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Photoperiod and temperature sensitivity in early soybean accessions from the VIR collection in Leningrad Province of the Russian Federation

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Abstract: The photoperiod and temperature sensitivity of the onset of flowering in 106 soybean accessions from the VIR collection has been studied for 8 years in a vegetation experiment in the conditions of Leningrad Province at 59°N, the northernmost point of soybean evaluation in the world. The accessions were previously field-assessed for the ability to form fully developed seeds in this region. The experimental conditions were extreme for soybean in terms of both photoperiod and heat supply. The emergence to flowering period length (L_{EF}) in the sample set was 7.9 days longer, and the sum of the temperatures required for the transition to flowering was 143.2 °C higher, on an average, under the natural long day (LD) compared to those under the artificial short day (SD). The photoperiod sensitivity of the accessions was estimated as the ratio of L_{EF} under LD (T_1) to L_{EF} under SD (T_2), and expressed as the coefficient of photoperiod sensitivity $C_{phs} = T_1/T_2$. A coefficient of 1.25 was taken as the limit of a very weak photosensitivity. Varieties with a coefficient not higher than this value totaled 73.6% of the sample set. The dominating influence of weather conditions over the photoperiod for the reference variety 'Svetlaya' is shown for over 8 years of observations: weather conditions caused 84.3% of the L_{EF} variability, while the differences in the photoperiod determined only 9.9% of variability. Excessive precipitation in 2016 and 2017 caused a significant delay in flowering. C_{phs} proved to be a stable characteristic of a variety because it did not differ significantly in contrasting years. A broader regional adaptability of varieties created in high latitudes compared to those of southern origin is discussed.

Key words: Soybean, photoperiod, temperature sensitivity, early maturity, latitudinal adaptability, Leningrad Province, Russian Federation

1. Introduction

Soybean is a short-day and a warm climate crop. The primary center of soybean origin is Northeast China (Vavilov, 1935; Wang et al., 2016). From the focus of its origin located between 30° and 45°N, soybean has spread to no less than 55°N and 35–40°S latitudes in both Eastern and Western hemispheres of the globe, while the area of its cultivation includes equatorial regions (Klein and Vidal Luna, 2021).

In the Russian Federation (RF), a significant part of soybean crop was traditionally concentrated in the Far East, which is located near the supposed center of the crop origin. However, the complexity and high costs of logistics, the development of the soybean processing industry in the European part of the RF determined the expansion of its production in this region. In 2020, the Central Federal District accounted for 38.3% of all soybean cultivation areas in the RF (large soybean crops are found in the Belgorod and Kursk provinces, somewhat smaller in the Bryansk, Lipetsk, Oryol, Ryazan, Tambov, Tula and Voronezh provinces). For comparison, in 2010 this indicator was 13.5%, while in 2007 it was only 5.1%. At the same time, the share of the Far Eastern Federal District has decreased (Plugov, 2020).

Back in the 1930s, N.I. Vavilov set the task of expanding the areas of crop cultivation to the north (Vavilov, 1965). Soybean is a vivid example of the development of this trend. Over the past 30 years, the cultivation area of soybeans in RF has shifted northward in the European part by at least 300–400 km. This was facilitated by the presence in the soybean gene pool of varieties that differ in photoperiodic and temperature sensitivity and the need for moisture supply.

The VIR soybean collection provides opportunities for studying the diversity of adaptive capabilities of the crop in different climatic zones with different photoperiods. Therefore, the work underway at VIR since the 1980s aims at identifying the material in the soybean gene pool that would be adapted to the conditions of the Northwest of the RF, namely Leningrad Province, where the experimental site of the institute is located. The long-term screening of the collection has identified a certain set of ultraearly

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and early maturing accessions (Seferova, 2016) and determined the limiting weather and climatic factors for their cultivation in the conditions northernmost for soybeans (Seferova and Novikova, 2015).

