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GENES OF PHOTOPERIODIC SENSITIVITY AND EARLY MATURITY *E1-E4*: DYNAMICS OF SOYBEAN GROWTH IN DIFFERENT DAYLENGTH CONDITIONS

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Background. Morphometric indicators are crucial for evaluating the development and productivity of soybeans. They are influenced by genetic and environmental factors. The use of nearly isogenic soybean lines is a convenient model for determining the impact of early maturity genes and daylength on growth indicators. The aim of this study was to determine the influence of different daylengths and early maturity genes on soybean morphometric indicators under conditions of the temperate zone (at the latitude of Kharkiv – 50° N).

Materials and Methods. The study involved nearly isogenic soybean lines of the "Clark" cultivar with varying sensitivity to daylength. The research covers the results of field experiments over three seasons using different soybean lines. After reaching the V3 stage, some plants were subjected to short-day conditions for 14 days. Morphological indicators of ten plants per experimental variant were determined: plant height, dry weight, leaf number, and leaf surface area of soybean plants.

Morphometric measurements were taken on the day of the beginning of different daylength treatments and on days 7, 14 and 21. The study results are presented as the mean values of the investigated parameters (plant height, dry weight, number of leaves and leaf surface area of soybean plants).

Results. It was shown that under long-day conditions, dominant alleles of the *E1* and *E3* genes increased the dry weight of plants, while the dominant allele *E2* increased plant height. The dominant allele *E4* had no significant effect on plant height and weight indicators of soybean plants. Plants with dominant alleles of genes *E1-E4* under long-day conditions had smaller leaf area compared to lines with recessive alleles of these genes.

Conclusions. The obtained results on the relationships between genetic and environmental factors in influencing soybean plant height, weight, and leaf area can be useful in improving soybean yield and selecting cultivars that will be productive in high latitude conditions.

Keywords: *Glycine max* (L.) Merr., nearly isogenic lines, photoperiod duration, morphometric parameters, crop adaptation

INTRODUCTION

Soybean is the most valuable leguminous crop due to its high nutrient content. In recent decades, soybean production has experienced significant growth and gained importance in agriculture (Zhou *et al.*, 2022). Several factors affect the growth and development of soybeans, including photoperiod, temperature, soil moisture, and sowing dates. These factors impact the plant's stress responses, rates of transition to flowering, seed maturation and morphological parameters, such as plant height, leaf area, and grain yield (Xu *et al.*, 2013; Zhang *et al.*, 2020). The photosynthetic productivity of soybean plants is determined by the size of the photosynthetic apparatus and the efficient use of the products of photosynthesis (Wu *et al.*, 2022). Soybean is a short-day crop, and its genotypes are adapted to specific latitude ranges due to their sensitivity to photoperiod (Ort *et al.*, 2020). Soybean's wide adaptability to different latitudes is due to genetic variation in major genes and quantitative trait loci (QTL) that control flowering and maturity. These loci have been subject to human selection, which has resulted in soybeans' flexibility to adapt to different zones and photoperiodic conditions (Staniak *et al.*, 2023).

The regulatory loci *E1*, *E2*, *E3*, and *E4* have the greatest influence on adaptation to latitude. Mutations in these loci resulted in variation in flowering and ripening time, which was associated with the adaptation of soybean cultivars to diverse geographic regions and farming systems. It was found that *E1* and *E2*, especially *E2*, significantly affect the flowering time and maturity of soybeans (Liu *et al.*, 2020). Soybeans with dominant *E* genes grown in regions with a light period of more than 15–16 hours experience significantly slowed-down plant development, resulting in late seed formation and ripening, or sometimes they do not reach full maturity. This significantly reduces the production efficiency of soybean (Yukhno & Zhmurko, 2021; Staniak *et al.*, 2023).

MATERIALS AND METHODS

The study focused on soybean (*Glycine max* (L.) Merr.) of the cultivar “Clark”, nearly isogenic concerning *E* genes, which were sourced from the National Center for Plant Genetic Resources of Ukraine. Various lines with distinct photoperiodic sensitivities were employed in the study (**Table 1**).

