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BIOLOGICAL CHARACTERISTICS AND ECONOMIC PRODUCTIVE POTENTIAL OF FORAGE PEA GENOTYPES

SUMMARY

The biological characteristics and productive potential of forage pea genotypes were evaluated under field conditions. Seven genotypes were tested, including five hybrid lines (№115, №29, №9A, №8, and №11) and two control varieties, Kristal and Kerpo. Biometric analyses were performed on the main quantitative traits and phenological stages. Through multiple individual selection within a hybrid population obtained from the cross between Harkovskii Etalon and Harkovskii 376 (LN29), the new spring forage pea variety Ivkos was developed. The vegetation period ranged from 78 to 90 days, similar to that of the control variety Kerpo. The plants were medium tall (average height 74 cm), well-leafy, and resistant to lodging, with 6–8 pods and about 21 seeds per plant. The 1000-seed weight averaged 209.9 g. The variety demonstrated very good drought tolerance, stable yields, and a high productive potential. In competitive variety trials at the Institute of Forage Crops, Pleven, Ivkos (№29) produced 338 kg/ha grain, 20% higher than Kerpo. In 2022, by decision of the Expert Commission at the Executive Agency for Variety Testing, Field Inspection and Seed Control, Bulgaria (appointed by Order RD-10-1/14.01.2022) and Order RD-12-1 of the

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Minister of Agriculture of the Republic of Bulgaria (dated 02.03.2022), Ivkos was officially recognized as a new and original variety.

Keywords: pea, variety and line, yield, genotype $\times$ environment interaction, economic productivity

INTRODUCTION

In many countries worldwide, peas occupy a significant share of the total area sown with leguminous crops. They are cultivated both for the food industry and for animal husbandry purposes (Zotikov *et al.* 2014. Field peas have exceptional forage value and can be grown for grain, hay, and green forage. Established pea cultivars can be successfully grown on poor and sandy soils, have a wide geographic distribution, and are adaptable to cooler northern climates (Kosolapov *et al.* 2009; Chekmarov, 2014).

The cultivation of legumes is essential to the implementation of more environmentally friendly farming methods (Clark and Lenaghan, 2020). A major global legume crop, peas (*Pisum sativum* L.) are vital for bioenergy, animal feed, and human consumption. The pea is a diploid ($2n=14$) legume crop that is self-pollinating and a member of the Leguminosae (Fabaceae) family. *Pisum sativum* that is high in micronutrients, fibre, protein, and bioactive substances that can improve human health. Because of these characteristics, legume products are a strong candidate for biofortification. With 12.4 million tonnes of dry peas and 20.5 million tonnes of green peas produced in 2021, peas are presently the third most important pulse crop produced worldwide, behind common beans and chickpeas (FAO, 2025). The production of peas is seriously threatened by drought, which has gotten worse due to global warming. Therefore, in order to guarantee global food security and the sustainable development of agriculture, there are pressing needs and a lot of interest in finding or creating drought-tolerant pea variety using biotechnological methods.

In light of climate change, drought is becoming more common and is thought to be a significant crop productivity limitation. Water scarcity can diminish water use efficiency, disrupt plant water interactions, and hinder growth. In reducing pea yield because of drought, the intensity and duration of stress are critical. By using techniques like breeding, screening, and marker-assisted selection, pea drought tolerance can be controlled. Because their cultivation significantly affects soil microbial diversity, soil water protection, and soil organic matter enrichment, peas are a crucial rotation crop (Knight, 2012; Liu *et al.*, 2017). Due to peas' capacity, less fertilizer is needed during production, which lowers cultivation costs.

Boosting the production of legumes like peas also contributes to the reduction of poverty. Pea root nodules can fix atmospheric nitrogen (N₂) by forming a symbiotic relationship with soil bacteria (*Rhizobium leguminosarum*). Sustainable agriculture greatly benefits from symbiotic nitrogen fixation (SNF), which lowers the need for fertilizers and enhances soil quality (Knight, 2012). Up to 15–25 kg of shoot nitrogen for every tonne of aboveground biomass is the ideal nitrogen fixation rate for legume crops. Therefore, it is possible to lower these emissions as well as the nitrate and ammonium levels in agricultural soils by utilising pulses like peas, either in rotation or as intercrops (Peoples *et al.*, 2019).

