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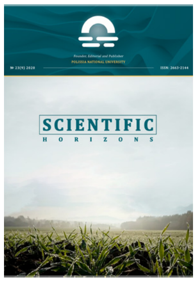

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Ecological stability, plasticity, and adaptability of asparagus pea (*Tetragonolobus purpureus* Moench) under different sowing dates

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Abstract. This study aimed to examine the response of asparagus pea grown under different sowing dates to abiotic factors characteristic of the Right-Bank Forest-Steppe of Ukraine, considering their impact on marketable bean yield. The research employed a comprehensive approach, incorporating field experiments and statistical analysis of the obtained data. Asparagus pea yield was largely dependent on sowing dates and weather conditions. The average yield of pods ranged from 2.0 to 6.4 t/ha, depending

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on the sowing date. The lowest amplitude of yield fluctuations (0.2-0.3 t/ha) was observed for sowing in the third ten-day period of April and the first ten-day period of May, whereas for other sowing dates, this indicator was significantly higher (up to 0.5-0.6 t/ha). It was established that yield positively correlated with temperature (r = 0.88) and precipitation (r = 0.66). An increase of these climatic factors by 10 units contributed to a yield increase of 0.703-0.877 t/ha. Plants sown in the third ten-day period of April and the first ten-day period of May exhibited the lowest regression coefficient b_i (0.77 and 0.40, respectively), indicating lower sensitivity to changes in growing conditions. In contrast, sowing in the third ten-day period of May and the first ten-day period of June resulted in greater sensitivity (b_i = 1.55 and 1.28, respectively). The optimal sowing dates were the first ten-day period of May and the third ten-day period of April, as they ensured the highest productivity and stability, along with a high content of dry matter (20.3-25.4%), sugars (5.56.8%), vitamin C (49.5-51.8 mg/100 g), and total nitrogen (3.5-3.7%). The poorest indicators were recorded for later sowing dates

Keywords: legumes; productivity; adaptive trait parameters; limiting factors; correlation

INTRODUCTION

Given the rapid growth of the global population, food and nutritional security has become one of the most pressing global challenges. Addressing this issue depends on increasing the productivity and resilience of agricultural crops. This requires a thorough understanding of how plants adapt to adverse conditions and the development of modern cultivation approaches. According to the Food and Agriculture Organization of the United Nations (FAO, 2023), approximately 730 million people (one in eleven globally) suffered from hunger in 2023. More than a third of the world's population cannot afford a healthy diet, particularly in low-income countries. The situation is projected to worsen, with hunger potentially affecting 582 million people by 2030, primarily in Africa.

The 20th century, with an average air temperature increase of approximately 0.6°C, has been the warmest of the last millennium. According to predictions by M. Muluneh (2021), future temperature increases are likely to be even greater, with expected rises of 0.1 to 2°C per decade. Specifically, global warming has numerous adverse effects on agricultural crops, including sharp temperature fluctuations, disrupted rainfall patterns, and the occurrence of floods and droughts, which in turn lead to outbreaks of numerous pests and diseases. These factors ultimately have a negative impact on crop production, reducing both the quality and quantity of agricultural output. As a result of climate change and rapid population growth, global food demand is significantly increasing (Zavadska *et al.*, 2021; Munaweera *et al.,* 2022; Natalchuk & RudnykIvashchenko, 2024)

To address this challenge, various approaches are being employed, including plant breeding, genetic engineering, microbial production, innovations in cultivation technologies, and the preservation of plant biodiversity. S. Kalenska (2022) and R. Bepary *et al.* (2023) argue that studying underutilised crops from a food and nutritional security perspective is an economically efficient and reliable method. For example, A. Aboltins *et al.* (2024) emphasise that cultivating underutilised protein-rich legumes is one of several crucial solutions to overcome protein deficiency. One such crop is asparagus pea, which, according to M. Raai *et al.* (2020), exhibits high adaptability to adverse conditions and contains a significant amount of protein.

The consumption of asparagus pea is primarily observed in Southern African and South Asian countries, as well as India and Malaysia. All parts of the asparagus pea, depending on the species, are edible, including the pods (which are eaten raw or pickled, particularly in India), flowers (added to salads and used to enhance the colour of dishes), leaves (prepared and consumed like spinach), tubers (eaten raw or cooked, mainly in Ghana, Papua New Guinea, Burma, Thailand, and Indonesia), and seeds. H. Bassal *et al.* (2020) and A. Mahobia *et al.* (2024) describe various culinary uses of asparagus pea. Immature seeds are used to prepare soups, while mature seeds are eaten roasted or dried and ground into flour. Oil can also be extracted from the seeds and used in cooking, for example, in the preparation of fried dishes.

