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Phenological growth and development stages of asparagus pea (*Tetragonolobus purpureus* Moench.) under different sowing patterns in the conditions of the Right-Bank Forest-Steppe of Ukraine

Abstract. The study synthesised data on the application of phenological models to develop adaptive production technologies for asparagus pea, enabling the regulation of phenological phase progression while considering the unique characteristics of the cultivar and regional conditions. This approach is crucial for improving both yield and quality across various ecological conditions. The study aimed to determine the rate of key growth and development phases of asparagus pea and to establish the dependence of these processes on specific cultivation technology elements, particularly sowing patterns, in the Right-Bank Forest-Steppe of Ukraine. A comprehensive

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approach was employed, integrating field research on cultivation practices, visual observations of plant development dynamics, and statistical analysis to quantify the impact of various factors. The findings revealed a correlation between sowing patterns and the duration of phenological phases. In the 45×10 cm and 45×15 cm (control) variants, emergence occurred on 11 May, 11 days after sowing, under a cumulative temperature above 10°C of 59.4°C and 45 mm of precipitation. In the 45×20 cm and 45×25 cm variants, emergence was recorded on 17 May, 13 days after sowing, with a cumulative temperature of 71.2°C and 45.7 mm of precipitation. The onset of flowering was recorded between 16 and 23 June, depending on plant density. The shortest "emergence-flowering" period was observed in the 45×10 cm variant (32 days), with a cumulative temperature of 252.9°C and 84.5 mm of precipitation, while the longest was in the 45×25 cm variant (37 days), with a cumulative temperature of 328.5°C and 92.7 mm of precipitation. The onset of the technical maturity stage was noted between 24 June and 5 July, with the "flowering-technical maturity" period ranging from 8 to 12 days, depending on plant density. Biological maturity occurred between 10 and 18 July, with the "technical-biological maturity" phase lasting 12-16 days. The growing season lasted 56-62 days, with a cumulative temperature of 534-619.9°C and precipitation levels of 156-169.7 mm. A strong inverse correlation was established between plant density and the duration of the interphase periods from sowing to technical maturity (r = -0.84 to -0.98), while a strong direct correlation was observed between density and the "technical-biological maturity" period (r = 0.92). Increasing plant density by 5,000 plants per hectare shortened phenological periods by 0.8-2 days. A direct correlation was also identified between precipitation (r = 0.86 to 1.0), temperature (r = 0.97 to 1.0), and phase duration. A temperature increase of 10°C extended the phases by 0.6-1.7 days. The findings provide a basis for optimising sowing patterns to enhance plant growth and development, thereby improving asparagus pea productivity

Keywords: BBCH; emergence; flowering; growing season; critical phases; cumulative temperature and precipitation

INTRODUCTION

Food security has become one of the most pressing global challenges due to the rapidly increasing world population. This situation is further complicated by climate change, which leads to a rise in both environmental and biological stresses. A lack of diversity is another significant issue within the current food system. Globally, humans rely on a limited range of food sources, with 75% of the world's food supply coming from just 12 plant and 5 animal species (Colgrave *et al.*, 2021). As highlighted by R. Ambikapathi *et al.* (2022), a lack of dietary diversity may have negative health implications. Research into underutilised and overlooked agricultural species is crucial for addressing global food security. These crops, often rich in nutrients and resilient to climate change, are frequently neglected due to their low commercial value. However, they are key to reducing malnutrition and enhancing food security, particularly in vulnerable regions (Aboltins *et al.*, 2024). For example, F. Mudau *et al.* (2022) point out that Southern Africa has substantial potential in utilising underutilised indigenous crops, but these remain underdeveloped due to insufficient attention from researchers and policymakers. The authors stress the need to accelerate research and develop value chains for these crops, and advocate for a transdisciplinary approach to successfully integrate them into modern food and medical systems.

One promising crop for addressing food security is asparagus pea (*Tetragonolobus purpureus* Moench.), a tropical legume with high protein content in its seeds, often referred to as "the soybean for the tropics" (Ho *et al.*, 2024). R. Bepary *et al.* (2023) describe this vegetable crop as a "single species supermarket" or "one stalk supermarket" because all parts of the plant, including pods, young seeds, flowers, leaves, tubers, and mature seeds, are consumable. It is worth noting that the plant also has a high nutritional value. Specifically, as noted by H. Bassal *et al.* (2021), it is an important source of vitamins

(A and C), minerals (calcium and iron), as well as erucic acid, polyunsaturated fatty acids, and proteins (30-45% of which are lectins).

The yield of modern asparagus pea varieties ranges from 5 to 10 tonnes per hectare of fresh pods, while seed yield ranges from 1 to 1.5 tonnes per hectare. Therefore, P. Singh *et al.* (2022) identify overcoming the "yield gap" as a key task for expanding production and consumption. According to S. Klutse *et al.* (2025), optimising plant density is a crucial factor not only for achieving maximum yield but also for improving its quality. A high density of plant cover increases competition between plants for resources, leading to the depletion of limited resources (Azmat *et al.*, 2024). Practical observations by M. Haque & S. Sakimin (2022) indicate that high plant density leads to many adverse effects, including disease susceptibility, fruit drop, reduced fruit size, delayed ripening, decreased individual plant growth, and light interception. Through better planting structure, an optimal leaf area index can be achieved, which promotes increased photosynthetic capacity of plants through efficient absorption of solar radiation (Li *et al.*, 2021). However, the optimal plant density, according to I. Bobos *et al.* (2024), vary depending on the biological characteristics of the crop, including varietal differences in growth vigour, height, degree of branching, as well as sowing dates and weather conditions during the growing season.