Varieties intended for green mass production are usually characterized by longer stems, late maturity, a higher tendency to lodge, and lower seed yield. In most grain-type varieties, these limitations have been largely overcome (Kondykov *et al.* 2010; Bagheri *et al.*, 2023).

The development of new pea varieties that meet the modern requirements of agricultural production is impossible without the extensive use of the plant's genetic resources. A key factor in breeding such varieties is the choice of initial material, the main source of which is plant genetic collections. The use of a broader gene pool significantly increases the efficiency of breeding programs (Vishniakova 2017; Ashiev *et al.* 2018).

Finding advantageous alleles in the primary gene pool of crops and introducing them to elite cultivars is the major goal of plant breeding science. When these alleles are not found in the primary gene pool, they are moved to the secondary gene pool. A limited genetic base of cultivated pea germplasm results from the majority of pea breeding programs using a small number of genotypes as parents with strong relatedness. Per Castañeda-Alvarez *et al.* (2016), Rubiales *et al.* (2011), and Smýkal *et al.* (2012), pea germplasm collections, including wild relatives, might enhance the peas' larger genetic foundation to improve biotic and abiotic stress resistance and boost grain yield and quality.

According to Naim-Feil *et al.* (2017), certain characteristics of wild pea cousins, such as waxy leaves (in *P. sativum*) and root system architecture (RSA) and rhizome associations (in *P. fulvum*), show promising potentials to withstand drought stress. This wild material still exists in a variety of forms (Smýkal, *et al.*, 2011; Lakić *et al.*, 2019a; 2019b;) that may be helpful in upcoming breeding initiatives (Rakašćan *et al.*, 2021; Milunović *et al.*, 2022; Ljubičić *et al.*, 2023; Popović *et al.*, 2024). Agricultural research has advanced to a new level thanks to biotechnology and engineering advancements, thus creating "smart" goods is now feasible. The technology known as next-generation sequencing (NGS), as an a sophisticated and economical molecular instrument that has

transformed agriculture breeding initiatives, allowing us to understand the characteristics of intricate characteristics including yield-related features and drought tolerance (Singh *et al.*, 2020).

The strategic crossing of complimentary genotypes is encouraged by the high diversity of important features found in both domesticated and wild peas. In order to improve drought adaptation and yield improvements in other pea crops, this diversity is a crucial source of desired alleles in the agronomic, physiological, and biochemical parameters (Rispail *et al.*, 2023; Smýkal *et al.*, 2018; Yang *et al.*, 2022).

Improving resistance to biotic and abiotic stress, as well as increasing grain yield and seed nutritional profile, are the most important goals for pea breeding (Tayeh *et al.*, 2015). The reservoir of resistance to pests and diseases, drought adaptability, and other agronomic, physiological, and biochemical desired traits required by pea breeders may be expanded through interspecific crosses between *P. sativum* and wild pea species (Smýkal *et al.*, 2018; Rubiales *et al.*, 2021). Numerous physiological and biochemical alterations are part of plants' drought adaptation methods, and these mechanisms also involve a large number of genes linked to stress. While many plant species experience most changes, some have unique responses to dryness. As a result, it is difficult to comprehend how various plants react to drought (Carvalho *et al.*, 2019). It is well known that the broader the genetic base of the breeding material, the greater its adaptive potential. Productivity breeding remains one of the most complex areas of genetic crop improvement since this multi-component trait is largely influenced by prevailing environmental conditions (Sobolev and Shtetinina 2008).

By deducing the phenotypic variation as the sum of interactions influencing performances in the tested genotypes (G) across the various environments (E), plant breeders meticulously assess their material in several places and over several seasons. The assessment of G, E, and G×E interactions (also known as GEI) guarantees reliable suggestions for appropriate varieties that can withstand the strain brought on by changing circumstances. The identification of GEI variables aids geneticists in their breeding operations by directing selection toward cultivars that are niche-specific or suitable for a variety of conditions (Egea-Gilabert *et al.*, 2021).

The aim of this study was to evaluate spring forage pea lines in order to develop new varieties with enhanced grain productivity potential.

MATERIAL AND METHODS

The field trial was conducted during the period 2016–2018 at the experimental field of the Institute of Forage Crops, Pleven, Bulgaria. Seeds of individual spring pea samples were sown at a spacing of 0.20 m between rows and 0.05 m within the row, in three replications, with a plot size of 10 m². Sowing was carried out at the optimal time according to the crop's cultivation technology.