As noted by A. Bhadmus *et al.* (2023), due to significant variations in yield and other agromorphological characteristics among asparagus pea samples, there is limited information on its adaptability to diverse soil and climatic conditions. Simultaneously, K. Laosatit *et al.* (2022) emphasise the importance of studying the genetic diversity of existing varieties across different regions to ensure stable yields and enhance cultivation efficiency.

This research was driven by the desire to explore how the agronomic practice of altering sowing dates influences the adaptability of asparagus pea to the abiotic conditions of the Right-Bank Forest-Steppe region of Ukraine, and how this, in turn, is reflected in plant productivity.

MATERIALS AND METHODS

Field studies were conducted over three years (2014-2016) at the "Fruit and Vegetable Garden" educational laboratory of the National University of Life and Environmental Sciences of Ukraine (NULES of Ukraine) in the Kyiv Region. The soil used for the studies is classified as dark grey, medium podzolic, and light loamy.

The acidity level of this soil is near neutral (pH 6.1). The humus layer reaches a depth of 24 to 28 centimetres. However, the organic matter (humus) content in this layer is relatively low, ranging from 1.5 to 2.2%. Additionally, the soil is characterised by a medium content of nitrogen (26-38 mg/kg), phosphorus (43-61 mg/kg), and potassium (28-34 mg/kg).

The experiment was replicated three times. Asparagus pea seeds were sown at four different times: 24 April (third ten-day period of April – control), 8 May (first ten-day period of May), 23 May (third ten-day period of May), and 5 June (first ten-day period of June). Seeds were sown at a spacing of 45×15 cm and a depth of 2-3 cm. The method for assessing the general and specific adaptive capacity of samples is based on studying *n* samples in *m* environments (locations, years) and *c* replications (Tyshchenko *et al.*, 2023):

$$x_{ikr} = U + V_i + d_k + (Vd)_{ik} + e_{ikr}, \quad (1)$$

where x_{ikr} is the phenotypic value of trait *i* of the genotype when grown in environment *k* and replication *r*; *U* is the overall mean of the entire set of phenotypes; V_i is the effect of genotype *i*; d_k is the effect of environment *k*; $(Vd)_{ik}$ is the interaction effect of genotype *i* with environment *k*; e_{ikr} is the effect caused by random factors and associated with phenotype *ikr*.

Within this analysis, a series of constraints were imposed on the model elements:

$$\sum_i v_i = \sum_k d_k = \sum_k (vd)_{ik} = \sum_k (vd)_{ik} = \sum e_{ik} = 0. \quad (2)$$

Initially, dispersion factor analysis was employed to analyse the indicators of general adaptive capacity and sample stability.

The *F*-criterion was used to establish the significance of the influence of different samples, environments, and their interaction. In this case, the corresponding mean squares were compared with the mean square of random deviations *Me*:

For samples

$$F_{[n-1.nm(c-1)]} = \frac{M_n}{M_e}. \quad (3)$$

For environments

$$F_{[n-1.nm(c-1)]} = \frac{M_m}{M_e}. \quad (4)$$

For the interaction of samples and environments

$$F_{[n-1.nm(c-1)]} = \frac{M_{nm}}{M_e}. \quad (5)$$

When assessing the significance of individual differences, the standard error of the mean difference *Sd* was calculated:

For means

$$S_d = \sqrt{\frac{2Me}{c}}. \quad (6)$$

For samples

$$S_d = \sqrt{\frac{2Me}{mc}}. \quad (7)$$

For environments

$$S_d = \sqrt{\frac{2Me}{nc}}. \quad (8)$$

To compare individual means, samples, and environments, the least significant difference for the 5% significance level was found by multiplying the t_{05} criterion by the corresponding standard error of the mean difference *Sd*. The next stage of evaluation involved determining the general (GACi) and specific adaptive capacity (SACi) and stability of the samples. The effect of the general adaptive capacity of the sample GACi was *Vi*. In this case, the deviation from the sum *U*+*Vi* is the effect of the specific adaptive capacity of the variety in the *R* environment – SAC_{iR}. This effect includes a linear (effect of the *R* environment) and a non-linear part (effect of the interaction $(Vd)_{iR}$).