Due to variations in soil type and other environmental conditions, the optimal plant density for a particular crop may not be suitable for other locations. This necessitates the development of region-specific recommendations to ensure effective and sustainable management of agricultural resources. Thus, this study aimed to determine the rate of progression of the main growth and development phases of asparagus pea and to establish the dependence of these processes on specific elements of cultivation technology, in particular sowing patterns, under the conditions of the RightBank Forest-Steppe region of Ukraine.

MATERIALS AND METHODS

The experimental study was conducted over three years (2016-2018) at the National University of Life and Environmental Sciences of Ukraine (NULES of Ukraine). The soil of the experimental site is classified as dark grey, medium podzolic, and light loamy, with a soil pH of 6.1. The humus horizon was 24-28 cm. The experimental site was characterised by a low humus content, ranging from 1.5 to 2.2%, a medium nitrogen content of 26 to 38 mg/kg, phosphorus content of 43 to 61 mg/kg, and potassium content of 28 to 34 mg/kg.

In December, a gradual decrease in temperature was observed, with minor peaks in individual years and an average ten-day temperature ranging from 2.2°C to -2.8°C, while precipitation ranged from 9.5 to 73.0 mm per ten-day period (Fig. 1). In January and February, the average temperature continued to decrease, reaching -9.6°C in the coldest ten-day period. Precipitation during this time was relatively low (0.4-57.1 mm), typical of the winter period when snowfall and periods of relative dryness prevail. Some instability was noted: in the third ten-day period of February 2016, precipitation significantly exceeded the corresponding values in other years.

The onset of spring was marked by a gradual warming, increasing on average by 2-3°C per ten-day period. March 2018 saw relatively low air temperatures, fluctuating between -4.3 and 0.7°C. This was accompanied by increased precipitation, particularly in the first ten-day period of March (2018), when values reached 58.1 mm. In April, temperatures continued to rise (to 7.4-15.6°C), while precipitation became uneven, with both dry ten-day periods and periods of intense rainfall (up to 90.2 mm in the second ten-day period of 2016). In May, temperatures rose to 13.3-20.8°C, maintaining a trend of gradual increase. Precipitation reached maximum values, especially in the third ten-day period of May 2016, when significant downpours occurred with a maximum value of 89.5 mm per ten-day period.

The summer months were characterised by the highest temperatures: in June, they ranged from 17.0 to 24.8°C per ten-day period, in July they reached values from 19.3 to 23.5°C, and in August they remained at 17.1 to 25.6°C. Precipitation during this period showed significant variability: June saw periods of heavy rain (up to 113.1 mm in the third ten-day period of 2018), while July proved to be drier in some years. August was characterised by alternating dry and rainy ten-day periods – in 2016 in the first ten-day period and in 2017 in the second ten-day period, minimal precipitation was recorded, while in the third ten-day period of 2017, a sharp increase in precipitation was observed (up to 55.2 mm).

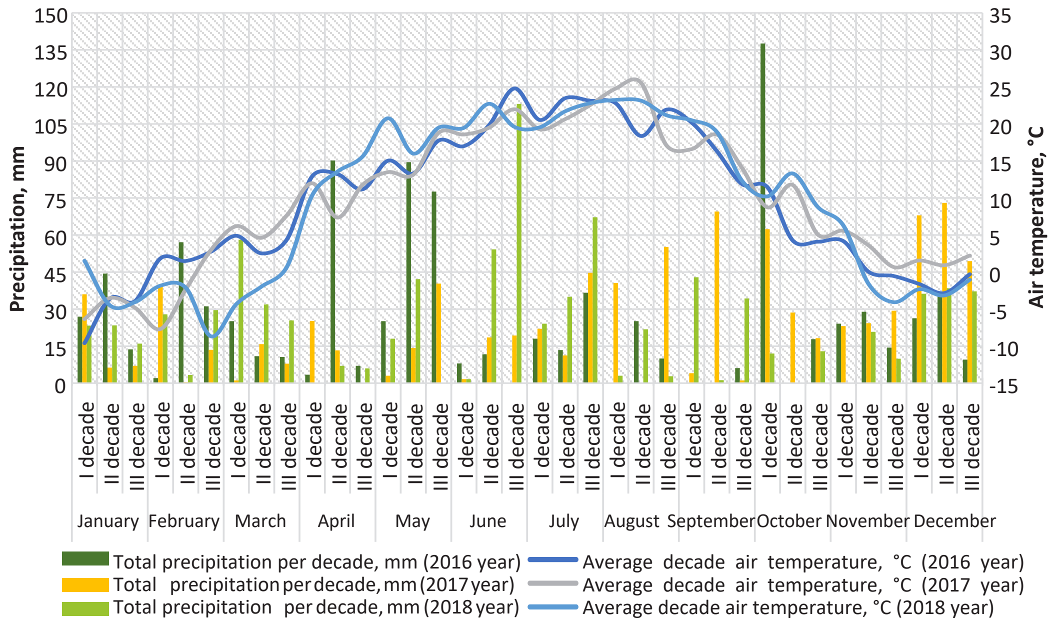

Figure 1. Analysis of air temperature and precipitation dynamics for 2016-2018
Source: developed by the authors based on the conducted study

In September, temperatures gradually decreased (from 20.2°C in the first ten-day period to 11.9°C in the third ten-day period), and precipitation was unevenly distributed: heavy rains were observed in the second ten-day period, while the first and third ten-day periods were relatively dry. October showed a steady decrease in temperature (to 4.1-8.8°C in the third ten-day period). An unusually high amount of precipitation was recorded in the first ten-day period of 2016 – 137.6 mm. November continued the trend of decreasing temperature (from 6.3°C at the beginning of the month to 4.1°C at the end), and precipitation was unevenly distributed across the years (from 0.0 mm in the first ten-day period of 2018 to 29.3 mm in the third ten-day period of 2017).