It is known that due to different sensitivity to photoperiod and temperature, i.e. differences in the maturity groups, the cultivation area of particular soybean varieties is usually limited to a narrow latitudinal strip (Watanabe et al., 2012). This was proved, in particular, in our previous works, where it was shown that some ultraearly accessions, adapted to the conditions of Leningrad Province, abruptly shortened the growing season and reduced productivity in the North Caucasus, while some varieties developed dwarfism (Seferova and Vishnyakova, 2018).

Among the accessions capable of forming fully developed seeds in the conditions of Leningrad Province, there are varieties resulting from breeding, but no landraces have been identified among them, since selection had been carried out mainly in the southern regions (Seferova, 2016).

The biological essence of the photoperiodic response is the transition of a plant from the vegetative phase of development to the reproductive one, namely, the onset of flowering under the daylength conditions optimal for the genotype. However, for plants requiring a certain heat supply, the combination of photoperiod and temperature is important. The combined influence of these factors not only on the flowering onset, but also on the subsequent development of soybeans has been discussed quite actively (Song et al., 2019).

Our research was carried out in the northernmost known point of soybean experimental cultivation on the Earth, where soybean responds strongly to long days and low temperatures during its development. It had been previously shown for common beans that under these conditions the flowering was delayed by 10.5 days in years with insufficient heat supply, and by 4.5 days under the influence of a long day compared to conditions when the air temperature and photoperiod are optimal for the crop (Vishnyakova et al., 2014). We showed previously (Seferova and Novikova, 2015) in the same Leningrad Province that the onset of flowering in soybean depends on temperature and precipitation in the field. The temperature dependence of the emergence to flowering period length (L_{EF}) was nonlinear, and the maximum development rate was recorded at temperatures of 20–22 °C. With an increase in precipitation during the emergence to flowering (EF) period, the beginning of flowering was delayed.

To understand the mechanisms of adaptation of soybeans to northern latitudes and to identify the temperature and photoperiodic optimal values that initiate flowering in soybeans in Leningrad Province, we undertook a study of the diversity of ultraearly and very early maturing soybean varieties in terms of the emergence to flowering period length (L_{EF}) under conditions of a natural long day (LD) and artificial short day (SD) over a number of years.

This article aimed at analyzing the photoperiodic and temperature dependence of the onset of flowering in early maturing soybean accessions from the VIR collection in the conditions of Leningrad Province.

2. Material and methods

One hundred and six (106) soybean accessions from the VIR collection were used as the research material. The investigations were conducted in glasshouses and photoperiod chambers. The study was carried out for 8 years: in 2002, and from 2014 to 2020. From 10 to 20 accessions were observed annually. In each variant of the experiment (LD and SD), an accession was represented by 5–10 plants.

The studied sample set included scientifically bred varieties and breeding material from 16 countries of the world, which previously underwent field screening in Leningrad Province in 1999–2018 and were identified as sufficiently early for the formation of fully developed seeds, i.e. the earliest ones for the crop (Seferova, 2016; Seferova and Vishnyakova, 2018). Seeds in beans were dried when stored in sheaves under a canopy. The experiment of 2020 included Chinese breeding lines, specially selected for their early maturity. The experiment also included the variety 'Merit' that ripened early under SD and late under LD. This variety is known as early maturing when cultivated in Canadian provinces Ontario and Quebec, in relatively northern latitudes, as high as 51–52°N, but in our conditions, it bloomed only by the end of the season. The studied sample set included accessions with low photoperiodic sensitivity, since accessions with high sensitivity do not begin flowering until the first autumn frosts under the natural day conditions.

Each year, the reference variety used in the study was an ultraearly 'Svetlaya' variety created in Ryazan Province and commercialized in four regions, including the Russian northwest (State Register, 2020).