The specific adaptive capacity indicator was calculated using the following formula:

$$\sigma^2\ SAC_i = \frac{1}{m-1} * \sum_R (d_R + Vd_{iR})^2 - \frac{m-1}{m} * \sigma^2, \quad (9)$$

$$\sigma\ SAC_i = \sqrt{\sigma^2\ SAC_i}. \quad (10)$$

The relative stability index S_{gi} was used to compare the variability of different traits in the studied samples:

$$S_{gi} = \frac{\sigma_{SAC_i}}{U+GAC} * 100\ \%. \quad (11)$$

The regression coefficient b_i was determined using the formula:

$$b_i = \frac{\sum x_{iR} * d_R}{\sum_R d_R^2}. \quad (12)$$

The breeding value of the genotype (BVG_i) was used to select samples that combined productivity and stability:

$$BVG_i = U + GAC_i - p\sigma_{SAC_i}). \quad (13)$$

The calculation of the sum of effective air temperatures was carried out using the formula:

$$\sum t_{eff} = (t_{avg} - B) * n. \quad (14)$$

where Σt_{eff} is the sum of effective air temperatures over the period, °C; t_{avg} is the average air temperature for the period, °C; *B* is the value of the biological minimum, which in this analysis is taken to be 10°C; *n* is the number of days in this period.

The research results were processed using the *Statistica* 13.1 software (StatSoft, Inc., Tulsa, Oklahoma, USA). Tukey's test was also used to determine differences between sowing dates, with differences considered significant at $p < 0.05$ (accounting for the Bonferroni correction). To establish the direction and degree of correlation between the studied parameters, the correlation coefficient was calculated. The authors adhered to the standards of the Convention on Biological Diversity (1992) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1979).

RESULTS AND DISCUSSION

The yield of marketable pods of asparagus pea, when sown in the third ten-day period of April (control), the first ten-day period of May, and the first ten-day period of June, shows a non-normal distribution, although without any outliers. The mean, median, and mode are located at different points within the distribution (Fig. 1). The overall yield of marketable pods of asparagus pea when sown in the third ten-day period of May indicates a normal distribution, but with significant deviations: one case falls outside the lower line of the diagram. The mean, median, and mode of the overall yield are located almost at the same point, but do not quite, resemble a normal curve.

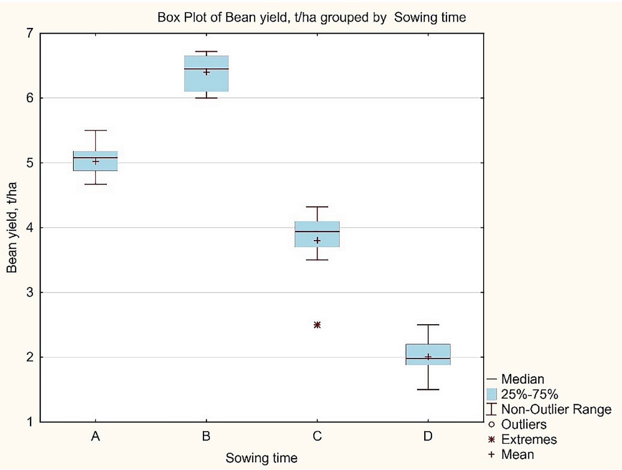

Figure 1*. Box plot illustrating the yield of marketable pods of asparagus pea*

Note: *the x-axis represents the sowing date: A) the third ten-day period of April (control); B) the first ten-day period of May; C) the third ten-day period of May; D) the first ten-day period of June (2014-2016)*

Source: *developed by the authors*

The average yield of pods of asparagus pea varied across different sowing dates, ranging from the lowest of 2.0 t/ha in the first ten-day period of June to the highest of 6.4 t/ha in the first ten-day period of May. The smallest amplitude of yield fluctuations over the years of research was observed in the first ten-day period of May (0.2 t/ha), followed by the third ten-day period of April (control) (0.3 t/ha), indicating their stable productivity across all studied years. In contrast, the largest amplitude of yield fluctuations was recorded in the third ten-day period of May (0.6 t/ha), followed by the first ten-day period of June (0.5 t/ha), indicating their variable yield and high sensitivity to changes in environmental conditions.

A strong positive linear correlation (r = 0.88) was found between the duration of the asparagus pea growing season and the yield of pods (Fig. 2). Based on the regression equations, it was established that an increase in the duration of the asparagus pea growing season by 5 days led to an increase in the yield of pods by 1.54 t/ha.

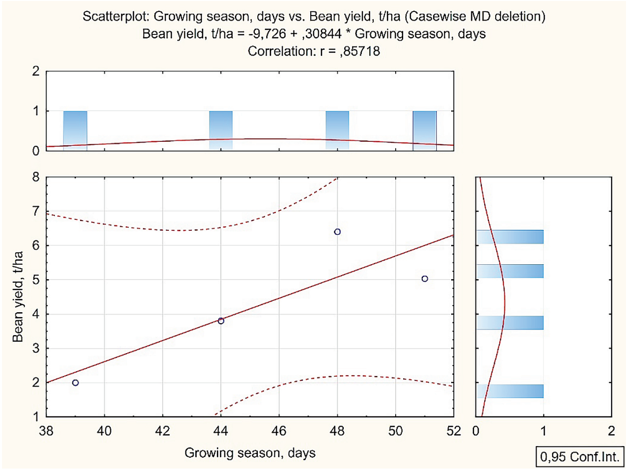

Figure 2*. Analysis of the relationship between the yield of marketable green pods of asparagus pea at different sowing dates and the duration of the growing season, mm (2014-2016)*

Source: *developed by the authors*

During the 2014-2016 asparagus pea growing seasons, the sum of effective air temperatures (>10°C) ranged from 450.3 to 500.8°C, and the total rainfall ranged from 49.6 to 78 mm. A direct moderate correlation exists between the yield of marketable pods and the sum of effective temperatures (r = 0.88) and the sum of rainfall (r = 0.66) (Fig. 3).