The Department of Vegetable Crops at NULES of Ukraine studied four sowing patterns of asparagus pea during 2016-2018: A) 45×10 cm; B) 45 × 15 cm; C) 45 × 20 cm; D) 45 × 25 cm. The control was the distance between plants in the row of 15 cm. Seeds were sown on 4 May at a depth of 2-3 cm. The area of each plot was 5 m^2. The phenological development of asparagus pea plants was determined using the BBCH scale (Meier *et al.*, 2009). According to the BBCH scale, the life cycle of asparagus pea includes nine developmental stages, each with characteristic duration and distinct features, where: 0 – germination (00: dry seed); 1 – leaf development (10: cotyledons fully unfolded; 13: 3rd true leaf (first trifoliate) unfolded); 2 – development of side shoots (29: 9 or more side shoots visible); 5 – inflorescence emergence (59: first petals visible, flowers still closed); 6 – flowering (65: stage reached when 50% of flowers are open); 7 – fruit development (75: pods have reached typical length in approximately 50% of cases, with pods beginning to fill); 8 – fruit and seed ripening (89: pods fully ripe, showing hardened state, indicating complete maturity) (Fig. 2).

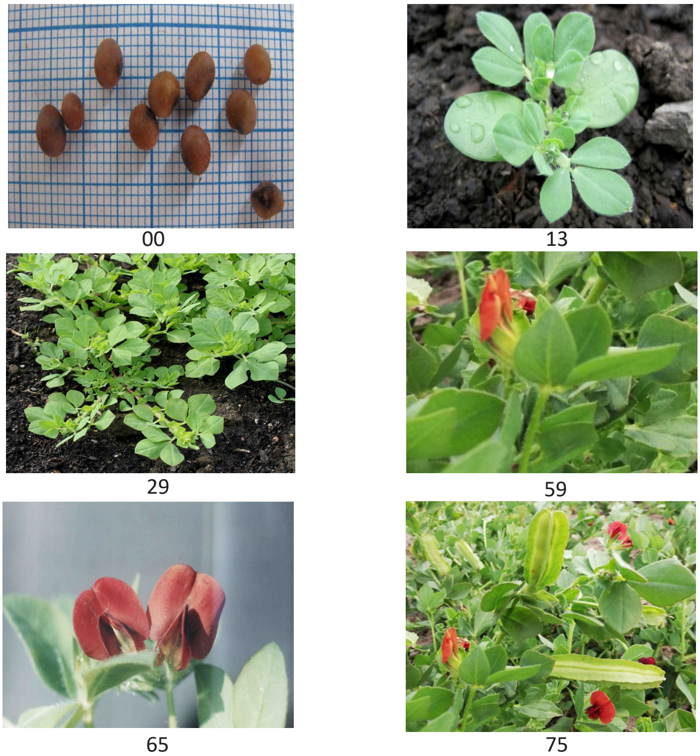

Figure 2. Main and secondary phenological stages of asparagus pea (*P. tetragonolobus*) according to the extended BBCH scale

Note: 0 – germination (00: dry seed); 1 – leaf development (13: 3rd true leaf (first trifoliate) unfolded); 2 – development of side shoots (29: 9 or more side shoots visible); 5 – inflorescence emergence (59: first petals visible, flowers still closed); 6 – flowering (65: stage reached when 50% of flowers are open); 7 – fruit development (75: pods have reached typical length in approximately 50% of cases, with pods beginning to fill)
Source: developed by the authors based on the conducted study

The growth and development stages of asparagus pea were determined visually for the entire experiment simultaneously. The onset of a stage was recorded when it was observed in 10% of the plants in the plot, and mass onset was recorded upon reaching 75%. The sum of effective air temperatures was calculated using formula (1):

$$\sum t_{eff} = (t_{avg} - B) * n, \qquad (1)$$

where $\Sigma\, t_{eff}$ is the sum of effective air temperatures for the period, °C; t_{avg} is the average active air temperature for the period, °C; B is the biological minimum, which was taken as 10°C in this study; n is the number of days in the period.

The research results were processed using Statistica 13.1 software (StatSoft, Inc., Tulsa, OK, USA). To determine the direction and degree of correlation between the studied indicators, the correlation coefficient was calculated (Nageswara Rao, 2021). During the study, the Convention on Biological Diversity (1992) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1973) were adhered to.

