Influence of climatic indicators on the dynamics of the growing season duration and forecasting vegetable peas' harvest date

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Abstract. The aim of the study was to determine the variability of climatic factors, to assess their influence on the yield and the duration of interfacial periods of vegetable pea varieties. The experiment was carried out from 2000 to 2019. 4 varieties with shrunken seeds of different ripening groups were studied. For interfacial periods, the sum of effective temperatures above 4.4 °C (ET), the sum of heat units from 4.4 °C (HU), the sum of active temperatures above 10 °C (SAT), the sum of precipitation (SP), the hydrothermal coefficient (HTC), the number of days with temperatures above 30 °C (T˃30 °C), with precipitation from 1 to 20 mm/day (1˂P, mm˂20) and with precipitation over 20 mm/day (P, mm>20) were calculated. In the south of Russia, the yield of vegetable peas is limited by precipitation frequency (from 1 mm to 20) on the days from sowing to technical ripeness. The studied parameters of environmental conditions characterizing the provision of moisture (HTC, SP, 1˂P, mm˂20, P, mm>20) and the number of days with T˃30°C have a high level of variability. The number of days from sowing to sprouting and SAT of the "sprouting-technical ripeness" period are stable traits recommended for predicting the harvesting date of vegetable peas. A significant reduction in the growing season and its components was established in varieties of medium and late ripening when comparing modern (2000-2019) and earlier data (1964-1990). The results obtained indicate climatic changes, in connection with which it becomes necessary to use earlier varieties in production.

1. Introduction

Vegetable peas varieties (*Pisum sativum* L.) with a marrowy seeds' surface have a high dietary value. In comparison with round ones, the content of protein, fiber, lipids and the ratio of amylose to amylopectin in native starch are higher in shrunken seeds [1, 2]. Vegetable peas are one of the sources of micronutrients necessary for a healthy human life [3-5].

The grain of vegetable peas is used as food at the onset of the "technical ripeness" phase when the lower beans are green and ripe. During this period, peas are characterized by an optimal ratio of biochemical parameters. When ripe, there is an increase in the content of dry matter and starch, a decrease in the concentration of sugar, the grain becomes denser [6, 7]. The favorable harvesting period lasts from 3 to 7 days depending on weather conditions. Thus, the quality of the obtained product is determined by the accuracy of predicting the harvesting start date. Its establishment largely depends on the biological characteristics of used genotypes.
Prediction of the vegetable peas’ harvesting is formed on the basis of the variety’s growing season duration. This indicator significantly depends on agroecological conditions [8, 9]. Determination of the harvesting date can be based on the sum of active or effective temperatures, which are used on other crops [10, 11]. Some [12, 13] use the sum of heat units (heat sum (HS) / heat units (HU)) expressed in degree-days (growing-degree days (GDD)) as an indicator. The indicators’ calculation of the sum of effective temperatures and thermal units is carried out considering the crop’s biological minimum \( t_{\text{base}} \). At present, there are few comparisons of linear thermal indicators (the sum of active and effective temperatures, thermal units) among themselves in terms of stability and forecasting probability. The authors [12, 13] offer additional accounting factors in the existing calculation formulas.

The noted trends in climate change [14] make the task of monitoring the plants’ response urgent. The information obtained will make it possible to assess the possibility of further genotypes’ cultivation in changing conditions and to improve the accuracy of predicting the vegetable peas’ harvesting date.

The aim of the study was to determine the variability of climatic factors, to assess their influence on the yield and the duration of interfacial periods of vegetable pea varieties in the conditions of the Krasnodar Krai.

2. Materials and Methods
The experiment was carried out from 2000 to 2019 at the Krymsk Experiment Breeding Station – Branch of Federal State Budgetary Scientific Institution “Federal Research Center the N.I. Vavilov All-Russian Institute of Plant Genetic Resources” (Krymsk EBS VIR Branch, Russia, Krasnodar Krai). To analyze the variability of yield and the duration of interfacial periods of vegetable peas, 4 varieties of different groups of ripeness with shrunken seeds were taken. ‘Alfa’ (VIR catalog k-7071) of early ripening period, ‘Berkut’ (k-8856) - mid-early, ‘Adagumsky’ (k-7216) - mid-late and ‘Istok’ (k-9353) - late. The data of competitive variety testing were used. The seeds were sown with a SKS-6-10 seeder with a row spacing of 15 cm. The plot area was 15 m², the experiment had four-fold repetition.