Since the *E5* and *E7* genes in the studied lines share the same conditions, they will not be explicitly mentioned in the subsequent text.

Determination of Morphometric Indicators. To investigate the influence of early maturity genes on soybean morphometric parameters under varying daylight conditions, we performed measurements including soybean plant height (cm), dry weight (g) of the soybean plant, as well as the leaf count and surface area (cm^2) of the second, third, and fourth fully formed leaves on each plant.

Table 1. **Plant material used in the study**

Soybean Lines	Genotype	Photoperiodic sensitivity
Cultivar “Clark”	*e1E2E3E4e5E7*	SD line*
L63-3016	*e1E2E3e4e5E7*	SD line*
L80-5879	*E1e2e3E4e5E7*	SD line*
L63-3117	*e1e2E3E4e5E7*	ND line*
L71-920	*e1e2e3E4e5E7*	ND line*

Note: * – SD line – short-day line, ND line – photoperiodically neutral line

Plants were excavated and examined in the laboratory on the initial day of exposure to varying photoperiod durations, with subsequent evaluations performed every 7 days over a three-week period.

The height of ten plants was precisely measured using a ruler (in centimeters). Dry mass determination involved the desiccation of leaves, stems, and roots from ten plants in a drying chamber, followed by meticulous weighing and calculation of the mean value (in grams). Leaf enumeration involved accurate counting of fully developed leaves across ten plants. Additionally, the leaf surface area (measured in square centimeters) was assessed in ten specimens using the second, third, and fourth fully matured leaves. Subsequently, photographic documentation of the leaves was conducted, and their respective areas were calculated using the PhotoM program.

Morphometric indicators were recorded at specific time points throughout the experiment: “0” – before the study began, “7” – after 7 days of exposure to a short photoperiod (I period), “14” – following 14 days of exposure to a short photoperiod (II period), and “21” – 7 days after the conclusion of exposure to a short photoperiod (III period).

Statistical analysis. The data were statistically analysed using Statistica 7.0 software (StatSoft Inc., USA). We calculated standard mean values (x) and standard deviation (Sd). Differences between groups were determined using Tukey’s test, where the differences were considered reliable at $P < 0.05$ (taking into account Bonferroni correction).

RESULTS AND DISCUSSION

Plant height, a crucial characteristic linked to soybean’s main morphological and biological traits, significantly impacts soybean productivity (Cao *et al.*, 2017; Bilyavska & Rybalchenko, 2019). In both long (natural) and short photoperiod conditions, the ND line *e1e2E3E4* exhibited the highest plant height values (**Table 2**).

SD lines consistently demonstrated lower linear indicators compared to ND lines under both long and short photoperiod conditions. The impact of photoperiod length varied across different soybean lines, influencing plant height to different extent. In general, a long day increased plant height for all lines, with differences ranging from 3.34 % to 12.46 % compared to a short photoperiod. Notably, the SD line *E1e2e3E4* exhibited the most significant response, with a 12.46 % difference from the short photoperiod.

Throughout the experimental period, stem height growth indicators for soybean plants under long daylight conditions varied between 6.8 % and 26.2 % (**Table 4**). The most substantial increases were observed in the SD line *E1e2e3E4* and ND line *e1e2E3E4*, at 26.6% and 17.9%, respectively. The smallest increase was recorded in the cultivar "Clark", at 6.8% (Table 4). In summary, a natural long day contributed to an increased linear stem growth across all soybean lines compared to a short day.

The study results demonstrate differential responses in structural biomass indicators among soybean lines exposed to natural (long) and short photoperiods (**Table 2**). The SD line *E1e2e3E4* consistently exhibited the highest structural biomass indicators under both long and short photoperiods, while the SD lines *e1E2E3E4* and *e1E2E3e4* consistently showed the lowest indicators.