RESULTS AND DISCUSSION

The analysis results show a clear relationship between the sowing pattern and the duration of the asparagus pea germination period. In the variants with a row spacing of 45 cm and a plant spacing of 10 cm and 15 cm (control), seedlings emerged on 11 May, which corresponds to 11 days from the time of sowing (Figs. 3, 4). The characteristic conditions for the "sowing-emergence" phenological phase were a total temperature (above 10°C) of 59.4°C and a precipitation amount of 45 mm (Fig. 5). In the variants with a row spacing of 45 cm and a plant spacing of 20 and 25 cm, seed germination occurred somewhat slower, and seedlings appeared on 17 May. The duration of the "sowing-emergence" phenological phase in these variants was 13 days, which is 2 days later than the control, and was accompanied by a total temperature (above 10°C) of 71.2°C and a precipitation amount of 45.7 mm.

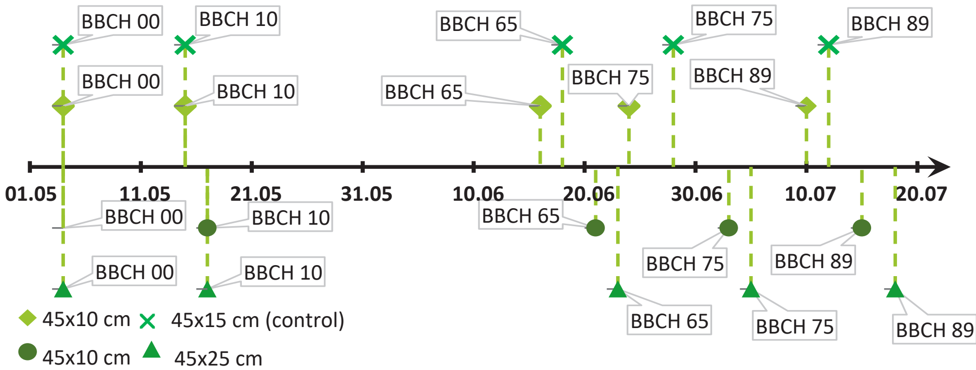

Figure 3. Results of phenological observations of asparagus pea plant growth and development under different sowing patterns (average for 2016-2018)

Note: phenological development of asparagus pea plants: sowing (BBCH 00) – dry seed; emergence (BBCH 10) – cotyledons fully unfolded; start of flowering (BBCH 65) – stage reached when 50% of flowers are open; technical maturity (immature (green) pods) (BBCH 75) – pods have reached typical length in approximately 50% of cases, with pods beginning to fill; biological seed maturity (BBCH 89) – pods fully ripe, showing hardened state, indicating complete maturity

Source: developed by the authors based on the conducted study

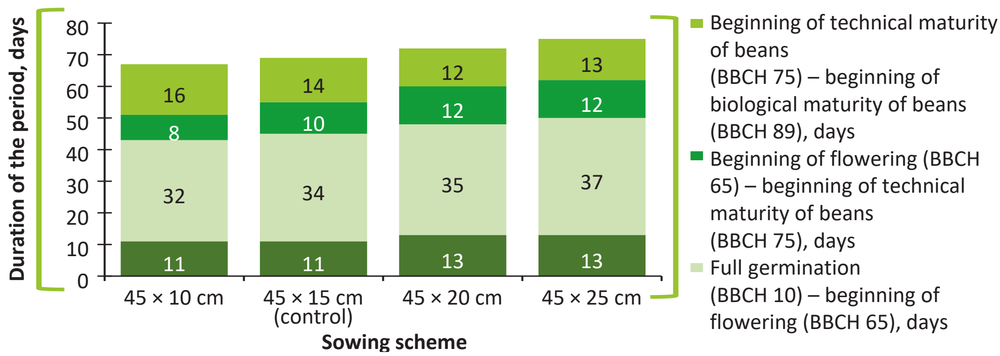

Figure 4. Duration of asparagus pea plant growth and development phenological stages depending on plant density (average for 2016-2018)

Note: phenological development of asparagus pea plants: sowing (BBCH 00) – dry seed; emergence (BBCH 10) – cotyledons fully unfolded; start of flowering (BBCH 65) – stage reached when 50% of flowers are open; technical maturity (immature (green) pods) (BBCH 75) – pods have reached typical length in approximately 50% of cases, with pods beginning to fill; biological seed maturity (BBCH 89) – pods fully ripe, showing hardened state, indicating complete maturity