Five spring forage pea lines (№115, №29, №9A, №8, and №11) were evaluated, and the varieties Kristal and Kerpo were used as controls. The following traits were recorded at the stage of technical maturity: plant height (cm), height of the first pod (cm), number of pods per plant, number of seeds per plant, number of seeds per pod, seed weight per plant (g), and 1000-seed weight (g).

Phenological observations included the beginning of flowering (days), full flowering (days), and duration of the growing season (days). Biometric measurements were taken from 10 plants per sample.

The data were processed using a two-factor analysis of variance (ANOVA) for each trait to determine the effects of genotype and environment. The degree of earliness was determined according to Kuzmova (2002). The date of beginning of flowering was used as the criterion for earliness, and the coefficient of earliness served as a quantitative measure. According to this coefficient, ultra-early varieties have values between 1.00 and 1.17; early varieties 1.17–1.33; medium-early 1.34–1.66; and late varieties > 1.66. The coefficient of variation (CV, %) was calculated following the formula of Dimova and Marinkov (1999).

All experimental data were statistically processed using the software GENES 2009.7.0 for Windows XP (Cruz, 2009) and STATGRAPHICS Plus for Windows, Version 2.1.

RESULTS AND DISCUSSION

Agrometeorological characteristic

Agrometeorological conditions during the study period are presented in Figures 1-3. Precipitation in the late autumn and winter months plays a key role in realizing the biological potential of spring pea varieties and lines.

The average amount of precipitation showed a pronounced maximum in May 2017 (155.9 mm) and June 2018 (155.2 mm), and a minimum in July (7.8 mm) and December (14.4 mm) of 2016, as well as in April (19.6 mm) and September (15.4 mm) of 2018. In 2016, the lowest average monthly air temperatures were recorded in December (−0.5 °C) and January (8.7 °C), while the highest was in July (24.6 °C), Figure 1. The combination of high average daily temperatures and low rainfall during the active vegetation period negatively affected plant growth and development. During 2017, average daily temperatures in April, May, and June ranged from 12.2 °C to 23 °C, Figure 2. The lowest average monthly air temperatures occurred in January (−4.4 °C) and December (1.1 °C), and the highest again in July (23 °C). The climatic conditions during the 2016–2017 growing seasons were favorable for the growth and development of spring pea genotypes, supporting normal overwintering and the realization of productive potential. In the third year (2018), plant development began under favorable temperature and moisture conditions, Figure 3. October 2017 was characterized by high precipitation (108.9 mm) and relatively high temperatures. In February and March, precipitation exceeded the norm, while April and May were extremely dry.