The experiments were carried out in photoperiod chambers of VIR in Pushkin town, Leningrad Province (59°43′N, 30°25′E). The plants were grown in 5-L vessels, 5 normally developed plants per vessel. Fertilization and watering were carried out in an optimal mode for soybeans. The flowering onset date was noted upon appearance of the first flower for each plant, the stem marked with a paper label, and L_{EF} calculated. The experiment was carried out under natural LD (maximum 18 h 45 min) and SD (12 h). The latter was created by rolling the trolleys with vessels into a light-tight photoperiodic chamber, in which they

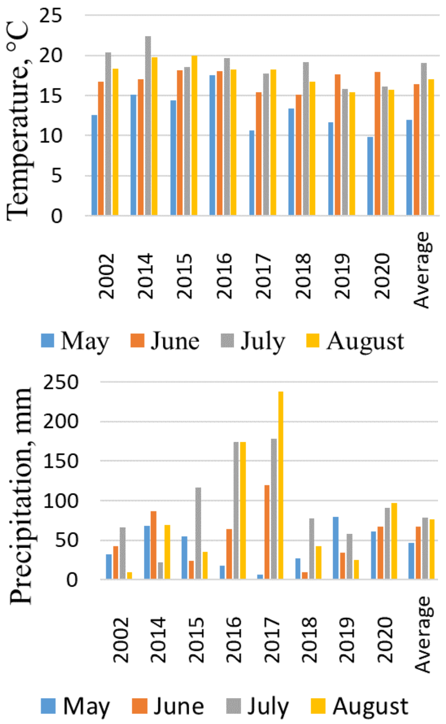

Figure 1. Weather conditions during the years of research: a) average daily air temperature; b) monthly precipitation. Average for 1991–2020.

were kept from 9 PM to 9 AM. LD was provided by rolling the trolleys for the same period of time into a glasshouse.

Sowing was carried out in late May – early June, and emergence was observed 1–2 weeks later. Flowering of different accessions ranged from late June to mid-August.

The data of the meteorological station located at the experimental site of the Pushkin Laboratories of VIR were used. The weather conditions during the sowing through flowering period over the years of research are shown in Figure 1. The May-August temperatures above the average for the last 30 years were characteristic of 2002 and 2014–2016. A distinctive feature of 2016 and 2017 was an abnormal amount of precipitation in July and August.

The sums of temperatures for the EF period were calculated for all accessions.

Photoperiod sensitivity (PhS) was determined from the value of the PhS coefficient (C_{phs}) calculated by the formula $C_{phs} = T_1/T_2$, where T_1 and T_2 are the EF period length (days) in plants grown under conditions of a long natural and short 12-h day, respectively (Koshkin, 2012).

The data were statistically processed using the Statistica 13.3 package.

The contribution of the 'photoperiod' and 'year' factors to the L_{EF} variability in the 'Svetlaya' variety during 8 years of observations was estimated by two-way analysis of variance with Tukey HSD test. Spearman's rank correlation coefficient was used to determine the relationship between characteristics of the varieties. A comparison of characteristics of 5 varieties in the contrasting 2014 and 2018 was carried out by the paired samples Wilcoxon test. Kruskal-Wallis criterion was used for a comparison of groups of varieties by geographical origin. The study adopted 5% level of significance.

3. Results

3.1. Differences in photoperiod sensitivity in accessions

In most accessions, the first flowers opened earlier under SD than under LD in all the years of the study. During two years, 2016 and 2020, this difference was minimal, as the onset of flowering in many accessions differed under LD and SD by less than a day.

On an average for the sample set, L_{EF} under LD was by 7.9 days (or 1.2 times) longer compared to SD. The average L_{EF} under SD amounted to 39.2 days, varying from 24 to 64 days between accessions, and to 47.2 days under LD, varying from 26.0 to 78.6 days (Table 1). Under SD, the accessions flowered more simultaneously than under LD: the spread of L_{EF} values under SD was 40 days, and 53 days under LD. The sum of the temperatures accumulated during the EF period, necessary for the flowering of accessions, was on an average 143.2 °C higher under LD compared to SD.