Source: developed by the authors based on the conducted study

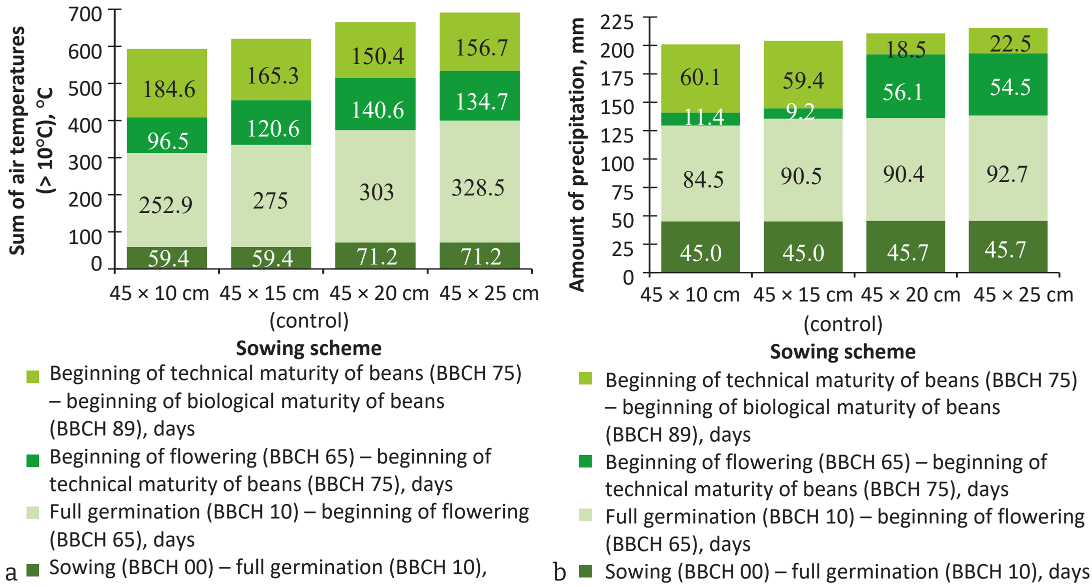

Figure 5. Analysis of the dynamics of the sum of effective temperatures (>10°C) (a) and precipitation (b) during the asparagus pea growing season (average for 2016-2018)

Note: phenological development of asparagus pea plants: sowing (BBCH 00) – dry seed; emergence (BBCH 10) – cotyledons fully unfolded; start of flowering (BBCH 65) – stage reached when 50% of flowers are open; technical maturity (immature (green) pods) (BBCH 75) – pods have reached typical length in approximately 50% of cases, with pods beginning to fill; biological seed maturity (BBCH 89) – pods fully ripe, showing hardened state, indicating complete maturity

Source: developed by the authors based on the conducted study

The studies noted the influence of row spacing on the onset of flowering. The earliest flowering was observed on 16 June in the 45×10 cm variant, while in the control (45×15 cm) it occurred on 18 June, and in the 45×20 cm and 45×25 cm variants, it occurred even later, on 21 and 23 June. The shortest period from emergence to flowering was 32 days in the 45×10 cm variant, which is 2 days less than the control. The average precipitation was 84.5 mm, and the sum of air temperatures (above 10°C) during this interphase period was 252.9°C. The longest "emergence-flowering" interphase period was characterised by the 45×25 cm variant – 37 days, which is 3 days longer than the control, and was accompanied by a total temperature of 328.5°C and a precipitation amount of 92.7 mm. With a sowing pattern of 45×20 cm, the duration of the "emergence-flowering" period was 35 days, which is 1 day longer than the control. In this case, the average sum of temperatures (above 10°C) was 303°C, and the precipitation amount was 90.4 mm. Meanwhile, in the 45×15 cm control, the period from emergence to flowering lasted 34 days with an average sum of temperatures (above 10°C) of 275°C and a precipitation amount of 90.4 mm.

The onset of technical maturity of the pods in the experimental plants was observed from 24 June to 5 July. The longest period from the start of flowering to the start of technical maturity of the pods was recorded in the variants with sowing patterns of 45×20 cm and 45×25 cm (12 days), which is 2 days longer than the control. The sum of temperatures (above 10°C) during this phenological period was 134.7-140.6°C, and the average precipitation was 54.5-56.1 mm. With a sowing pattern of 45×10 cm, the shortest period "start of flowering-start of technical maturity of pods" was observed (8 days), which is 2 days less than the control, and was accompanied by a sum of temperatures (above 10°C) of 96.5°C and a precipitation amount of 11.4 mm. In the variant with a plant spacing of 45×15 cm (control), the onset of technical maturity of the pods occurred

10 days after the start of flowering and was marked by a sum of temperatures (above 10°C) of 120.6°C and a precipitation amount of 9.2 mm.

The onset of biological maturity of the pods was reached earliest in the 45 × 10 cm variant (10 July), while in the control (45 × 15 cm) it occurred on 12 July, and in the 45 × 20 cm and 45 × 25 cm variants, it occurred on 15 and 18 July, respectively. The period from technical to biological maturity shortened with increasing distance between plants in the row: it was longest in the planting with a plant spacing of 10 cm and lasted 16 days, which is 2 days longer than the control, in the plantings with a spacing of 20 cm and 25 cm – 12 and 13 days respectively, or 1-2 days less than the control, and the control variant (15 cm) – 14 days. The duration of the "technical maturity-biological maturity" phenological phase was accompanied by the accumulation of a temperature sum (above 10°C) from 184.6 to 165.3°C and a precipitation sum from 18.5 to 60.1 mm. This indicates that denser plant spacing leads to slower pod development, which may be due to increased mutual shading. For asparagus pea, the growing season, depending on the sowing pattern, ranged from 56 to 62 days. Plant growth and development from emergence to the onset of biological maturity of the pods was directly accompanied by a total temperature (above 10°C) from 534 to 619.9°C and a precipitation amount of 156 to 169.7 mm.

It was established that there is a strong inverse relationship between the density of asparagus pea plants and the duration of the interphase period "sowing-emergence" (r = -0.84), "emergencestart of flowering" (r = -0.96), "start of flowering-start of technical maturity of pods" (r = -0.98), and the growing season (r = -0.92). A strong direct relationship was found between the density of asparagus pea plants and the duration of the interphase period "start of technical maturity of pods-start of biological maturity of pods" (r = 0.92) (Fig. 6). Statistical analysis of the experimental data and their graphical representation revealed that an increase in plant density by 5,000 plants/ha led to a reduction in the interphase periods: "sowing-emergence" by 0.8 days, "emergence-start of flowering" by 1.7 days, "start of flowering-start of technical maturity of pods" by 1.6 days, and the growing season by 2 days. At the same time, an increase in the period "start of technical maturity of pods-start of biological maturity of pods" by 1.3 days was observed.