During the growing season, the dates of the phases’ onset were noted: sowing, sprouting, flowering, technical ripeness. The length of the main interfacial periods was calculated. The harvest was recorded in the “technical ripeness” phase. The data of maximum \( t_{\text{max}} \), minimum \( t_{\text{min}} \), average \( t_{\text{av}} \), day temperatures and the sum of precipitation (SP) per day were obtained from the Hydrometeorological Service located 1.5 km away from the Krymsk EBS VIR Branch. For the interfacial periods, the sum of effective temperatures above 4.4 °C \( ET, \sum t_{\text{av} \cdot \text{day}} - 4.4 \), the sum of heat units \( s (HU, \sum t_{\text{max}} - t_{\text{min}}) * 0.5 - 4.4 \), the sum of active temperatures above 10 °C \( SAT, \sum t_{\text{av} \cdot \text{day}} 10 ^{\circ} \text{C} \), the sum of precipitation \( (SP, \sum SP) \), hydrothermal coefficient \( (HTC, (\sum SP \times 10)/\sum t_{\text{av} \cdot \text{day}} 10 ^{\circ} \text{C}) \), the number of days with temperatures above 30°C \( T>30 ^{\circ} \text{C} \), with precipitation from 1.0 to 20.0 mm/day \( 1<P, \text{mm}<20 \) and with precipitation over 20 mm/day \( P, \text{mm}> 20 \) were calculated. When calculating \( ET \) and \( HU \), daily values below 0 were taken equal to 0, the biological minimum \( \text{base} \) was taken as 4.4 ° C. Days with SAT values less than 10 °C were not considered. The characteristics of the growing seasons according to the HTC values were given in accordance with the criteria described in the guidelines for studying the collection of the world’s genetic resources of leguminous crops [15]. Mathematical data processing was performed using the Statistica 10 program. The traits were described by the mean with a confidence interval (mean±0.95 Conf. Interval) and coefficient of variation (CV,%). The correlation ratio between the parameters was established by calculating the Spearman correlation coefficient \( R \). Multivariate analysis of variance (Factorial ANOVA) assessed the interaction of vegetable peas’ yield and the environment, as well as compared the heat indicators.
3. Results and Discussion

Analysis of twenty-year data on 4 vegetable peas genotypes of different ripeness groups established a significant dependence of yield on all factors with a more pronounced influence of the environment (Table 1).

Table 1. The results of multivariate analysis of variance (Factorial ANOVA) to identify the influence share of factors on vegetable peas' yield.

| Source of variation                      | SS    | Df | MS    | F      | p      | η²,% |
|-----------------------------------------|-------|----|-------|--------|--------|------|
| Genotype (Factor A)                     | 129.8 | 3  | 43.26 | 288.8  | 0.00*  | 20.9 |
| Environment (Factor B)                  | 403.2 | 19 | 21.22 | 141.6  | 0.00*  | 65.0 |
| Interaction genotype*environment (A*B)  | 63.3  | 57 | 1.11  | 7.4    | 0.00*  | 10.2 |

SS is the sum of squares, Df is the number of degrees of freedom, MS is the standard deviation, F is the value of the Fisher criterion, p - the level of significance, * - significant differences, η² - the proportion of the factor's influence

The yield of vegetable peas varied in a wide range (2.45-9.96 t/ha) depending on the variety and the cultivation year. The average experimental yield amounted to 6.5 ± 0.2 t/ha. Reliably low indicators (LSD-test, p <0.05) were established in 2002 (5.3 t/ha), 2003 (3.3), 2013 (5.0), 2016 (5.1) and 2018 (5.3). In 2002, 2003 and 2018, the conditions were severely arid; in the period from sprouting to peas harvesting, the HTC amounted to 0.3, 0.4 and 0.6, respectively. Weather conditions in 2013 were characterized as moderately dry 0.8<HTC<0.9. At the same time, during the "flowering-beans filling" period there was a heavy rain with hail, which damaged the reproductive organs of plants. 2016 was a dry year during the period of active vegetative growth of peas. Whereas the period of reproductive development took place in conditions of excessive moisture (1.5<HTC<2.6). The largest harvest was obtained in 2001, 2004-2006, 2012 and 2015 (Figure 1). During these years, favorable conditions developed for the combination of climatic factors. The hydrothermal coefficient exceeded 1.0, precipitation fell evenly.

A significant difference (LSD - tect, at p˂0.01) in grain yield in the “technical ripeness” phase was revealed between the varieties. The indicator of the early-ripening ‘Alfa’ variety was the lowest and amounted to 5.4 ± 0.6 t/ha, mid-ripening ‘Berkut’ - 7.3±0.7, mid-ripening ‘Adagumsky’ - 6.3±0.7, late ‘Istok’ - 7.1±0.6. The yield of all varieties moderately depended on the number of days with precipitation from 1 to 20 mm in the "sprouting-technical ripeness" period, the correlation coefficient was at the level of 0.31-0.41.