The analysis of the number of leaves in soybean lines isogenic for *E* genes revealed that the impact of photoperiod duration was prominent during the III period of the study across all lines (**Table 3**). Specifically, it was found that under long day conditions, the number of leaves in the experimental lines increased, irrespective of the genotype. The most substantial effect was observed in the SD line *e1E2E3e4*, with a 16.7% difference compared to the short day. Conversely, ND line *e1e2e3E4* exhibited the smallest response to photoperiod duration, with a difference of 2.63 %. The SD line *E1e2e3E4* and the ND line *e1e2E3E4* demonstrated similar values, with differences of 5.26 % and 5.41 %, respectively, while SD line *e1E2E3E4* exhibited a slightly lower difference at 4.62 %.

The impact of a long day resulted in a more pronounced increase in the number of leaves across all studied lines compared to a short photoperiod (**Table 4**). This effect was especially notable in SD line *e1E2E3e4*, where the difference with a short day was 32.3%. Conversely, the ND line *e1e2e3E4* exhibited the smallest increase.

The analysis of leaf surface area indicators highlighted the impact of photoperiod duration on the assimilation apparatus of the studied soybean lines, with a more pronounced effect of the long photoperiod on SD lines, showing an average difference of 16.4% compared to the short day (**Table 3**).

Throughout the experiment, plants across all lines increased their leaf surface area, with a more significant manifestation observed in neutral lines and the SD line *E1e2e3E4*. Specifically, at the conclusion of the experiment, the leaf surface area indicators for SD lines *E1e2e3E4* and *e1E2E3e4* were 37.5 % and 29.1 % higher, respectively, compared to the short photoperiod.

The study revealed consistent trends across all examined soybean lines, showcasing an increase in plant height, weight, number of leaves, and leaf area under long photoperiod conditions compared to short photoperiods. Table 4 provides a comprehensive overview of the growth indicators, highlighting the significant impact of extended daylight on soybean morphometrics.

Notably, SD soybean lines, specifically *E1e2e3E4* and *e1E2E3e4*, exhibited a more pronounced surge in plant height, dry mass, and leaf area under the influence of a long photoperiod (**Table 4**).

This heightened response is attributed to the extension of the vegetative phase in SD lines when exposed to unfavorable day length conditions. Conversely, the cultivar *e1E2E3E4* demonstrated growth rates closer to neutral lines, which displayed comparatively lower growth rates. The findings underscore the differential sensitivity of soybean lines to varying day lengths, with short-day lines exhibiting more vigorous growth and substantial accumulation of structural biomass in response to prolonged daylight (**Table 4**).

Table 2. **Plant height dynamics of soybean lines isogenic for *E* genes under different photoperiod durations, average values in 2018, 2019, 2021, field experiment**

Lines	Light, h	Plant height, (mean ± Sd) cm			Dry mass of the plant, (mean ± Sd) g		
		I period	II period	III period	I period	II period	III period
e1E2E3E4	16	26.1±0.5^{agi}	33.1±1.4^{abgi}	40.2±1.1^{aegi}	2.46±0.08^{bgi}	3.15±0.14^{bcegi}	5.68±0.12^{begi}
	9	25.5±0.4^{bd}	30.8±0.6^{baj}	38.9±1.2^{bhj}	1.79±0.11^{adf}	2.79±0.05^{adfhj}	5.03±0.15^{adfhj}
e1E2E3e4	16	27.7±0.5^{cdg}	33.5±1.2^{cgi}	41.0±1.2^{cdegi}	2.54±0.13^{gi}	3.63±0.06^{daegi}	5.65±0.05^{degi}
	9	25.3±0.6^{dcbfh}	31.1±1.6^{d}	37.8±1.2^{dchj}	2.63±0.06^{bfhj}	3.37±0.08^{cbh}	4.29±0.11^{cbfhj}
E1e2e3E4	16	26.9±0.3^{egi}	34.3±0.8^{efgi}	43.3±0.8^{efacghj}	2.54±0.12^{fgi}	4.39±0.11^{facgi}	7.54±0.08^{facgi}
	9	24.7±0.4^{fd}	31.4±1.5^{fe}	38.5±1.4^{fe}	2.30±0.07^{ebdj}	3.57±0.18^{ebj}	6.61±0.05^{ebdhj}
e1e2E3E4	16	29.2±0.5^{ghaeci}	37.4±1.1^{ghace}	48.0±0.7^{ghacei}	3.08±0.09^{hacei}	4.81±0.19^{hacei}	6.13±0.14^{hacei}
	9	27.5±0.5^{hgd}	32.3±0.9^{hg}	44.2±1.4^{hgbde}	2.09±0.17^{gd}	3.71±0.05^{gbdj}	5.84±0.08^{gbdf}
e1e2e3E4	16	27.5±0.7^{iage}	36.3±0.5^{ijace}	43.8±0.7^{ijacg}	2.84±0.09^{jaceg}	3.98±0.08^{jaceg}	6.57±0.06^{jaceg}
	9	26.4±0.6^{j}	33.7±1.2^{jib}	41.6±0.4^{jibde}	1.96±0.12^{idf}	3.27±0.02^{ibfh}	5.92±0.19^{ibdf}