The research results demonstrated a direct correlation between the amount of precipitation and the duration of asparagus pea interphase periods, specifically the periods "sowing-emergence" (r = 1.0); "emergence-start of flowering" (r = 0.93); "start of flowering-start of technical maturity of pods" (r = 0.88); "start of technical maturity of pods-start of biological maturity of pods" (r = 0.86); and the growing season (r = 0.97). A direct correlation was also found between the total air temperature (above 10°C) and the duration of asparagus pea interphase periods, namely the periods "sowing-emergence" (r = 1.0); "emergence-start of flowering" (r = 0.98); "start of flowering-start of technical maturity of pods" (r = 0.98); "start of technical maturity of pods-start of biological maturity of pods" (r = 0.99); and the growing season (r = 0.97) (Fig. 7). Based on the regression equations, it was established that an increase in the sum of air temperatures (above 10°C) by 10°C led to an increase in the interphase periods: "sowing-emergence" by 1.7 days, "emergence-start of flowering" by 0.6 days, "start of flowering-start of technical maturity of pods" by 1.0 day, "start of technical maturity of pods-start of biological maturity of pods" by 1.1 days, and the growing season by 0.6 days.

The development of plant phenological processes is determined by weather conditions (Katal *et al*., 2022). Prolonged exposure to high temperatures causes stress in plants, which manifests as a decrease in photosynthetic efficiency. As a result, structural and functional changes occur in the photosynthetic apparatus (Ji *et al*., 2022). The results of research by R. Reed *et al*. (2022) show that thermal stress caused by high temperatures leads to several problems, namely: it negatively affects the process of seed formation and crop volume, and also significantly reduces the viability of already harvested seeds. At the same time, the amount and distribution of precipitation play a key role in plant growth and development, affecting the water balance and nutrient availability in the soil (Wang *et al*., 2022). Moisture deficit can lead to a slowdown in metabolic processes and a decrease in yield, while excessive precipitation can cause leaching of nutrients and the development of root diseases (Bhattacharya, 2021; Yanagi, 2021).

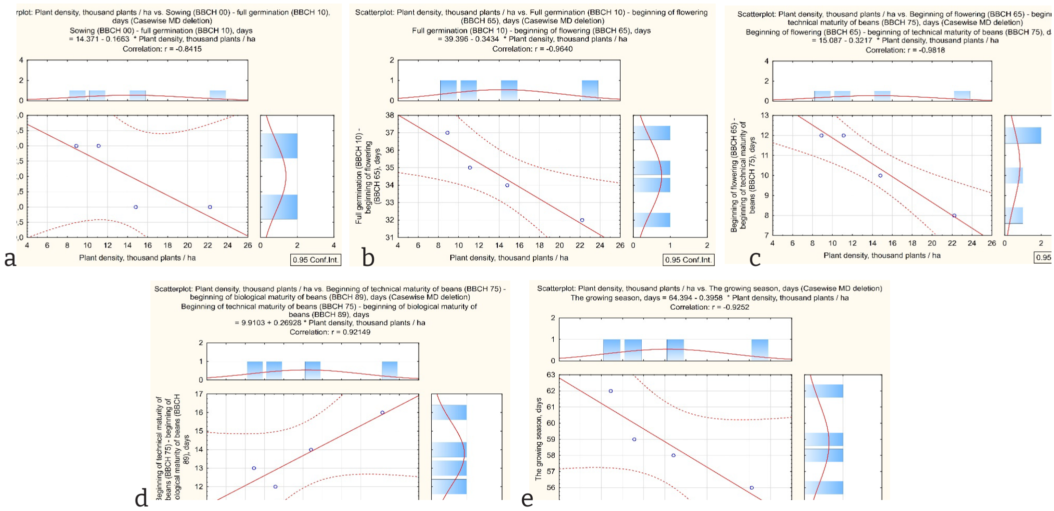

Figure 6. Influence of plant density on the duration of asparagus pea interphase periods (average for 2016-2018)

Note: phenological development of asparagus pea plants: sowing (BBCH 00) – dry seed; emergence (BBCH 10) – cotyledons fully unfolded; start of flowering (BBCH 65) – stage reached when 50% of flowers are open; technical maturity (immature (green) pods) (BBCH 75) – pods have reached typical length in approximately 50% of cases, with pods beginning to fill; biological seed maturity (BBCH 89) – pods fully ripe, showing hardened state, indicating complete maturity a) "sowing-emergence"; b) "emergence-start of flowering"; c) "start of flowering-start of technical maturity of pods"; d) "start of technical maturity of pods-start of biological maturity of pods"; e) growing season