C_{phs} varied among the accessions from 1.00 to 2.41, and T_1-T_2 from 0 to 46 days (Table 1). In the study of Shchelko et al. (1990), the sensitivity to the photoperiod is ranked into 5 classes without quantitative values. The accessions with very high photosensitivity were not chosen for the study. Therefore, the range of C_{phs} variability recorded in our work was split into 4 intervals: 1.0–1.25; 1.26–1.50; 1.51–2.00; and 2.01–2.41. The plants from the first interval were classified as having a very low photoperiod sensitivity, those from the second as low sensitive, from the third as medium sensitive, and the fourth contained plants highly sensitive to photoperiod. The first interval included 78 accessions (73.6%), the second 23 (21.7%), the third 4 (3.8%), and the fourth just one accession (0.9%). In the most numerous group of accessions, flowering under LD vs. SD was delayed by 0 to 13 days, by 12 to 19 days in the second one, and by more than 20 days at C_{phs} above 1.5. The delay amounted to 46 days for the Canadian variety 'Merit', which formed the fourth group.

Photoperiod sensitivity of an accession is weakly related to the time before flowering under SD; the Spearman correlation coefficient is $r_s = 0.26$ for C_{phs} and L_{EF} under SD. This indicates that accessions with low photoperiod sensitivity can be found in different groups of maturity.

3.2. Factors affecting L_{EF}

The most objective picture of the plant development dependence on external factors can be observed in long-

Table 1. Intervarietal variability of the emergence to flowering period characteristics in 106 soybean accessions in 2002, 2014–2020 (Russia, Leningrad Province, Pushkin town).

Characteristic	Average	Min	Max	Max-min
Emergence to flowering under long day (T_1), days	47.2	26	79	53
Emergence to flowering under short day (T_2), days	39.3	24	64	40
$C_{PhS} = T_1/T_2$	1.20	1.00	2.41	1.41
T_1-T_2, days	7.9	0	46	46
Sum of temperatures under long day, °C	838.1	477.2	1300.2	823.0
Sum of temperatures under short day, °C	694.9	443.4	1185.3	741.9

term experiments with one variety. An assessment of the role of weather factors and daylength was made for the 'Svetlaya' reference variety observed for all 8 years. C_{phs} of the variety averaged 1.14 (from 1.00 in 2016 to 1.25 in 2019), i.e. the variety had a very low photoperiod sensitivity. C_{phs} of the 'Svetlaya' variety was a more stable characteristic of photoperiod sensitivity (with a coefficient of variation over the years CV = 7.1%) than the (T_1-T_2) difference (CV = 58.9%), which evidences in favor of a greater independence of C_{phs} from conditions of a year. This indicator did not significantly correlate with any weather data, which also testifies in favor of its independence from conditions of a year.

L_{EF} under LD in the vegetation experiment averaged 42.5 days (ranging from 28 to 57 days on day 29), and 37.3 days under SD (from 27 to 49 days on day 22) (Figure 2). Thus, the L_{EF} variation was 5.2 days under the daylength influence, and 22–29 days under the influence of weather conditions. During the long-term field studies at the same location, L_{EF} varied within the 27 to 57 days range for the 'Svetlaya' variety; that is, the weather conditions over the years of the vegetative experiment varied over an extremely wide range.

The two-way ANOVA showed that the influence of conditions of the year determined 84.3% of the L_{EF} variability (the factor significance level $p < 0.001$), while the photoperiod determined only 9.9% ($p < 0.001$). The interaction between the year and the photoperiod was significant (2.9%, $p < 0.001$), 2016 and 2020 were special in this respect, when flowering occurred almost simultaneously under LD and SD. The year 2016 was distinguished by a large amount of precipitation in the week preceding the flowering (76 mm, i.e. 10.9 mm/day), which led to a delay in the opening of flowers under SD, i.e. the factor of excess precipitation was the limiting one. The year 2020 was characterized by the shortest L_{EF} over the years of observations, namely 27 days under SD and 28 days under LD, when the protracted spring gave way to a sharp warming.