Note: firstly, comparisons were made within the isogenic line of soybean between long (16 h) and short (9 h) photoperiods; secondly, comparisons were made between the isogenic lines of soybean within long (16 h) and short (9 h) photoperiods, means in each column followed by different letters are significantly different one from another based on the results of comparison using the Tukey test (P <0.05) with Bonferroni correction: a – SD line *e1E2E3E4* under long (16 h) photoperiod, b – SD line *e1E2E3E4* under short (9 h) photoperiod, c – SD line *e1E2E3e4* under long (16 h) photoperiod, d – SD line *e1E2E3e4* under short (9 h) photoperiod, e – SD line *E1e2e3E4* under long (16 h) photoperiod, f – SD line *E1e2e3E4* under short (9 h) photoperiod, g – ND line *e1e2E3E4*under long (16 h) photoperiod, h – ND line *e1e2E3E4* under short (9 h) photoperiod, i – ND line *e1e2e3E4* under long (16 h) photoperiod, j – ND line *e1e2e3E4* under short (9 h) photoperiod

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Table 3. **Dynamics of the number of leaves and leaf surface area in plants of soybean lines isogenic for *E* genes under different photoperiod durations, average values in 2018, 2019, 2021, field experiment**

Lines	Light, h	Number of leaves, (mean ± Sd) pcs			Leaf surface area, (mean ± Sd) cm^2		
		I period	II period	III period	I period	II period	III period
e1E2E3E4	16	4.02±0.11^{aeg}	5.53±0.14^{a}	6.85±0.17^{abegi}	171.7±12.6^{agi}	206.8±15.8^{aeg}	333.4±14.1^{aei}
	9	3.91±0.15^{bfj}	5.37±0.15^{bdfhj}	6.54±0.15^{badfhj}	164.2±15.6^{b}	206.2±15.1^{bf}	327.2±27.7^{bj}
e1E2E3e4	16	3.95±0.14^{cegi}	5.65±0.28^{cd}	7.01±0.21^{cdegi}	178.8±9.6^{cgi}	224.3±21.6^{cg}	349.3±12.1^{cei}
	9	4.16±0.22^{dfh}	5.08±0.14^{dcbfhj}	6.08±0.24^{dcbfh}	186.1±14.7^{d}	209.9±13.4^{df}	300.1±16.7^{dhj}
E1e2e3E4	16	4.73±0.11^{eaci}	6.01±0.22^{e}	8.03±0.11^{efac}	156.2±15.2^{egi}	253.2±14.2^{ea}	397.1±19.7^{eac}
	9	4.64±0.11^{fbdh}	6.08±0.21^{fbdh}	7.68±0.15^{febd}	168.5±17.0^{f}	259.8±15.8^{fbd}	340.9±32.9^{fj}
e1e2E3E4	16	4.52±0.13^{ghac}	5.73±0.12^{g}	7.82±0.19^{ghac}	205.6±13.2^{gace}	268.1±21.6^{gac}	369.3±25.4^{gi}
	9	4.13±0.16^{hgdf}	5.57±0.14^{hbdf}	7.43±0.11^{hgbd}	171.5±12.2^{h}	235.3±18.9^{h}	357.5±23.9^{hdj}
e1e2e3E4	16	4.38±0.27^{ice}	5.85±0.17^{i}	7.85±0.15^{iac}	210.8±7.2^{iace}	236.3±13.6^{i}	434.5±28.1^{iacg}
	9	4.36±0.28^{jb}	5.71±0.12^{jbd}	7.61±0.13^{jb}	193.1±16.3^{j}	238.4±17.6^{j}	429.9±8.8^{jbdfh}