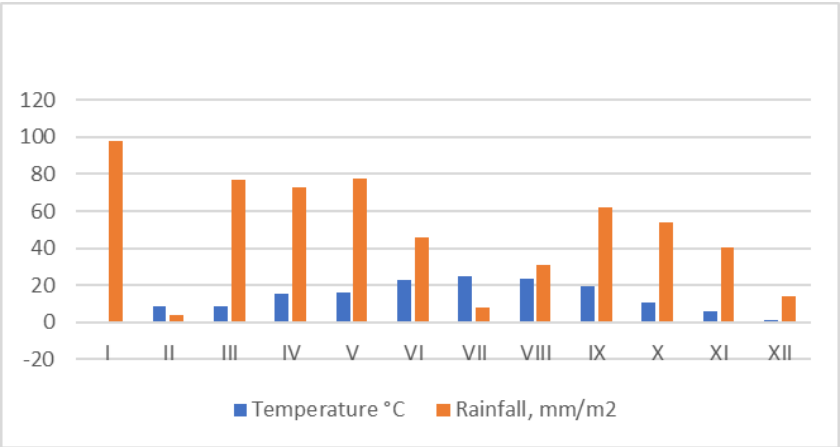


Figure 1. Agrometeorological conditions for 2016

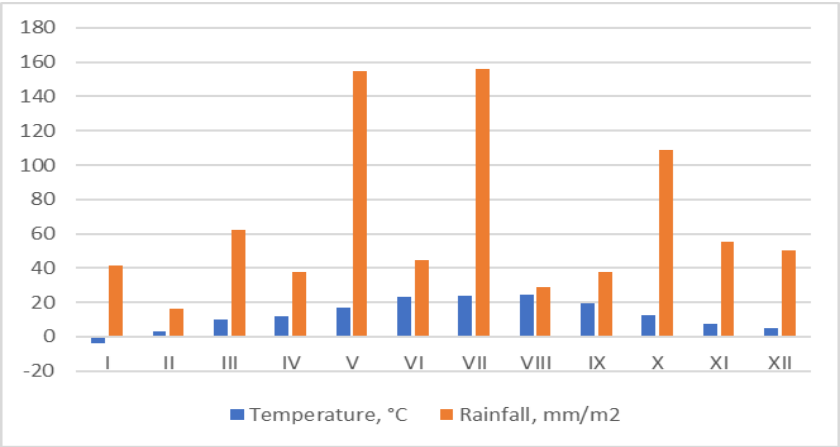


Figure 2. Agrometeorological conditions for 2017

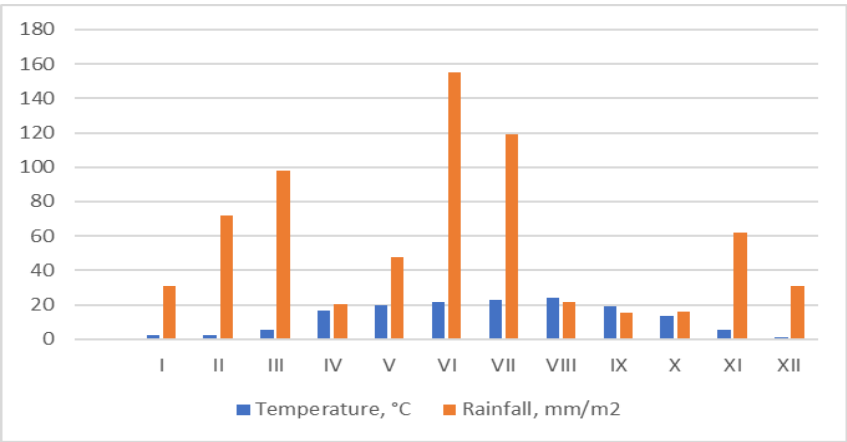


Figure 3. Agrometeorological conditions for 2018

Insufficient moisture and high temperature sums during these months negatively affected seed germination and crop establishment. In May, high temperatures combined with low and unevenly distributed rainfall (20.2–47.7 mm). The abundant rains at the end of the growing season (June–July) did not significantly affect productivity or yield structure.

Some differences were observed among the spring pea lines and varieties regarding flowering rate, growth, and time to technical maturity. The earliest flowering was recorded for the varieties Kristal, Kerpo, and line №29 (12–28 May) (Table 1).

Table 1. Phenological development of the studied spring pea samples (2016–2018)

Phenological stages	Year	Sowing date	Beginning of flowering	Technical maturity	Vegetation period (days)
Kerpo	2016	31.3.2016	25.5.2016	24.6.2016	90
	2017	06.3.2017	12.5.2017	23.6.2017	81
	2018	05.4.2018	28.5.2018	22.6.2018	78
Kristal	2016	31.3.2016	25.5.2016	24.6.2016	90
	2017	06.3.2017	12.5.2017	23.6.2017	81
	2018	05.4.2018	28.5.2018	22.6.2018	78
№115	2016	31.3.2016	31.5.2016	30.6.2016	96
	2017	06.3.2017	23.5.2017	30.6.2017	96
	2018	05.4.2018	06.6.2018	29.6.2018	85
№29	2016	31.3.2016	25.5.2016	24.6.2016	90
	2017	06.3.2017	12.5.2017	23.6.2017	81
	2018	05.4.2018	28.5.2018	22.6.2018	78
№9A	2016	31.3.2016	30.5.2016	27.6.2016	93
	2017	06.3.2017	22.5.2017	30.6.2017	91
	2018	05.4.2018	05.6.2018	28.6.2018	84
№8	2016	31.3.2016	30.5.2016	29.6.2016	95
	2017	06.3.2017	22.5.2017	29.6.2017	91
	2018	05.4.2018	05.6.2018	29.6.2018	85
№11	2016	31.3.2016	30.5.2016	29.6.2016	95
	2017	06.3.2017	22.5.2017	29.6.2017	91
	2018	05.4.2018	05.6.2018	29.6.2018	85

Lines №115 and №9A began flowering 10–12 days later, while lines №8 and №11 were the latest.