The longest L_{EF}, 57 days under LD and 49 days under SD, was observed in 2017. This year was characterized by an abnormally high amount of precipitation, 5.4 mm/day for the EF period, which was above the optimal limit of 4 mm/day determined by us (Seferova and Novikova, 2015) and also contributed to the delay in flowering.

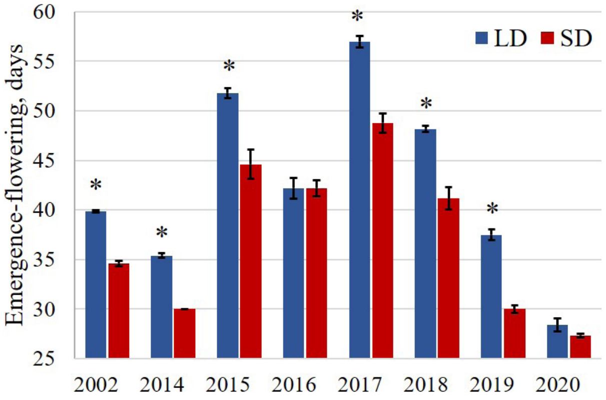

Figure 2. Emergence to flowering period length (L_{EF}) for the 'Svetlaya' variety under long day (LD) and short day (SD). *: the differences between LD and SD are significant ($p < 0.001$).

The correlations of the EF period length with the average temperature for the period were of medium strength and unreliable (r = –0.46 under LD and r = –0.48 under SD), and with the June temperature r = –0.50 under LD and r = –0.39 under SD. The coefficients of L_{EF} correlation with per day precipitation were r = 0.57 under LD and r = 0.77 under SD, while those with precipitation in July were r = 0.59 under LD and r = 0.77 under SD (coefficients above 0.7 are significant). Thus, precipitation was a significant factor influencing L_{EF} during the years of study.

The interannual variability of the average L_{EF} for the sample set of 106 accessions strongly correlated with the L_{EF} of the 'Svetlaya' variety under LD (r = 0.92) and under SD (r = 0.98). The correlation between the average C_{phs} for the sample set and C_{phs} for the 'Svetlaya' variety was r = 0.75, the connections being reliable. This makes it possible to extrapolate the revealed regularities to the entire studied sample set of early maturing accessions.

3.3. Comparison of photoperiod sensitivity of varieties in years with contrasting temperature conditions

The dependence of the onset of flowering in soybeans on the conditions of the year and photoperiod was analyzed for 5 varieties, which were studied in two years with contrasting heat supply, in 2014 and 2018 (Table 2). The year 2018 was the coldest year over the study period, while 2014 was the warmest. The average temperature during the EF period under LD was 21.1 °C in 2014 and 15.9 °C in 2018, that is, it differed by 5 °C. A significant difference in L_{EF} was observed in the years of research for the total studied accessions: on an average, it amounted to 12.4 days under LD ($p = 0.043$), and 11.4 days under SD ($p = 0.043$). At the same time, the sums of temperatures did not significantly change either under LD ($p = 0.500$) or under SD ($p = 0.345$). In comparison with SD, the sum of temperatures under LD was on an average higher for 5 varieties by 90.8 °C ($p = 0.005$). In the years of research, C_{phs} for the total varieties did not differ significantly ($p = 0.345$).