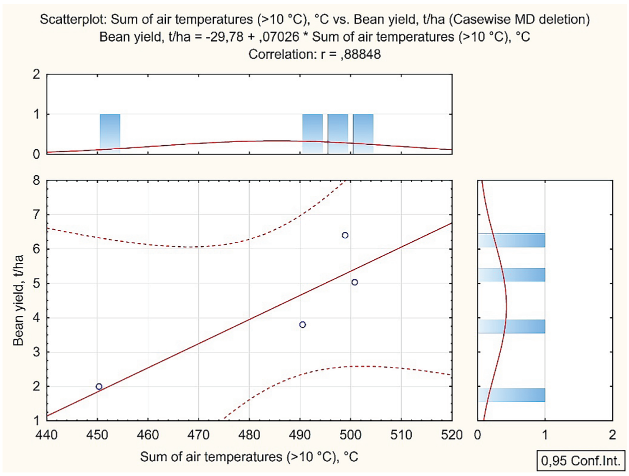

Figure 3*. Analysis of the relationship between the yield of marketable pods of asparagus pea at different sowing dates and the sum of temperatures above 10°C during the growing season, °C (2014-2016)*

Source: *developed by the authors*

By substituting the values into the regression equations presented, it is possible to predict the yield of asparagus pea (*Y*) based on data on the sum of effective air temperatures (>10°C) and rainfall (*X*) during the growing season. An increase in the average sum of effective air temperatures during the growing season by every 10°C led to an increase in the yield of pods of asparagus pea by 0.703 t/ha. Simultaneously, every additional 10 mm of rainfall contributed to an increase in the yield of this crop by 0.877 t/ha (Fig. 4).

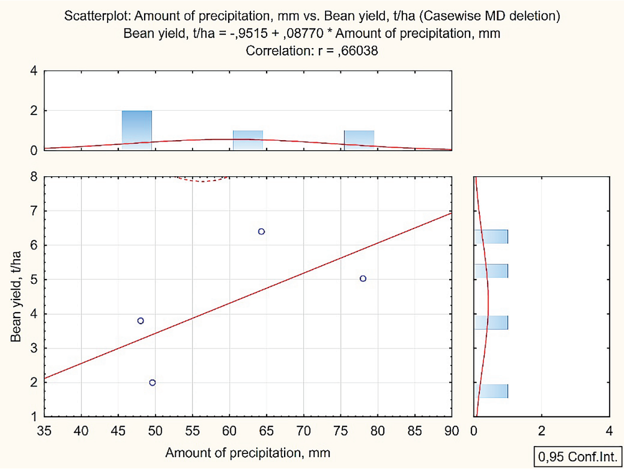

Figure 4*. Analysis of the relationship between the yield of marketable green pods of asparagus pea at different sowing dates and the sum of rainfall during the growing season, mm (2014-2016)*
Source: *developed by the authors*

According to the coefficient of variation in a pod of asparagus pea yield, it was established that the variation for sowing in the third ten-day period of April (control) (*V* = 3.03%) and the first ten-day period of May (*V* = 2.34%) is not significant, as the coefficient of variation is less than 10%. However, for sowing in the third ten-day period of May (*V* = 7.89%) and the first ten-day period of June (*V* = 13.23%), moderate variability was recorded, meaning the coefficient of variation is higher than 10% but less than 20% (Table 1). The term "adaptive capacity" is used to describe the ability of a genotype to maintain the phenotypic expression of a given trait in the presence of certain environmental conditions. The concept of general adaptive capacity is used to characterise the average value of a trait under different environmental conditions. Conversely, specific adaptive capacity represents a deviation from the general adaptive capacity in a specific environment.

The highest general adaptive capacity for asparagus pea productivity was observed when sown in the first ten-day period of May (GAC = 2.09), and the lowest in the first ten-day period of June (GAC = -2.31). However, in terms of specific adaptive capacity, the third ten-day period of May stood out (SAC = 0.079). All studied sowing dates of asparagus pea were characterised by variability in the stability of the studied trait (S_{gi} from 0.18 to 2.96) depending on growing conditions. However, overall, they exhibited high stability (S_{gi} < 25%) in pod yield.