Note: firstly, comparisons were made within the isogenic line of soybean between long (16 h) and short (9 h) photoperiods; secondly, comparisons were made between the isogenic lines of soybean within long (16 h) and short (9 h) photoperiods, means in each column followed by different letters are significantly different one from another based on the results of comparison using the Tukey test (P <0.05) with Bonferroni correction: see **Table 1** for letters labels description

Table 4. **Growth indicators in plants of soybean lines isogenic for *E* genes under conditions of a long photoperiod, average values of 2018, 2019, 2021, increase, % for the I-III periods of the study (value of the difference between the long and short photoperiod)**

Soybean Lines	Growth under long day condition, %			
	Plant height	Dry mass of the plant	Number of leaves	Leaf surface area
e1E2E3E4	6.8	43.1	10.0	3.8
e1E2E3e4	15.5	90.4	32.3	29.1
E1e2e3E4	26.2	59.3	12.1	37.5
e1e2E3E4	17.9	17.1	10.8	8.3
e1e2e3E4	10.4	33.5	5.9	2.9

DISCUSSION

The timing of the transition to flowering and the subsequent phases of soybean development are intricately regulated by the combination and state of early maturity genes, with the *E1-E4* genes playing a pivotal role in controlling developmental rates (Xu *et al.*, 2013; Ort *et al.*, 2020; Staniak *et al.*, 2023). The Kharkiv region in the east of Ukraine, with a typical daylight length of 16 hours, poses challenges for cultivating short-day soybean cultivars. Consequently, understanding the influence of different maturity gene combinations on soybean growth and development becomes crucial for expanding the cultivation areas of this crop. Our prior studies unveiled interactions among key early maturity genes leading to the transition to the flowering phase, crop formation, and the interplay between the genes and photoperiod duration that influence soybean development (Raievska & Schogolev, 2023).

The duration of the photoperiod emerged as a crucial factor shaping soybean development. Notably, the *E1* gene and the combination of *E2E3* genes demonstrated a significant influence on soybean morphometric parameters. This observation may be linked to day length affecting photosynthetic activity and assimilate redistribution, inhibiting the transition to the reproductive phase and prolonging the vegetative phase (Weraduwage *et al.*, 2015; Mathur *et al.*, 2023). Shoot architecture, a critical component of crop growth, particularly plant height, is regulated by a combination of genetic and environmental factors (Yang *et al.*, 2021).

Our study revealed distinct impacts of dominant alleles *E2* and *E3* on soybean plant height under long-day conditions (**Table 2**). Specifically, the dominant allele *E3* increased plant height compared to the recessive allele, while the presence of the dominant allele *E2* decreased plant height. This finding aligns with research by Zhen, which demonstrated the influence of *E2* and *E3* genes on soybean plant height in low and middle latitudes (30°N~32°N) (Zheng *et al.*, 2023). Notably, variations in the *E1* and *E4* genes did not result in significant differences in plant height under long-day conditions, contrary to existing literature suggesting the involvement of phytochromes *E3* and *E4* in height regulation through the activation of the *Dt1* locus (Takeshima *et al.* 2019; Miranda *et al.*, 2020; Zhou *et al.*, 2022). Yang's work also supported the assumption that, under certain conditions, the dominant *E1* allele affects soybean plant height, with increased *E1* expression contributing to an increased plant height under long-day conditions (Yang *et al.*, 2021).

Beyond influencing the linear growth, early maturity genes had a notable impact on biomass indicators. Dominant alleles of the *E1* and *E3* genes were found to increase the dry biomass of soybean plants under natural day conditions, compared to their recessive alleles (**Table 2**). The dominant allele *E1* also increased dry plant weight under short photoperiods. Existing literature suggests that the joint influence of genes *E1* and *E3* contributes to biomass accumulation, possibly through their impact on the flowering and ripening timing of soybeans (Zheng *et al.*, 2023).