The data obtained confirm the dependence of vegetable peas' yield on hydrothermal conditions. In the climatic conditions of the South of Russia, the limiting factor of the environment is the moisture supply to plants throughout the entire peas' growing season.

Climatic factors influenced the duration of the growing season of vegetable peas and its components.

The sowing-sprouting period lasted 16.8 ± 1.5 days and was characterized by an average level of stability (CV = 18.8%). According to the correlation analysis data, the period duration moderately depended on SP and HTC; Spearman's coefficient (R, at p<0.05) was 0.50 and 0.44, respectively. ET, HU and SAT did not affect the change in the number of days from sowing to sprouting. Parameters of weather conditions varied greatly (CV>20%).

"Sprouting-flowering" period. Starting from this stage of development, there is a varieties' differentiation into ripeness groups. There is a significant difference between the genotypes in terms of the period duration and the parameters of environmental conditions. The number of days from germination to flowering was 34.2 ± 1.9 days for Alfa variety, 40.2 ± 2.1 for Berkut variety, 43.2 ± 2.0 for Adagumsky variety, and 49.5 ± 2.1 for Istok. The duration of the "sprouting-flowering" period was characterized by an average and low level of variation (table 2). The period duration of the studied cultivars was significantly influenced (R> 0.25) by the parameters of environmental conditions.
describing the provision of moisture: the number of days with precipitation from 1 mm to 20, the amount of precipitation and HTC. At the same time, their values were highly variable. Thermal traits (SAT, ET, HU) were more stable.

![Figure 1. Yield of vegetable peas depending on the cultivation year (2000-2019, Krymsk EBS VIR Branch, Krymsk, Krasnodar Krai).](image)

The "flowering-technical ripeness" period is most important when growing vegetable peas, since it is at this growth stage that the harvest is formed, and the peas are harvested for processing. The number of days from mass flowering to technical ripeness did not differ significantly between the varieties and amounted to 20.0±1.9 days for ‘Alfa’ variety, 20.4±1.8 days for ‘Berkut’ variety, 20.3±1.8 days for ‘Adagumsky’ variety, and 19.6±1.0 for ‘Istok’. The greatest variation of the trait was noted in early variety ‘Alfa’, intermediate values in mid-early ripening ‘Berkut’ and mid-ripening ‘Adagumsky’, more stable values in late-ripening variety 'Istok' (table 2). Of the periods under consideration, this one is most dependent on climatic factors. The duration of the "flowering-technical ripeness" period moderately and strongly depended on SAT, HU, ET, SP, HTC, the number of days with precipitation from 1 mm to 20. The variability of the ET, HU and SAT indicators was of an average level (CV<20%), the rest of the parameters of weather conditions were less stable (CV>20%).

The period "sprouting-technical ripeness" unites the two previous ones. The length of the growing season of ‘Alfa’ variety amounted to 54.2±3.1 days, ‘Berkut’ - 60.5±3.2, ‘Adagumsky’ - 63.5±3.0, ‘Istok’ - 69.1±2.4. Depending on the variety, the duration of this development stage is characterized by a low and medium level of variability (CV<20%). The number of days from sprouting to technical ripeness was in direct dependence to SAT, SP, HTC, the number of days with precipitation from 1 mm to 20. An inverse dependency was noted with the number of days with temperatures above 30°C in the early ‘Alfa' variety R = -0.49. Most of the weather conditions' parameters had a high level of variation, only SAT was low, TU and ET were medium and low (Table 2).
Table 2. Correlation dependence of the interfacial periods’ duration of vegetable peas varieties on the parameters of environmental conditions and the level of their variability (Krasnodar Krai, 2000-2019).

