1439413**	988604**	451890**	3.58**	3.63**	4.00**	3.63**	4.00**	12.08**	9.11**	9.11**	5.79**
Error	28	112369	21029	25399	0.02	0.03	0.02	0.03	0.06	0.15	0.89	0.89	1.18
Total	44	1597170	1019198	485420	3.62	3.72	4.14	3.72	4.14	12.26	10.07	10.07	7.11

* and ** - Significant at 5 % and 1 % level of probability, respectively.

df: Degrees of freedom; K: *Kharif*; R: *Rabi*; S: Summer; SCMR: SPAD chlorophyll meter reading; DIF: Days to initiation of flowering; CHA: Chlorophyll 'a'; DFF: Days to 50 per cent flowering; CHB- Chlorophyll 'b'; DM: Days to maturity; CHT: Total chlorophyll; PH: Plant height. NBP: Number of branches per plant; SY: Seed yield; NPP: Number of pods per plant; PC: Protein content; NSP: Number of seeds per pod; OC: Oil content; HSW: Hundred seed weight.

chlorophyll meter reading at 45 DAS, chlorophyll 'a', 'b' and total at 45 DAS), phenological traits (Days to initiation of flowering, days to 50 per cent flowering and days to maturity), yield components (Plant height, number of branches per plant, number of pods per plant, number of seeds per pod, hundred seed weight), seed yield and seed quality traits (Protein content and oil content) during *kharif* 2022, *rabi* 2022-23 and summer 2023 (Table 1). This signifies the existence of genetic variability among genotypes for different seasons (Photoperiods and temperature). The availability of genetic variability is a pre-requisite for further analysis and gives scope for the selection of stable genotypes across seasons. Earlier, Ibrahim (2012); Kandil *et al.* (2012); Deshmukh *et al.* (2019); Mandić *et al.* (2020) and Saicharan *et al.* (2022) reported significant differences among soybean genotypes for different traits under different seasons.

The analysis of per cent change for various traits across the studied genotypes during *rabi* over *kharif* season revealed that the highest reduction occurred for seed yield followed by plant height, number of pods per plant, chlorophyll 'b' and chlorophyll 'a' while, least was exhibited by number of seeds per pod across genotypes (Table 2). The reduction in seed yield can be attributed to insufficient vegetative growth (Fatichin *et al.*, 2009), decreased light interception (Umburanas *et al.*, 2019; Nleya *et al.*, 2020) and reduced growth cycle (Mattos *et al.*, 2020) and reduced photoperiod during *rabi* (11 h 20 min) when compared to *kharif* (12 h 33 min). Reduced photoperiod during *rabi* caused early flowering which resulted in shorter plants that had lower vegetative growth, fewer pods per plant, smaller seed size and ultimately lower seed yield (Ibrahim, 2012; Umburanas *et al.*, 2019; Mattos *et al.*, 2020). Number of seeds per pod was consistent across seasons implying less effect of photoperiod and temperature on this trait

which could be due to no effect of prevailing environmental conditions on ovule fertilization success or embryo retention. The genotype MACS 330 attained maturity at 69 DAS during *kharif*, 70 DAS during *rabi* and summer indicating its photoperiod and temperature insensitivity with respect to days to maturity. Earlier, Kumar *et al.* (2005) observed similar results in MACS 330 while studying under different photoperiods.

During summer, highest per cent reduction was observed for seed yield followed by number of pods per plant, hundred seed weight, plant height and chlorophyll 'a' whereas, least reduction was observed for days to maturity and protein content across genotypes during summer over *kharif* (Table 2). The decrease in seed yield can be ascribed to the prevailing photoperiod (11 h 56 min) and elevated temperatures (average: 33.8°C) between 32 and 37°C during summer, which had a major influence on soybean seed yield (Zheng *et al.*, 2009; Mishra and Cherkauer, 2010; Hu and Wiatrak, 2012; Mandić *et al.*, 2020) and number of pods per plant (Hu and Wiatrak, 2012; Puteh *et al.*, 2013). The reduction in hundred seed weight is attributed to increased temperature, plant's response to the increased temperature and reduction in seed reserve (Yari *et al.*, 2013; Mandić *et al.*, 2020).