Leaf surface area indicators, crucial for soybean productivity, were found to be influenced by the allelic states of early maturity genes. Dominant alleles of *E1*-*E4* reduced the leaf surface area under long-day conditions, potentially due to altered assimilate distribution affecting shoot height (**Table 3**). The intricate relationship between the predicted leaf area, total leaf area, and overall plant weight, changing between growth phases, underscores the complexity of these interactions (Weraduwage *et al.*, 2015). Additionally, the *E1* gene was implicated in regulating soybean leaf development, particularly it impacted the leaf tissue structure (Li *et al.*, 2021).

In conclusion, both photoperiod duration and the allelic states of early maturity genes exert a profound influence on morphological indicators. Consideration of the dominant/recessive alleles of *E* genes is crucial for successful soybean cultivation in the high-latitude conditions of Ukraine.

CONCLUSION

Our research provides a comprehensive analysis of field studies conducted in high-latitude conditions, focusing on the interplay between day length and early maturity genes concerning the morphological parameters of the cultivar "Clark", soybean lines, nearly isogenic in terms of *E* genes. Key findings underscored that, under the extended daylight conditions, plants exhibited increased measurements of height, mass, and leaf area.

Early maturity genes *E1-E4* emerged as pivotal influencers of soybean morphometric parameters. In the context of extended daylight in high-latitudes, dominant alleles of genes *E1-E4* were associated with a reduction in leaf area compared to their recessive alleles. Specifically, dominant alleles of genes *E1* and *E3* contributed to an increased plant weight, while the presence of the *E2* allele correlated with a reduced height and weight of soybean plants. Intriguingly, the dominant *E4* gene did not exhibit a significant impact on the height and mass of soybean plants.

Future research should explore biochemical indicators under different photoperiods to better understand the interaction between early maturity genes and soybean traits improving cultivation strategies.

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COMPLIANCE WITH ETHICAL STANDARDS

Conflict of Interest: the authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Animal Rights: this article does not contain any studies with animal subjects performed by any of the authors.

AUTHOR CONTRIBUTIONS

Conceptualization, [Sch.A.; R.I.]; methodology, [Sch.A.; R.I.]; validation, [Sch.A.]; formal analysis, [R.I.]; investigation, [Sch.A.; R.I.]; resources, [R.I.]; data curation, [R.I.]; writing – original draft preparation, [R.I.]; writing – review and editing, [Sch.A.]; visualization, [Sch.A.; R.I.] supervision, [Sch.A.]; project administration, [Sch.A.]; funding acquisition, [Sch.A.].

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REFERENCES

Biliavska, L. H., & Rybalchenko, A. M. (2019). The variability of the economically-valuable characteristics of soybean in the conditions of the Left Bank Forest-Steppe of Ukraine. *Bulletin of Poltava State Agrarian Academy*, 1, 65–72. doi:10.31210/visnyk2019.01.08 (In Ukrainian)
Crossref • Google Scholar

Cao, D., Takeshima, R., Zhao, C., Liu, B., Jun, A., & Kong, F. (2017). Molecular mechanisms of flowering under long days and stem growth habit in soybean. *Journal of Experimental Botany*, 68(8), 1873–1884. doi:10.1093/jxb/erw394
Crossref • PubMed • Google Scholar

Li, Y., Hou, Z., Li, W., Li, H., Lu, S., Gan, Z., Du, H., Li, T., Zhang, Y., Kong, F., Cheng, Y., He, M., Ma, L., Liao, C., Li, Y., Dong, L., Liu, B., & Cheng, Q. (2021). The legume-specific transcription factor *E1* controls leaf morphology in soybean. *BMC Plant Biology,* 21(1), 531. doi:10.1186/s12870-021-03301-1
Crossref • PubMed • PMC • Google Scholar