| Parameter                  | Alfa          | Berkut         | Adagumsky      | Istok         |
|----------------------------|---------------|----------------|----------------|---------------|
|                            | R  | CV, % | R  | CV, % | R  | CV, % | R  | CV, % |
| duration of the "sprouting-flowering" period, days |
| ET, °C                     | 0.13 | 10.6 | 0.20 | 9.3  | 0.28 | 13.1 | 0.23 | 12.1 |
| HU, °C                     | 0.34 | 10.3 | 0.32 | 9.0  | 0.45* | 13.3 | 0.43 | 12.0 |
| SAT, °C                    | 0.26 | 9.4  | 0.31 | 9.1  | 0.41 | 12.5 | 0.34 | 11.0 |
| SP, mm                     | 0.58* | 50.1 | 0.38 | 60.4 | 0.53* | 58.8 | 0.64* | 46.9 |
| HTC                        | 0.53* | 48.2 | 0.36 | 54.7 | 0.51* | 53.3 | 0.56* | 44.0 |
| T>30°C, days               | -0.37 |       |       |       | -0.38 |       | -0.27 |       |
| 1<P, mm<20, days           | 0.47* | 52.2 | 0.54* | 51.2 | 0.49* | 49.0 | 0.49* | 38.9 |
| P, mm>20, days             | -0.02 | 0.12  |       |       | 0.27 |       | 0.38 |       |
| duration of the "flowering-technical ripeness" period, days |
| ET, °C                     | 0.70* | 16.2 | 0.86* | 18.2 | 0.85* | 20.6 | 0.31 | 13.1 |
| HU, °C                     | 0.75* | 14.7 | 0.85* | 16.4 | 0.82* | 18.2 | 0.40* | 10.6 |
| SAT, °C                    | 0.90* | 14.2 | 0.92* | 16.0 | 0.88* | 17.4 | 0.54* | 9.7  |
| SP, mm                     | 0.71* | 80.3 | 0.59* | 80.3 | 0.65* | 89.1 | 0.61* | 87.0 |
| HTC                        | 0.59* | 70.9 | 0.48* | 70.4 | 0.54* | 84.1 | 0.55* | 86.0 |
| T>30°C, days               | -0.31 |       |       |       | -0.23 |       | -0.17 |       |
| 1<P, mm<20, days           | 0.61* | 53.4 | 0.48* | 50.1 | 0.45* | 51.9 | 0.41 | 49.3 |
| P, mm>20, days             | 0.45* | 0.35 |       |       | 0.47* |       | 0.39 |       |
| duration of the "sprouting-technical ripeness" period, days |
| ET, °C                     | 0.52* | 11.4 | 0.61* | 11.4 | 0.49* | 12.7 | 0.27 | 10.4 |
| HU, °C                     | 0.64* | 10.1 | 0.63* | 9.9  | 0.60* | 11.2 | 0.33 | 9.0  |
| SAT, °C                    | 0.66* | 9.2  | 0.65* | 9.6  | 0.62* | 10.7 | 0.40* | 8.2  |
| SP, mm                     | 0.69* | 47.5 | 0.72* | 43.3 | 0.59* | 44.0 | 0.52* | 39.6 |
| HTC                        | 0.67* | 41.8 | 0.66* | 38.2 | 0.49* | 41.9 | 0.48* | 40.2 |
| T>30°C, days               | -0.49* |       |       |       | -0.35 |       | -0.26 |       |
| 1<P, mm<20, days           | 0.73* | 40.5 | 0.66* | 37.9 | 0.63* | 36.9 | 0.49* | 32.5 |
| P, mm>20, days             | 0.33 |     | 0.33 |     | 0.35 |     | 0.30 |     |
| "sowing-sprouting", days   | 0.33 | 18.8 | 0.29 | 18.8 | 0.13 | 18.8 | 0.10 | 18.8 |
| "sprouting-flowering", days | 0.75* | 12.0 | 0.85* | 11.3 | 0.77* | 10.1 | 0.89* | 9.1  |
| "flowering-tr", days       | 0.78* | 20.1 | 0.74* | 18.4 | 0.74* | 19.0 | 0.44 | 11.5 |
| "sprouting-tr", days       | 1.00 | 12.1 | 1.00 | 11.3 | 1.00 | 10.2 | 1.00 | 7.7  |
| Yield, t/ha                | 0.19 | 22.9 | 0.21 | 22.0 | 0.31 | 24.1 | 0.16 | 18.9 |

R-Spearman's correlation coefficient, CV-coefficient of variation, %
ET-sum of effective temperatures, HU-thermal units, SAT-sum of active temperatures above 10 °C, SP-sum of precipitation, mm, HTC-hydrothermal coefficient, T>30°C - number of days with temperatures above 30°C, 1<P, mm<20 - number of days with precipitation from 1 mm to 20, P, mm>20 - number of days with precipitation over 20 mm/day, tr - technical ripeness
* - significant correlations at p<0.05, 9.4 - low level of variability

In the climatic conditions of the Krasnodar Krai, the duration of the interfacial periods of vegetable peas is most influenced by precipitation, its sum and frequency. Frequent precipitation with high
values of SAT, HU, and ET leads to prolongation of the growth stages. A moderate inverse correlation (R > -0.25) was noted between the length of the periods and the number of days with temperatures above 30 °C (Table 2). Consequently, an increase in the number of days with high temperatures causes a reduction in the passage of interfacial periods; to a greater extent, this is characteristic of the early ‘Alfa' variety. The late variety 'Istok' was characterized by a decrease in the "flowering-technical ripeness" period under the influence of high temperatures. The studied vegetable peas varieties react to high temperatures like grain varieties [8, 9, 16].