Among the genotypes studied, DSb 34 exhibited low per cent reduction during *rabi* (51.6%) and summer (50.6%) over *kharif* with high seed yield of 1697 kg ha⁻¹ during *rabi* and 1731 kg ha⁻¹ during summer when compared to *kharif* (3503 kg/ha). Therefore, DSb 34 might be considered as stable genotype across the three seasons as it is high yielding and exhibited low per cent reduction during *rabi* and summer over *kharif*.

As far as oil content is concerned, there was per cent increase (4.3%) during *rabi* over *kharif* season. The oil content increased due to reduced photoperiod (11 h

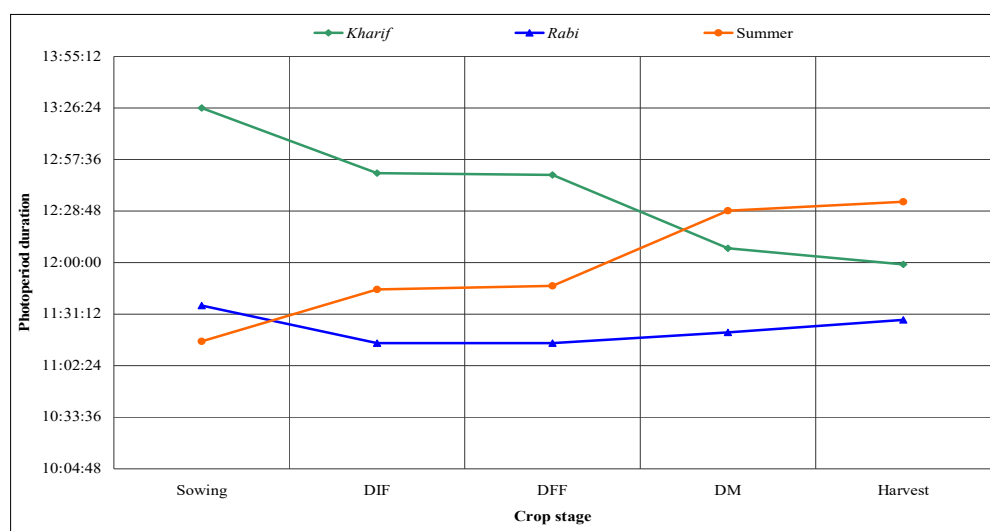


Fig 1: Photoperiod duration in *kharif*, *rabi* and *summer* during different growth stages of soybean at University of Agricultural Sciences, Dharwad.

Table 2: Per cent change in *rabi* 2022-23 and summer 2023 over *kharif* 2022 of soybean genotypes for various traits.