Source: developed by the authors based on the conducted study

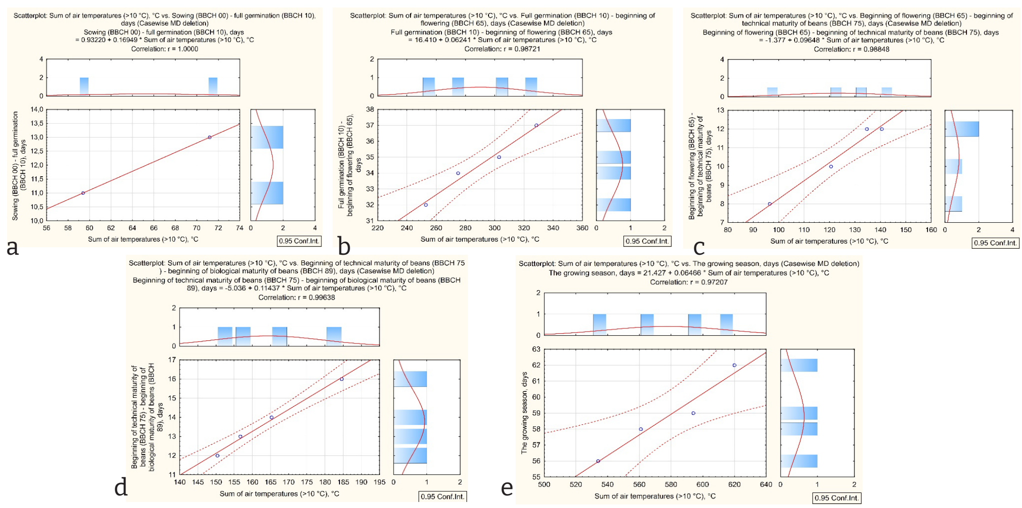

Figure 6. Influence of total air temperature (> 10°C) on the duration of asparagus pea interphase periods (average for 2016-2018)

Note: phenological development of asparagus pea plants: sowing (BBCH 00) – dry seed; emergence (BBCH 10) – cotyledons fully unfolded; start of flowering (BBCH 65) – stage reached when 50% of flowers are open; technical maturity (immature (green) pods) (BBCH 75) – pods have reached typical length in approximately 50% of cases, with pods beginning to fill; biological seed maturity (BBCH 89) – pods fully ripe, showing hardened state, indicating complete maturity a) "sowing-emergence"; b) "emergence-start of flowering"; c) "start of flowering-start of technical maturity of pods"; d) "start of technical maturity of pods-start of biological maturity of pods"; e) growing season

Source: developed by the authors based on the conducted study

J. Dhillon *et al.* (2020) note that insufficient understanding of morphological scales of plant development complicates decision-making, in particular regarding the optimal timing of sowing and harvesting. In recent years, numerous models of agricultural crop growth have been developed, which focus on predicting key stages of development, such as flowering or ripening, or individual periods, for example, from sowing to flowering (Schieler *et al.*, 2023).

The growing degree-day indicator is often used to characterise crop cultivation processes. It reflects the accumulated sum of temperatures exceeding a defined threshold, specific to each crop. It is believed that using this parameter instead of conventional time counting helps to make the growth process more predictable and proportional to accumulated heat (Tschurr *et al.*, 2023). In particular, E. Pinzón-Sandoval *et al.* (2024) in their study highlight the influence of temperature regime on the processes of forming total and organ-specific mass in beans. It allows for a deeper understanding of the patterns of phenological development, features of growth and accumulation of degree-days in different periods – from the vegetative to the reproductive phase. The authors of this study propose to use phenological analysis with the use of such assessments as the sum of effective temperatures and the amount of precipitation, which allows for building more accurate growth models adapted to the real conditions of asparagus pea. This will allow not only to more accurately describe the development of the crop, but also to minimise errors associated with subjective interpretation of morphological scales in different regions.

It was observed that elevated temperatures significantly shortened the pod development period of asparagus pea, thereby reducing the time available for pod filling and assimilate partitioning, and consequently, the yield was reduced. In legumes, heat stress during flowering causes a decrease in male fertility, and also negatively affects the structure of the female reproductive system (Sher *et al.*, 2024). The results of research by F. Angelotti *et al.* (2020) demonstrate that genotypes in which flowering begins before the onset of extreme temperature conditions may be able to avoid the negative impact of such high temperatures. A. Lamichaney *et al.* (2021) found a significant negative correlation ($p < 0.001$) between pea seed germination and maximum temperature during flowering and the reproductive period. In addition, the number of accumulated growing degree-days during the growing season had a positive correlation with seed germination ($p < 0.001$). Experiments on asparagus pea plants with different sowing patterns showed that with an increase in the sum of air temperatures, the development stages took much longer.

Research in Australia, conducted with a sowing pattern of 100×75 cm and encompassing three sowing dates and three asparagus pea samples, showed that the average duration of the period from sowing to the opening of the first flower ranged from 68 to 167 days (Eagleton, 2022). Another study conducted in India with a sowing pattern of 100 × 60 cm revealed a minimum duration of this period in the VRWB-84 genotype (68.66 days), and the longest period was recorded in the VRWB23 genotype (83.3 days) (Hansda *et al.*, 2023). Based on the observations of the authors of this study, in Ukraine this period lasted from 51 to 62 days. Significant correlations showed that lengthening the periods of interphase events to 50% flowering and ripening negatively affects seed yield. In addition, the presence of a strong correlation between these periods indicates their synchronicity, where earlier flowering ensures earlier ripening and, accordingly, increased yield (Bhadmus *et al.*, 2023). A genetic correlation coefficient ≥ 0.95 between the average duration of the period to flower opening and the number of days to the appearance of the first pod and 50% of the pods is biologically significant (Adebayo & Shonde, 2024).

This research demonstrates the significant impact of sowing patterns on the development of asparagus pea, a key factor for improving agricultural technologies. The results indicate that increasing the distance between plants in a row, thus reducing their overall density, can slow down certain stages of development, including germination, the start of flowering, and the achievement of technical maturity. At the same time, during the pod ripening stage, there is a tendency for slower ripening with less distance between plants. This will allow for better adaptation of technologies to the growing conditions of the crop.