Liu, L., Song, W., Wang, L., Sun, X., Qi, Y., Wu, T., Sun, S., Jiang, B., Wu, C., Hou, W., Ni, Z., & Han, T. (2020). Allele combinations of maturity genes *E1-E4* affect adaptation of soybean to diverse geographic regions and farming systems in China. *PLoS One*, 15(7), e0235397. doi:10.1371/journal.pone.0235397
Crossref • PubMed • PMC • Google Scholar

Mathur, S., Seo, B., Jajoo, A., Reddy, K. R., & Reddy, V. R. (2023). Chlorophyll fluorescence is a potential indicator to measure photochemical efficiency in early to late soybean maturity groups under changing day lengths and temperatures. *Frontiers in Plant Science,* 14, 1228464. doi:10.3389/fpls.2023.1228464
Crossref • PubMed • PMC • Google Scholar

Miranda, C., Scaboo, A., Cober, E., Denwar, N., & Bilyeu, K. (2020). The effects and interaction of soybean maturity gene alleles controlling flowering time, maturity, and adaptation in tropical environments. *BMC Plant Biology*, 20(1), 65. doi:10.1186/s12870-020-2276-y
Crossref • PubMed • PMC • Google Scholar

Ort, N. W. W., Morrison, M. J., Cober, E. R., McAndrew, D., & Lawley, Y. E. (2022). A comparison of soybean maturity groups for phenology, seed yield, and seed quality components between eastern Ontario and southern Manitoba. *Canadian Journal of Plant Science*, 102(4), 812–822. doi:10.1139/cjps-2021-0235
Crossref • Google Scholar

Raievska, I. M., & Schogolev, A. S. (2023). Genetic variation in four maturity genes and photoperiod insensitivity effects on the yield components and on the growth duration periods of soybean. *Regulatory Mechanisms in Biosystems*, 14(1), 55–63. doi:10.15421/022309
Crossref • Google Scholar
Staniak, M., Szpunar-Krok, E., & Kocira, A. (2023). Responses of soybean to selected abiotic stresses – photoperiod, temperature and water. *Agriculture*, 13(1), 146; doi:10.3390/agriculture13010146
Crossref • Google Scholar
Takeshima, R., Nan, H., Harigai, K., Dong, L., Zhu, J., Lu, S., Xu, M., Yamagishi, N., Yoshikawa, N., Liu, B., Yamada, T., Kong, F., & Abe, J. (2019). Functional divergence between soybean *FLOWERING LOCUS T* orthologues *FT2a* and *FT5a* in post-flowering stem growth. *Journal of Experimental Botany*, 70(15), 3941–3953. doi:10.1093/jxb/erz199
Crossref • PubMed • PMC • Google Scholar
Weraduwage, S. M., Chen, J., Anozie, F. C., Morales, A., Weise, S. E., & Sharkey, T. D. (2015). The relationship between leaf area growth and biomass accumulation in *Arabidopsis thaliana*. *Frontiers in Plant Science*, 6, 167. doi:10.3389/fpls.2015.00167
Crossref • PubMed • PMC • Google Scholar
Wu, Y., Chen, P., Gong, W., Gul, H., Zhu, J., Yang, F., Wang, X., Yong, T., Liu, J., Pu, T., Yan, Y., & Yang, W. (2022). Morphological and physiological variation of soybean seedlings in response to shade. *Frontiers in Plant Science*, 13, 1015414. doi:10.3389/fpls.2022.1015414
Crossref • PubMed • PMC • Google Scholar
Xu, M., Xu, Z., Liu, B., Kong, F., Tsubokura, Y., Watanabe, S., Xia, Z., Harada, K., Kanazawa, A., Yamada, T., & Abe, J. (2013). Genetic variation in four maturity genes affects photoperiod insensitivity and PHYA-regulated post-flowering responses of soybean. *BMC Plant Biology*, 13, 91. doi:10.1186/1471-2229-13-91
Crossref • PubMed • PMC • Google Scholar
Yang, Q., Lin, G., Lv, H., Wang, C., Yang, Y., & Liao, H. (2021). Environmental and genetic regulation of plant height in soybean. *BMC Plant Biology,* 21, 63. doi:10.1186/s12870-021-02836-7
Crossref • PubMed • PMC • Google Scholar
Yukhno, Y., & Zhmurko, V. (2021). Effects of *E*-genes and photoperiod duration on assimilation processes in isogenic lines of soybean. *ScienceRise: Biological Science*, 1(26), 32–39. doi:10.15587/2519-8025.2021.229512
Crossref • Google Scholar
Zhang, L. X., Liu, W., Mesfin, T., Xu, X., Qi, Y. P., Sapey, E., Liu, L. P., Wu, T. T., Sun, S., & Han, T. F. (2020). Principles and practices of the photo-thermal adaptability improvement in soybean. *Journal of Integrative Agriculture*, 19(2), 295–310. doi:10.1016/S2095-3119(19)62850-9
Crossref • Google Scholar
Zheng, N., Guo, Y., Wang, S., Zhang, H., Wang, L., Gao, Y., Xu, M., Wang, W., Liu, W., & Yang, W. (2023). Identification of *E1-E4* allele combinations and ecological adaptability of soybean varieties from different geographical origins in China. *Frontiers in Plant Science,* 14, 1222755. doi:10.3389/fpls.2023.1222755
Crossref • PubMed • PMC • Google Scholar
Zhou, X., Wang, D., Mao, Y., Zhou, Y., Zhao, L., Zhang, C., Liu, Y., & Chen, J. (2022). The organ size and morphological change during the domestication process of soybean. *Frontiers in Plant Science*, 13, 913238. doi:10.3389/fpls.2022.913238
Crossref • PubMed • PMC • Google Scholar