Genotype	SPAD chlorophyll meter reading				Chlorophyll 'a'				Chlorophyll 'b'				Total chlorophyll				Days to initiation of flowering				Days to 50 per cent flowering				Days to maturity				Plant height			
	% C1	% C2	% C1	% C2	% C1	% C2	% C1	% C2	% C1	% C2	% C1	% C2	% C1	% C2	% C1	% C2	% C1	% C2	% C1	% C2	% C1	% C2	% C1	% C2	% C1	% C2	% C1	% C2	% C1	% C2	% C1	% C2
DSb 21	8.0	14.4	-25.0	-25.0	-16.2	-15.4	-23.3	-23.1	-7.5	8.2	-7.8	6.4	-11.2	1.7	-26.0	7.8																
DSb 23	12.7	15.8	-30.4	-31.3	-35.1	-22.2	-32.1	-29.2	-6.8	9.8	-6.5	10.1	-9.2	2.3	-37.8	-1.9																
DSb 28	-4.6	-0.3	-30.1	-20.8	-42.1	105.2	-33.7	12.0	-2.3	19.5	-4.9	15.4	-7.3	-4.0	-36.8	-39.2																
DSb 33	-0.7	13.0	-36.1	-8.1	-59.9	81.8	-43.5	17.7	-7.9	6.3	-7.6	5.3	-8.8	0.0	-37.7	-20.6																
DSb 34	2.5	5.1	-38.9	-14.2	-51.3	105.8	-42.5	17.6	-7.8	7.8	-7.5	7.5	-11.4	4.2	-47.0	-21.0																
DSb 39	17.3	13.0	-22.7	-20.0	7.2	142.3	-16.7	14.3	-9.0	6.7	-8.6	6.4	-12.4	-3.2	-34.7	-23.3																
DSb 40	10.0	-2.6	-29.7	-24.9	-35.0	-9.8	-31.4	-21.4	-8.8	4.0	-10.5	2.3	-8.2	4.3	-45.5	-23.0																
DLSb 1	-2.0	-2.3	-23.6	-25.1	-49.3	-29.1	-31.5	-26.6	-1.5	10.8	-1.5	9.6	-11.9	-1.9	-35.7	-17.8																
DLSb 3	7.1	-4.1	-18.8	-20.4	-54.2	-18.2	-30.5	-20.3	-7.3	-1.6	-7.7	-2.3	-13.1	-2.0	-50.7	-29.3																
DLSb 5	15.2	-9.0	-26.2	-14.4	-57.4	131.3	-35.0	23.9	-5.7	2.4	-8.4	0.8	-9.2	-4.6	-55.1	-38.9																
DLSb 6	-2.9	-10.2	-36.3	-21.3	-19.7	153.3	-33.3	11.6	-8.9	-2.4	-11.4	-3.8	-20.7	-14.7	-64.6	-45.3																
JS 335	1.3	11.4	-28.4	-15.2	-26.7	95.9	-28.3	14.6	-6.5	-2.4	-6.2	-1.6	-9.5	-2.9	-45.5	-17.2																
JS 93-05	-1.4	-6.6	-24.8	-11.8	-52.2	75.7	-33.3	13.4	-7.3	3.3	-8.5	3.9	-9.2	3.3	-40.3	-26.5																
LBS	-6.6	-9.6	-19.3	-9.5	-16.2	143.5	-18.9	28.1	-12.5	1.4	-12.0	0.7	-18.6	-1.4	-44.8	17.8																
MACS 330	-0.3	5.7	-22.8	-21.6	-44.6	54.7	-28.6	-3.2	59.1	3.2	52.5	3.0	1.9	1.9	-52.5	-41.3																
Mean	3.7	2.2	-27.5	-18.9	-36.8	66.3	-30.8	2.0	-2.7	5.1	-3.8	4.2	-10.6	-1.1	-43.6	-21.3																

Table 2: Continue..