Assessment of the variability level of environmental parameters and the duration of the growing season made it possible to identify the most stable ones that can be used for forecasting. The period from sowing to sprouting is determined by the "sowing-sprouting, days" indicator.

Prediction of the harvesting start date of vegetable peas can be based on the indicators SAT, HU, ET and the number of days of the "sprouting-technical ripeness" period. The characteristics of the "sprouting-technical ripeness" period of vegetable pea varieties according to the studied parameters of environmental conditions are presented in Table 3. Analysis of the data did not reveal significant differences between the ET and HU indicators for each genotype. The SAT values of each genotype were significantly higher in comparison with ET and HU. Multivariate analysis of variance found significant differences in SAT indicators between all genotypes (Table 3).

The data analysis has shown a decrease in the number of days from sowing to technical ripeness for vegetable pea varieties by 4-12 days, depending on the ripeness group. A decrease in the interfacial period "sowing-sprouting" by 3.5-5.2 days in 2000-2019 in comparison with earlier indicators was common for all groups. The growing season of varieties of the early and mid-early ripening groups was practically unchanged (Table 4). A significant decrease in the period's duration is typical for the mid-season and late groups. The number of days from sprouting to technical ripeness onset of the mid-ripening variety "Adagumsky" decreased by 3.5 days due to a reduction in the "sprouting-flowering"
period. When comparing the values of late varieties, a decrease in the duration of the periods "sprouting-flowering", "flowering-technical ripeness" and "sprouting-technical ripeness" was revealed by 7.5 days, 1.5 and 6.9, respectively. It has been previously found that shorter growth stages are caused by high temperatures. Similar conclusions were made in works [9, 16]. Consequently, during the growing season of genotypes of the mid and late ripeness period, the average daily temperatures over the past 20 years increased and began to accumulate in a shorter period. The revealed changes indicate the need to use earlier ripening varieties in production in order to increase the period of raw materials' reception for processing.

Table 4. Duration of interfacial periods of vegetable pea varieties (Krasnodar Krai).

| Variety | Observation period | Duration of interfacial periods, days |
|---------|-------------------|-------------------------------------|
|         |                   | sowing-sprouting | sprouting-flowering | flowering-tr | sprouting-tr |
| Alfa    | 1971-1990         | 20,5           | 32,6               | 22,0         | 54,5         |
| Alfa    | 2000-2019         | 16,8           | 34,2               | 20,0         | 54,2         |
| Vega    | 1976-1990         | 20,4           | 40,5               | 20,9         | 61,0         |
| Berkut  | 2000-2019         | 16,8           | 40,2               | 20,4         | 60,5         |
| Adagumsky | 1972-1990      | 20,3           | 46,4               | 20,2         | 67,0         |
| Adagumsky | 2000-2019       | 16,8           | 43,2               | 20,3         | 63,5         |
| Iulsky  | 1964-1977         | 22,0           | 57,0               | 21,0         | 76,0         |
| Istok   | 2000-2019         | 16,8           | 49,5               | 19,6         | 69,1         |

4. Conclusion

According to twenty-year data (2000-2019), the lowest yield of vegetable peas was obtained under severely arid conditions during the growing season (2002, 2003, and 2016), excessive moisture during reproductive growth (2018) and extreme weather events (2013). In the climatic conditions of southern Russia, the yield of vegetable peas is limited by the frequency of precipitation at the stage of plant development from sowing to technical ripeness.

Climatic factors affect the dynamics of the growing season duration of vegetable peas and its components. Frequent precipitation with high values of SAT, HU, and ET leads to prolongation of the growth stages. The increase in the number of days with high temperatures decreases the interfacial periods. This is especially typical for the early ‘Alfa’ variety. Under the influence of high temperatures, the reproductive period of the late variety ‘Istok’ is shortened.

When predicting the harvesting date of vegetable peas, it is recommended to use the "sowing-sprouting, days" and SAT indicators of the "sprouting-technical ripeness" period.

A significant reduction in the growing season and its components was established for varieties of medium and late ripening when comparing modern (2000-2019) and earlier data (1964-1990). The data obtained indicate climatic changes that have developed over the past 20 years, in connection with which it becomes necessary to use earlier varieties in the production to prolong the period of raw materials receipt for processing in the south of Russia.

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