3.4. Comparison of photoperiod sensitivity of accessions of different geographic origins

Early maturity in soybeans is a trait that is in demand in many regions of the RF, as well as in many countries of the northern hemisphere. The studied sample set included accessions which had been screened for early maturity and adaptability to the conditions of the northwest of the RF. These accessions originated from 16 countries displaying a significant gradient of the daylength and the temperature regime during the EF period. Despite the fact that parts of these countries are located within the subtropical (Italy, USA, Japan, China, etc.) and even tropical (China) belts, they breed ultraearly and very early maturing varieties for cultivation in relatively northern latitudes compared to them. Therefore, we considered it possible to analyze C_{phs} of the accessions in accordance with the geographic differentiation of the studied sample set, and found C_{phs} of varieties of different geographic origin to differ significantly ($p < 0.001$). The minimum average C_{phs} was typical for accessions from China (1.05), contrasting with respect to the accessions from Canada (1.37), the Netherlands (1.37), Japan (1.31), and the United States (1.29), while those bred in Austria (1.06) and created at the Fiskeby experiment station in Sweden (1.10) (Figure 3) were also characterized by a low C_{phs}.

4. Discussion

The conditions for our experiment were extreme for the crop. Over the eight years of research, average temperatures of the EF period varied from 16 °C to 21 °C, which is significantly below the optimum of 23–25 °C, at which soybeans reach the highest rate of development (Choi et al., 2016). The maximum length of daylight hours identified by Chinese scientists for varieties from different maturity groups was 16.4 h (Zhang et al., 2020). The daylength at our experimental site during the soybeans flowering (June-

Table 2. Characteristics of the emergence to flowering period in accessions studied during two contrasting years (2014 and 2018) (Russia, Leningrad Province, Pushkin town).

VIR cat. no.	Accession/ variety	Year	Parameters of the emergence to flowering period				
			Long day		Short day		C_{phs}
			Length, days	Sum of temperatures, °C	Length, days	Sum of temperatures, °C	
10043	Altom	2014	38	808.9	32	658.5	1.20
		2018	48	752.2	44	679.5	1.08
11114	Kasatka	2014	33	684.5	30	606.0	1.11
		2018	46	716.3	42	638.5	1.10
9959	Okskaya	2014	35	709.5	31	645.1	1.14
		2018	48	752.2	46	728.2	1.06
10651	PEP-2	2014	34	683.5	32	631.0	1.08
		2018	47	726.5	39	578.1	1.18
9960	Svetlaya	2014	35	709.5	30	606.0	1.18
		2018	48	752.2	41	616.8	1.17
	Average	2014	35.0	719.2	31.0	629.3	1.14
		2018	47.4	739.9	42.4	648.2	1.12

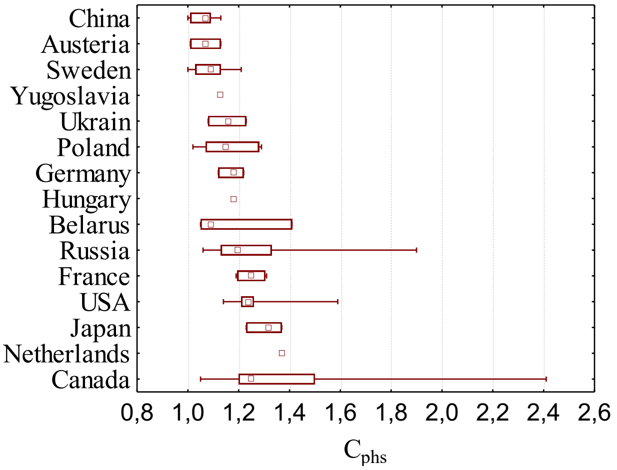

Figure 3. Coefficient of photoperiod sensitivity (C_{phs}) for accessions of different geographic origin. The median, quartiles, minimum and maximum are presented. Countries are ranked in ascending order of the average.

July) is much longer —from 17 h to 18 h 45 min. Our study shows the level of soybean preadaptation to a combination of long day and comparatively low temperatures.