Table 1*. Parameters of adaptive capacity and stability of asparagus pea at different sowing dates (2014-2016)*

Indicator		Sowing dates			
		Third ten-day period of April (control)	**First ten-day period of May**	**Third ten-day period of May**	**First ten-day period of June**
Yield of pods, t/ha	Min	4.9	6.3	3.5	1.8
	Max	5.2	6.5	4.1	2.3
	Range of variation	0.3	0.2	0.6	0.5
	Average	5.0 ± 0.088 [a]	6.4 ± 0.093 [d]	3.8 ± 0.185 [ac]	2.0 ± 0.111 [b]
Coefficient of variation (V), %		3.03	3.03	2.34	7.89
General adaptive capacity (GAC)		0.73	0.73	2.09	-0.51
Specific adaptive capacity (SAC)		0.013	0.013	0.012	0.079
Relative stability (S_{gi}), %		0.25	0.25	0.18	2.09
Plasticity (b_i), %		0.77	0.77	0.40	1.55
Homeostasis (*Hom*)		1.66	1.66	2.73	0.48
Selection value of genotype (SVG_i)		4.57	4.57	5.97	0.91

Note: *different letters (a, b, c, d) indicate values that were significantly different from each other within the same row of the table, according to comparisons using Tukey's test with Bonferroni correction*
Source: *developed by the authors*

The plasticity parameters (regression coefficient b_i) allow for predicting the behaviour of a variety under production conditions. In the asparagus pea cultivation variant sown in the third tenday period of April (control) and the first ten-day period of May, the regression coefficient for green pod yield was found to be less than one, 0.77 and 0.40, respectively. Cultivating the crop at these sowing dates results in a weak response to changes in environmental factors. While this approach may not achieve high yields under intensive farming, it leads to a smaller reduction in productivity under unfavourable conditions compared to sowing dates with a regression coefficient greater than one. Thus, for each 1 t/ha increase in the average yield of asparagus pea, there is only a 0.77 t/ha increase when sown in the third ten-day period of April (control) and a 0.40 t/ha increase when sown in the first ten-day period of May. Among the studied sowing dates, the third ten-day period of May and the first ten-day period of June showed the greatest sensitivity to changes in asparagus pea yield under experimental conditions. With an increase in the average yield of 1 t/ha, the yield when sown in the third ten-day period of May increased by 1.55 t/ha, and in the first tenday period of June, it increased by 1.28 t/ha.

It is known that one of the key indicators of adaptability is the homeostasis (*Hom*) of a genotype, which characterises the ability of an organism to exhibit minimal phenotypic variability when growing conditions change. This implies the ability to mitigate the effects of adverse environmental factors at various stages of plant growth and development. Accordingly, based on this indicator, two sowing dates stand out among the studied ones: the first ten-day period of May (*Hom* = 2.73) and the third ten-day period of April (control) (*Hom* = 1.66). The breeding value of the genotypes was determined to simultaneously select for general adaptive capacity and stability. The variants sown in the first ten-day period of May ($BVG_i = 5.9$) and the third ten-day period of April (control) ($BVG_i = 4.57$) demonstrated an optimal combination of high productivity and stable yield. The highest content of dry matter (25.4%) and total sugars (6.8%) in fresh asparagus pea beans was observed when sown in the first ten-day period of May, which is 5.1% and 1.3% higher than the control, respectively (Table 2). When sown in the third ten-day period of May, the dry matter content (20.1%) and total sugars (5.4%) were at the control level. The lowest dry matter content (18.5%) and total sugars (4.7%) were observed in asparagus pea beans when sown in the first ten-day period of June, which is 1.8% and 0.8% lower than the control, respectively. Regarding vitamin C content, a decrease was observed with later sowing dates and the lowest value of 30.3 mg/100g was obtained when sown in the first ten-day period of June, which is 21.5 mg/100 g less than the control. Additionally, the variants sown in the third ten-day period of April (control) and the first ten-day period of May, which accumulated a high vitamin C content (49.551.8 mg/100 g), can be highlighted. At the same time, the total nitrogen content also had the highest value of 3.7% when sown in the third ten-day period of April (control), gradually decreasing to 2.7% when sown in the first ten-day period of June.