ГЕНИ ФОТОПЕРІОДИЧНОЇ ЧУТЛИВОСТІ ТА РАННЬОЇ СТИГЛОСТІ *E1-E4*: ОСОБЛИВОСТІ ДИНАМІКИ РОСТУ СОЇ В УМОВАХ РІЗНОЇ ТРИВАЛОСТІ ФОТОПЕРІОДУ

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Вступ. Морфометричні показники є важливими для оцінки розвитку та продуктивності сої. Відомо, що вони перебувають під впливом генетичних факторів і чинників навколишнього середовища. Використання майже ізогенних ліній сої є зручною моделлю для визначення впливу генів ранньої стиглості та тривалості фотоперіоду на показники росту. Метою цього дослідження було визначити вплив різної тривалості фотоперіоду та генів ранньої стиглості на морфометричні показники сої під час вирощування в умовах середньої смуги (на широті Харкова – 50° пн. ш.).

Матеріали та методи. У дослідженнях використовували майже ізогенні лінії сої сорту “Clark” із різною чутливістю до тривалості світлового дня. Дослідження охоплюють результати польових дослідів протягом трьох сезонів з використанням різних ліній сої. Після досягнення фази V3 частину рослин піддавали дії короткого фотоперіоду протягом 14 днів. У роботі визначали морфологічні показники 10 рослин кожного варіанта досліду: висоту і суху масу рослин, кількість листків та площу листкової поверхні рослин сої. Визначення морфометричних показників проводили в день початку дії різної тривалості фотоперіоду та кожні 7 днів протягом трьох тижнів. У роботі представлено середні значення показників (висота і суха маса рослин, кількість листків і площа листкової поверхні рослин сої).

Результати. З’ясовано, що за умов тривалого фотоперіоду домінантні алелі генів *E1* та *E3* збільшували суху масу рослин, а домінантний алель *E2* – висоту рослин. Домінантний алель *E4* не мав суттєвого впливу на висоту і масу рослин сої. Встановлено, що рослини з домінантними алелями генів *E1-E4* за умов довгого дня мали меншу площу листової поверхні, порівняно з лініями з рецесивними алелями цих генів.

Висновки. Отримані результати визначення взаємозв’язків між генетичними факторами й чинниками навколишнього середовища у впливі на висоту, масу рослин сої та площу листків можуть бути корисними у роботі з підвищення врожайності сої, а також з підбору сортів, що будуть продуктивними в умовах високих широт.

Ключові слова: *Glycine max* (L.) Merr., майже ізогенні лінії, тривалість фотоперіоду, морфометричні показники, адаптація посівів

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