Soybean is considered a difficult crop to model due to a large number of yield formation compensatory mechanisms. A rather narrow optimum of the heat and moisture supply of the crop determines the difference in the influencing factors, depending on the geographic location and conditions of the experiment with respect to this optimum. Therefore, the quantitative assessment of the weather and climate factors influencing the growth and development of soybeans, different types of mathematical models are used, the multitude of which created for soybeans exceed numbers of those developed for any other plant (Shaykewich and Bullock, 2018; Kozlov et al., 2018; McCormick et al., 2021). The rate of passage of the interphase period is calculated as a function of the influence of temperature, daylength, and precipitation (Major et al., 1975; Hodges and French, 1985; Kozlov et al., 2018).

The rate of crop development accelerates with an increase in air temperature, and slows down under LD and in humid years. A delay in flowering in soybeans at high latitudes is associated with both the increased photoperiod and lower temperatures (Major et al., 1975; Hadley et al., 1984).

For soybean flowering, 25–28 °C was considered as the optimum. Excessive high temperatures also delay flowering, inhibit growth, and retard development (Zhao et al., 2017; Kim et al., 2020).

In addition to temperature, precipitation is also a significant factor (Major et al., 1975; Hodges and French, 1985). In this study, the plants were kept outdoors for at least 12 h and were exposed to the excessive moisture stress during heavy natural precipitation, even when irrigation was excluded. In 2017, under the influence of extreme precipitation amounting to 4 mm/day, the maximum L_{EF} for all the years of study was observed for the 'Svetlaya' variety, that is, 57 days under LD and 49 days under SD. In 2016, which was also characterized by a significant excess of precipitation in June-July compared to the long-term value of 76 mm in the week preceding flowering, led to a delay in the opening of flowers under SD and neutralized the effect of daylength. Excessive rainfall delays flower opening.

The combination of low temperatures and excessive precipitation during the flowering period played a limiting role in the development of soybeans with low photoperiod sensitivity in Leningrad Province and determined 84.3% of the interannual variability of the EF period, while the photoperiod accounted for 9.9% only.

C_{phs} proved to be a stable characteristic of the variety: in the 'Svetlaya' variety, it varied less over the years (CV = 7.1%) than the difference between the L_{ES} under LD and under SD (CV = 58.9%). No correlation was found between the C_{phs} of the 'Svetlaya' variety and any weather indicators over the 8 years of the study. A comparison of photoperiod sensitivity characteristics for a set of 5 varieties in the years with contrasting weather conditions (2014 and 2018), when the average daily air temperature during the flowering period differed by 5 °C on an average, showed the absence of significant differences in C_{phs} in contrasting years.

In highly photosensitive accessions, which include late maturing varieties of southern or Far East origin, flowering is absent or occurs late, the vegetative period increases, the growth of vegetative mass increases, and the seeds do not reach full ripeness under LD conditions in the northern latitudes with low average temperatures (Seferova, 2016). However, the ultraearly and very early maturing varieties created over the past decades, which are called the "northern ecotype" or varieties of high latitude cold regions (HCR), have a low or almost neutral PhS, which allows the promotion of the crop northward (Jia et al., 2014; Seferova and Novikova, 2015).

Although the studied sample set consisted of accessions selected as promising for cultivation in high latitudes in the northwest of the RF, the overwhelming number of the studied varieties delayed flowering under LD by 7.9 days on an average. At the same time, the sums of temperatures for the emergence to flowering period increased under LD by 143.2 °C on an average.

Early maturity of soybeans, associated with weak photosensitivity, is controlled by the genes/loci *E1 – E10* and *J*, the allelic combinations of which determine the time of flowering and maturation at different photoperiods (Samanfar et al., 2017), as well as the response to temperature (Jia et al., 2014; Kurasch et al., 2017). The genetic structure of a variety is largely determined by its adaptation to the place of creation. The origin of varieties significantly affects the diverse manifestation of the additive effect of photoperiod and temperature on the onset of flowering in soybeans with different genotypes. Obviously, among the many genetic factors that determine photo- and thermosensitivity, early maturing varieties from high latitudes are characterized by genes that induce early flowering at relatively low temperatures.