Genotype	Number of branches per plant		Number of pods per plant		Number of seeds per pod		Hundred seed weight		Seed yield		Seed protein content		Seed oil content	
	% C1	% C2	% C1	% C2	% C1	% C2	% C1	% C2	% C1	% C2	% C1	% C2	% C1	% C2
DSb 21	-33.3	-33.3	-24.5	-57.1	0.0	0.0	-7.6	-19.5	-57.1	-82.0	-2.8	-0.3	8.3	2.1
DSb 23	-20.0	-20.0	-37.5	-29.2	0.0	0.0	-2.4	-31.0	-45.3	-78.9	-3.0	-0.5	0.3	13.3
DSb 28	-33.3	-16.7	-36.5	-50.0	0.0	0.0	-3.0	-27.4	-28.1	-80.4	-2.4	-2.1	5.5	-18.1
DSb 33	-20.0	0.0	-40.4	-48.9	0.0	-25.0	-5.9	-26.7	-57.3	-66.8	-5.5	-1.8	3.5	-8.1
DSb 34	-20.0	0.0	-47.1	-27.5	0.0	0.0	-6.3	-20.3	-51.6	-50.6	-5.3	-2.8	2.7	-7.9
DSb 39	-20.0	-20.0	-32.7	-57.1	0.0	0.0	-10.3	-25.0	-50.7	-79.1	-5.5	1.6	-0.2	11.6
DSb 40	0.0	-20.0	-42.9	-44.9	0.0	0.0	-7.4	-32.4	-63.1	-85.2	-4.4	-3.0	-4.3	-8.1
DLSb 1	-20.0	-20.0	-28.8	-53.8	0.0	0.0	-12.1	-30.3	-41.0	-93.6	-3.7	-1.2	22.3	7.2
DLSb 3	-40.0	0.0	-52.0	-32.0	0.0	0.0	-6.1	-20.6	-68.3	-74.0	-5.3	-1.4	2.7	-15.5
DLSb 5	0.0	0.0	-38.0	-60.0	0.0	0.0	-5.1	-34.6	-69.6	-74.1	-2.8	-1.2	1.4	0.2
DLSb 6	-20.0	-20.0	-44.9	-49.0	0.0	0.0	-2.2	-22.6	-64.5	-79.9	-4.2	-1.2	-2.6	-10.6
JS 335	-33.3	-33.3	-36.5	-21.2	0.0	0.0	-13.7	-23.7	-64.3	-69.3	-1.8	1.7	-8.5	-5.1
JS 93-05	-33.3	-33.3	-38.3	-48.9	0.0	-25.0	-9.6	-28.9	-68.6	-69.1	-7.7	-4.6	0.1	-15.4
LBS	0.0	20.0	-44.1	-67.6	-33.3	-33.3	-42.4	-48.0	-58.1	-82.6	-5.6	-2.8	19.2	17.5
MACS 330	-25.0	-50.0	-52.0	-12.0	0.0	0.0	-33.3	-39.0	-70.9	-75.2	-1.7	0.5	13.5	2.1
Mean	-21.2	-16.4	-39.7	-44.0	-2.2	-5.6	-11.2	-28.7	-57.2	-76.0	-4.1	-1.3	4.3	-2.3

K- Kharif, R-Rabi, S-Summer, % C1- Per cent change in rabi 2022-23 over kharif 2022, %C2- Per cent change in summer 2023 over kharif 2022 CV-Coefficient of variation, CD- Critical difference.

20 min) in *rabi* (Junior *et al.*, 2017). Similarly, there was increased SCMR (3.7 %) during *rabi* over *kharif*. Highest per cent increase was exhibited by chlorophyll 'b' followed by days to initiation of flowering, days to 50 per cent flowering, SCMR and total chlorophyll during summer over *kharif* (Table 2). The increase in chlorophyll content could be attributed to higher temperature during summer (33.8°C) over *kharif* (28.3°C).

CONCLUSION

The present study demonstrated significant genotypic variability in response to seasonal photoperiod and temperature variations across *kharif*, *rabi* and *summer* seasons. Photoperiod sensitivity notably influenced phenological, physiological and yield-related traits in soybean. Seed yield declined substantially under *rabi* and summer conditions, primarily due to reduced photoperiod and elevated temperatures, which adversely affected plant height, pod number and seed weight. However, traits such as number of seeds per pod and days to maturity in some genotypes showed minimal seasonal variation, indicating partial or complete photoperiod insensitivity. Genotype MACS 330 exhibited photoperiod insensitivity for maturity duration, while DSB 34 demonstrated yield stability across seasons, making it a promising candidate for cultivation under diverse environmental conditions. Overall, the findings highlight the importance of evaluating soybean genotypes under contrasting photoperiod regimes to identify stable, high-yielding and photoperiod and thermo-resilient genotypes for year-round cultivation.

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Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Informed consent

No animal was involved in the conduct of the research.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish, or preparation of the manuscript.

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