CONCLUSIONS

Based on the conducted phenological observations, it was established that the growth and development of asparagus pea plants (*Tetragonolobus purpureus* Moench.) in the Right-Bank Forest-Steppe region of Ukraine is clearly dependent on the sowing pattern and plant density. The optimal conditions for rapid seedling emergence were found to be in the variants with a row spacing of 45 cm and a plant spacing of 10-15 cm, where seedlings appeared 11 days after sowing. Increasing the distance between plants to 20-25 cm slowed down the germination process by 2 days. It was established that plant density significantly affected the duration of interphase periods. The shortest period from emergence to the start of flowering (32 days) was observed with the 45 × 10 cm pattern, while in the 45 × 25 cm variant, this period lasted the longest – 37 days. Similar trends were observed for other phenological phases: shortening of interphase periods was observed with higher plant density, which is due to more intense competition for resources.

The period from the start of flowering to technical maturity of the pods lasted from 8 to 12 days, depending on the planting density, and the transition from technical to biological maturity occurred within 12-16 days. The earliest date for achieving biological maturity of the pods was 10 July (with the 45 × 10 cm pattern), and the latest was 18 July (with the 45 25 cm pattern). It has been proven that increasing plant density by 5,000 plants per hectare leads to a reduction in the overall growing season by 2 days. A strong correlation was found between plant density and the duration of phenological phases (r = from -0.84 to -0.98; 0.98), which confirms the significant impact of the sowing pattern on crop growth and development. Analysis of meteorological conditions showed that the duration of interphase periods positively correlates with the total air temperature (>10°C) (r = 0.97-1.0) and the amount of precipitation (r = 0.86-1.0). In particular, an increase in the sum of air temperatures by 10°C caused an extension of the interphase periods by an average of 0.6-1.7 days.

Future research will focus on an in-depth analysis of the impact of mineral nutrition, water regime, and varietal characteristics on the growth, development, and productivity of asparagus pea, taking into account predicted climatic conditions, which will contribute to the development of an adapted cultivation technology to increase the yield and stability of this crop in the region.

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CONFLICT OF INTEREST

None.

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Проходження фенологічних фаз росту та розвитку тетрагонолобуса (*Tetragonolobus purpureus* Moench.) залежно від різних схем сівби в умовах Правобережного Лісостепу України

Анотація. Узагальнено отримані дані з використання фенологічних моделей для створення адаптивних технологій виробництва тетрагонолобуса для забезпечення регулювання проходження фенологічних фаз з урахуванням індивідуальних особливостей сортозразку та умов регіону, що є критично важливим для підвищення врожайності та якості культури в різних екологічних умовах. Метою дослідження було визначення швидкості проходження основних фаз росту і розвитку тетрагонолобуса та встановлення залежності цих процесів від окремих елементів технології вирощування, зокрема схеми сівби, в умовах Правобережного Лісостепу України. У дослідженні застосовано комплексний підхід, що поєднує польові дослідження технологічних аспектів вирощування, візуальні спостереження за динамікою розвитку рослин та статистичний аналіз для кількісної оцінки впливу різноманітних факторів. Дослідження встановило залежність між схемами сівби тетрагонолобуса та тривалістю фенологічних фаз. У варіантах 45 × 10 см і 45 × 15 см (контроль) сходи з’явилися 11 травня, через 11 діб після сівби, за сумарної температури понад 10 °C 59,4 °C та опадів 45 мм. У варіантах 45 × 20 см і 45 × 25 см сходи з’явилися 17 травня, через 13 діб, при сумарній температурі 71,2 °C і опадах 45,7 мм. Початок цвітіння фіксували 16-23 червня залежно від густоти. Найкоротший період «сходи-цвітіння» спостерігався у варіанті 45 × 10 см (32 доби), за сумарної температури 252,9 °C і опадів 84,5 мм, а найдовший – у варіанті 45 × 25 см (37 діб), при температурі 328,5 °C і опадах 92,7 мм. Початок технічної стиглості відзначали 24 червня – 5 липня, тривалість періоду «цвітіння-технічна стиглість» варіювала від

8 до 12 діб, залежно від густоти. Біологічна стиглість настала 10-18 липня, а тривалість фази «технічна-біологічна стиглість» складала 12-16 діб. Вегетаційний період тривав 56-62 доби за сумарної температури 534-619,9 °С й опадах 156-169,7 мм. Встановлено сильний обернений зв'язок між густотою рослин і тривалістю міжфазних періодів від сівби до технічної стиглості (r = -0,84...-0,98) та прямий сильний зв'язок між густотою і періодом «технічна-біологічна стиглість» (r = 0,92). Підвищення густоти на 5 тис./га скорочувало фенологічні періоди на 0,8-2 доби. Виявлено пряму кореляцію між опадами (r = 0,86...1,0), температурою (r = 0,97...1,0) і тривалістю фаз. Збільшення температури на 10 °С подовжувало періоди на 0,6-1,7 доби. Отримані результати дозволяють оптимізувати схему сівби для покращення росту і розвитку рослин для підвищення продуктивності тетрагонолобуса

Ключові слова: BBCH; сходи; цвітіння; вегетаційний період; критичні фази; сума температур та опадів