***Table 2**. Qualitative assessment of fresh asparagus pea beans at different sowing dates (2014-2016)*

Experimental variant	Dry matter, %	Total sugars, %	Vitamin C, mg/100 g	Total nitrogen, % on air-dried matter
Third ten-day period of April – control	20.3 ± 0.199 [a]	5.5 ± 0.053 [a]	51.8 ± 0.507 [d]	3.7 ± 0.036 [d]
First ten-day period of May	25.4 ± 0.248 [c]	6.8 ± 0.066 [c]	49.5 ± 0.483 [c]	3.5 ± 0.034 [c]
Third ten-day period of May	20.1 ± 0.206 [a]	5.4 ± 0.055 [a]	35.7 ± 0.366 [b]	3.2 ± 0.032 [b]
First ten-day period of June	18.5 ± 0.528 [b]	4.7 ± 0.134 [b]	30.3 ± 0.866 [a]	2.7 ± 0.077 [a]

***Note:** different letters (a, b, c, d) indicate values that were significantly different from each other within the same row of the table, according to comparisons using Tukey's test with Bonferroni correction*
***Source:** developed by the authors*

Additionally, plants sown in summer were more severely affected by Fusarium wilt. Their growth and development were slower, and their fruits were smaller and of poorer quality. A direct correlation was established between the duration of the growing season and the biochemical indicators of fresh asparagus pea beans. The strength of the correlations was as follows: a strong correlation between the duration of the growing season and total sugars ($r = 0.96$), vitamin C ($r = 0.99$); a moderate correlation with total nitrogen ($r = 0.63$); and a weak correlation with dry matter ($r = 0.53$) (Fig. 5).

Based on the regression equations, it was established that an increase in the duration of the asparagus pea growing season by 5 days led to an increase in the dry matter by 1.53%, total sugars by 0.53%, vitamin C by 9.76 mg/100 g and total nitrogen by 0.42%. The best quality was demonstrated by asparagus pea beans sown in the third ten-day period of April and the first ten-day period of May. They contained high levels of dry matter (20.3-25.4%), sugars (5.5-6.8%), vitamin C (49.5-51.8 mg/100 g), and crude protein (3.5-3.7%). The results obtained indicate that the influence of year and genotype was significant for the yield of green beans, and that a better genotype and optimal environmental conditions are key elements in the successful production of asparagus pea. The presented experimental data are consistent with the results of S. Sriwichai *et al.* (2021), in which the genotype-environment interaction had an impact on the yield of *Psophocarpus tetragonolobus* (L.) DC., while samples *W*099 and *W*018 showed the most stable high bean yield, confirming their adaptability to various environmental conditions.

Plant architecture, as noted by X. Zhang *et al.* (2021), is an important factor for optimising crop management and achieving maximum bean yield. V. Kumar & R. Rajalekshmi (2021) emphasise that the hardness of asparagus pea seeds significantly limits their development, affecting germination rates. This is because the longer the seed storage period in cold, dry conditions, necessary for ensuring long-term seed viability during storage, the less its ability to absorb water when sown under optimal germination conditions. According to I. Fedosiy *et al.* (2022) and O. Litvinova *et al.* (2022), a sufficient level of soil moisture is a prerequisite for achieving high field seed germination.