It is worth noting that out of the five varieties studied during two years with contrasting weather conditions and found to react to temperature quite similarly, three (‘Svetlaya’, ‘Okskaya’ and ‘Kasatka’) were created in one and the same breeding institution of Ryazan Province; the ‘PEP-2’ line was created at VIR in Leningrad Province and the ‘Altom’ variety originated from Barnaul. All of these places are located above 53ºN. Earlier, in our work devoted to the screening of the VIR collection for accessions suitable for cultivation in Leningrad Province, it was stated that these should be varieties created in relatively high latitudes not lower than 48°N (Seferova, 2016).

A persistently negative correlation between the photoperiodic and temperature sensitivity of varieties and the latitude of their origin is also noted in the work of other scientists (Wu et al., 2015). They also state the fact discovered by us experimentally: low latitude varieties are more sensitive to these parameters than those created in high latitudes. This property of high latitude varieties is believed to determine their regional adaptation that is broader than in southern varieties (Tsubokura et al., 2013; Jia et al., 2014).

As noted above, the Russian varieties that participated in our experiment and had a weak photoperiod sensitivity were created in relatively high latitudes. The analysis of the area of their adaptation indicates a broader regional adaptation of most of them in comparison with varieties bred in the south. In general, of the 257 soybean varieties registered in the state register of selection achievements admitted for use (2020), 166 (64%) are commercialized in one region only. This is especially true for the varieties from the North Caucasian and Far Eastern regions —the main soybean cultivating areas in this country. The regions in which the early maturing varieties from our experiment ‘Kasatka’ (2 regions), ‘Okskaya’ (4), and ‘Svetlaya’ (4) are commercialized, are located above 50ºN, where the daylength in June is not less than 16 h. It was shown in our study that the need for heat in soybean varieties weakly sensitive to the photoperiod dominates over the photoperiod dependence.

All the regions for commercialization of the considered early varieties with low photoperiod sensitivity are located south of the Russian northwest in temperature conditions that are favorable for the cultivation of these early varieties. According to the aims of our research, the further task of studying the varieties with weak photoperiod sensitivity is to determine the optimal temperature for their development at different latitudes. The disturbance in the development of such varieties in the southern regions, as was mentioned above, is apparently determined by the heat supply above the optimal one.

5. Conclusion

A study of the photoperiod and temperature dependence of the onset of flowering in 106 soybean accessions from the VIR genetic resources collection, chosen as the most early ones in the conditions of Leningrad Province, revealed the dominant influence of weather conditions on this process in comparison with the photoperiod. The influence of weather conditions accounted for 84.3% of L_{EF} variability, while the photoperiod for only 9.9%. The experiment involved mainly accessions with very low photoperiod sensitivity (73.6% of the sample set); the varieties that we defined as low sensitive amounted to 21.7%, the medium sensitive ones to 3.8%, and only 0.9% (one accession) was characterized as highly sensitive to the photoperiod. In comparison with SD, the sum of temperatures for the EF period under LD conditions increased for the early maturing varieties by 143.2 °C on an average. C_{phs} proved to be a stable characteristic of a variety, as it did not change depending on the conditions of the year.

Abbreviations

ANOVA: analysis of variation;
$C_{phs} = T_1/T_2$: coefficient of photoperiodic sensitivity;
CV: coefficient of variation;
EF period: emergence to flowering period;
LD: long day;
L_{EF}: emergence to flowering period length;
p: significance level;
PhS: photoperiod sensitivity;
RF: Russian Federation;
SD: short day;
T_1: emergence to flowering period length under long day;
T_2: emergence to flowering period length under short day;
VIR: N.I. Vavilov All-Russian Institute of Plant Genetic Resources

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Conflict of interest

The authors declare no conflict of interests.

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