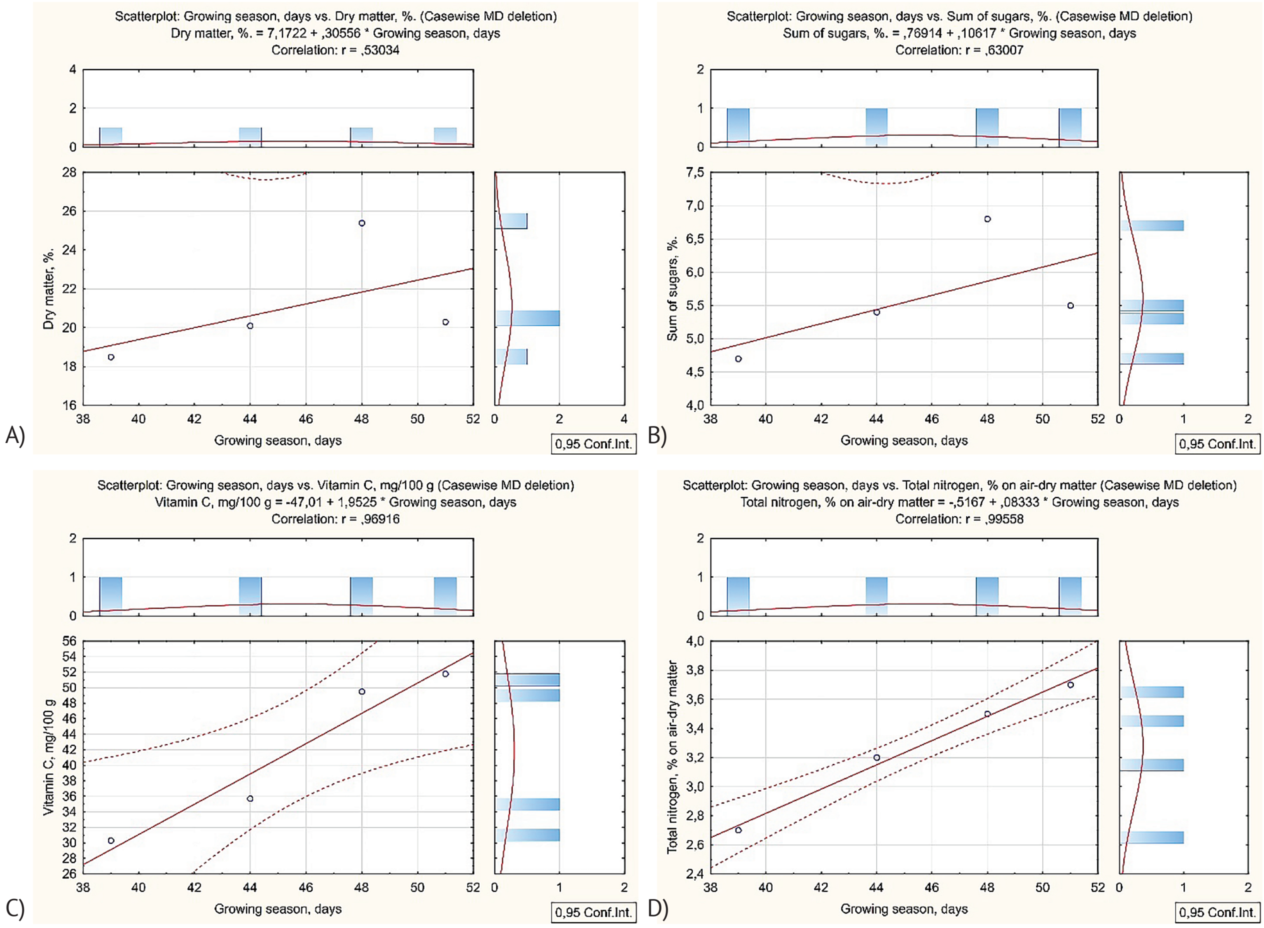

Figure 5*. Analysis of the relationship between the qualitative assessment of fresh asparagus pea beans and sowing dates*

Note: *A) Dry matter, %; B) Total sugars, %; C) Vitamin C, mg/100 g; D) Total nitrogen, % on airdry matter; (average for 2014-2016)*

Source: *developed by the authors*

Research I. Yulianah *et al.* (2020) indicates that in Indonesia, *Psophocarpus tetragonolobus* can be planted during both the rainy and dry seasons, producing beans in small to moderate quantities over several seasons. When *Psophocarpus tetragonolobus* is planted in the rainy season, it tends to produce more leaves rather than flowers and pods. In contrast, in Ukraine, where the climate is more continental, the optimal sowing times are the third ten-day period of April and the first ten-day period of May, when the soil is sufficiently warm. Subsequent sowing in the summer months can be problematic for plants due to pest damage, disease susceptibility, and moisture deficiency. P. Moorthy *et al.* (2022) report that a wide range of lepidopteran insects cause significant damage to flowers, leading to their premature drying and shedding without pod formation.

P. Singh *et al.* (2022) note that the asparagus pea is a short-day plant, with its flowering dependent on the length of daylight or photoperiod. This limits its year-round production, resulting in fluctuations in bean production volumes and prices. To ensure year-round production, as recommended by S. Sriwichai *et al.* (2022), it is advisable to use asparagus pea varieties with insensitive photoperiods. Thus, the significant genetic diversity of asparagus pea allows for the cultivation of plants in various geographical regions.

According to data from I. Bobos *et al.* (2022) and H. Slobodianyk *et al.* (2024), untimely harvesting can lead to a deterioration in crop quality due to adverse environmental conditions, including high temperature, high humidity, rainfall, drought, as well as damage from birds and animals, and infection by diseases and pests. Therefore, it is important to assess pod development and ripening by monitoring physical and physiological indicators. In a study by S. Sakthivel *et al.* (2020), three main stages of pod development were observed: rapid growth (5-30 days after the onset of pod formation, 57.9% moisture), slowed growth (30-50 days, 28.9% moisture), and ripening (50-60 days, 18.7% moisture). The fresh weight of the pods reached its maximum (27.84 g/pod) on the 30th day, and a positive correlation with pod size was also noted. The timing of asparagus pea pod harvesting varies significantly: in Myanmar, it takes place in December-January (Maw *et al.,* 2023), and Italy, in June (Vargiu, 2021), whereas in Ukraine, it occurs in June-July.

Results published by G. Eagleton (2022) demonstrate that under Australian conditions, the *MYO*-01 variety produced an average of 93 mature pods per plant when sown on 5 October, 68 pods when sown on 3 November, and 44 pods when sown on 24 November. At the same time, the *CHIMBU* and *MYAN*-05 varieties had a significant number of full-sized green pods, but a negligible number of mature seed beans. Similarly, the *WAM*-07 variety had almost no mature beans or full-sized green pods by the end of the study on 30 June. The results of current research also revealed a significant difference between the influence of sowing dates and the number of pods per plant, which directly affected the overall yield. Climate change, accompanied by rising temperatures and droughts, requires new approaches from agriculture. The study of asparagus pea has shown that sowing dates significantly affect plant yield and adaptability. These data provide a basis for developing cultivation recommendations that take into account the characteristics of different varieties and the climatic conditions of the region.

CONCLUSIONS

The global food crisis, exacerbated by climate change, necessitates the search for sustainable solutions. Scientific research has confirmed that asparagus pea, due to its ability to adapt to changing conditions and its high nutritional value, can become an important component in ensuring food security. The yield of asparagus pea at different sowing dates significantly depended on climatic conditions ($r = 0.88$ with the sum of effective temperatures; $r = 0.66$ with the sum of rainfall). Sowing asparagus pea from the third ten-day period of April to the first ten-day period of May ensures an optimal combination of high homeostasis (*Hom* = 1.66-2.73) and breeding value of the genotype (BVG_i = 4.57-5.9) and productivity (5.0-6.4 t/ha). Late sowing dates, especially under conditions of insufficient moisture and high temperatures, led to a decrease in yield.

Sowing in the first ten-day period of May provided the highest content of dry matter (25.4%) and sugars (6.8%), while the lowest indicators were recorded when sowing in the first tenday period of June (18.5% and 4.7%, respectively). Vitamin C content ranged from 30.3 to 51.8 mg/100 g, decreasing with later sowing dates. Similar to other biochemical indicators, the highest amount of nitrogen was observed in pods sown in the third ten-day period of April (3.7%), and the lowest in the first ten-day period of June (2.7%). A strong positive correlation was found between the duration of the growing season and the content of vitamin C ($r = 0.99$), sugars ($r = 0.96$), dry matter ($r = 0.63$), and total nitrogen ($r = 0.55$) in asparagus pea beans. The regression analysis model made it possible to quantify the influence of the growing season duration on the biochemical composition of the crop's beans. Thus, every additional five days of vegetation increases the nitrogen content by 1.53%, dry matter by 0.53%, sugars by 9.76%, and vitamin C by 0.42 mg/100 g in asparagus pea beans. The combination of breeding, genetic engineering, and agricultural technologies, while increasing the added value of production, creates significant challenges and opportunities for intensifying the cultivation of asparagus pea in different ecological conditions, which requires further scientific research.

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CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

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Екологічна стабільність, пластичність та адаптивність тетрагонолобуса (*Tetragonolobus purpureus* Moench) за різних термінів сівби

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Анотація. Метою даного дослідження було вивчення реакції рослин тетрагонолобуса, вирощених за різних строків сівби, на абіотичні фактори, характерні для Правобережного Лісостепу України, з урахуванням їхнього впливу на врожайність товарних бобів. Дослідження проводилося за допомогою комплексного підходу, який включає польові експерименти та статистичний аналіз отриманих даних. Врожайність тетрагонолобуса значною мірою залежить від термінів сівби та погодних умов. Середня врожайність бобів-лопаток змінювалася від 2,0 до 6,4 т/га залежно від терміну сівби. Найменшу амплітуду коливань врожайності (0,2-0,3 т/га) показала сівба в III декаді квітня та І декаді травня, тоді як для інших строків цей показник був значно вищим (до 0,5-0,6 т/га). Встановлено, що врожайність позитивно корелює з температурою ($r = 0{,}88$) та кількістю опадів ($r = 0{,}66$). Збільшення цих кліматичних факторів на 10 одиниць сприяло зростанню врожайності на 0,703-0,877 т/га. Рослини, висіяні в III декаді квітня та І декаді травня, мали найнижчий коефіцієнт регресії bi (0,77 та 0,40 відповідно), що свідчить про їхню меншу чутливість до змін умов вирощування. Натомість, сівба в III декаді травня та І декаді червня виявилася чутливішою ($b_i = 1{,}55$ та 1,28 відповідно). Оптимальними строками сівби є І декада травня та III декада квітня, адже вони забезпечили найвищу продуктивність і стабільність, а також високий вміст сухої речовини (20,3-25,4 %), цукрів (5,5-6,8 %), вітаміну С (49,5-51,8 мг/100 г) та загального азоту (3,5-3,7 %). Найгірші показники зафіксовано при пізніших строках сівби

Ключові слова: бобові; продуктивність; параметри адаптивних ознак; обмежуючі фактори; кореляція