Early-flowering varieties and lines (Kristal, Kerpo, and №29) reached technical maturity within 78–90 days, while the remaining lines matured 7–8 days later. Lines №11, №8, and №115 had the longest growing periods (85–96 days), associated with slower growth and development.

In some years, an extension of the growing season was observed, likely due to prolonged rainfall in the second half of plant development. Based on climatic conditions and genetic predisposition, the spring pea genotypes were classified by earliness as follows: Kerpo, Kristal, and №29 – ultra-early ($K=1.00$); №9A, №8, and №11 – late ($K=1.83$ – 1.91); №115 – the latest ($K=2.00$).

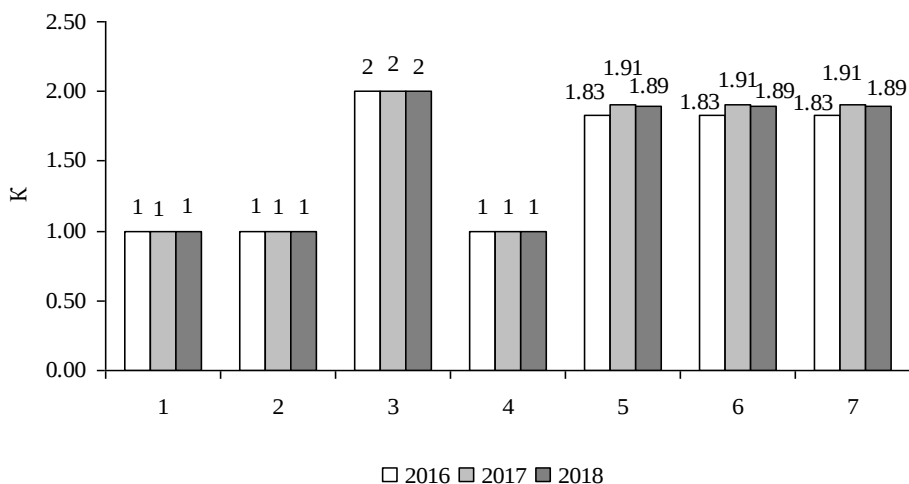


Figure 4. Coefficient of earliness (K) of forage pea varieties and lines (1-Kerpo; 2- Kristal; 3-№115; 4- №29; 5-№9A; 6-№8; 7- №11)

Significant differences were observed among genotypes for most quantitative traits (Table 2; Figure 4). Plant height, an important structural and agronomic characteristic, varied considerably. Stem height largely determines lodging resistance and suitability for mechanized harvesting. The average plant height was 48 cm for Kristal and 51 cm for Kerpo.

Considering the climatic conditions, Kerpo showed greater responsiveness to improved growing conditions, followed by line №115 (62 cm). Lines №11 and №8 formed the tallest plants (91–101 cm), while №9A and №29 were intermediate (71–74 cm).

Similar trends were found for the height of the first pod. Kristal set the lowest first pods (32 cm), followed by Kerpo (39 cm), №115 (43 cm), №9A (48 cm), №29 (56 cm), and the tallest lines №8 and №11 (≈ 61 cm).

The study of the main productivity components, viz. number of pods per plant, number of seeds per pod, and 1000-seed weight is essential for identifying

high-performing genotypes. Lines №11 and №8 produced the highest number of pods (8 per plant), followed by Kristal (7). Lines №29 and №9A formed six pods per plant, while Kerpo produced the fewest (5).

Table 2. Morphological characteristics of the studied spring pea samples (2016-2018)

Variety (line)	Plant height, cm	Height on first pod, cm	No pods per plant	No seeds per plant	No seeds per pod	Seed weight per plant, g	1000 seeds weight, g
Kerpo	51ab	39ab	5a	17ab	3a	3.37c	196.28cd
Kristal	48a	32a	7ab	20abc	3a	4.47d	206.33d
№115	62abc	43ab	5a	16a	3a	3.15bc	162.00bc
№29	74cd	56bc	6ab	21abc	3a	4.88d	209.88d
№9A	71bcd	48cd	6ab	24abc	4b	2.14a	105.02a
№8	91de	61d	8b	26bc	3a	2.45ab	129.33ab
№11	101e	61d	8b	28c	3a	1.93a	120.05a

a, b, c, d, e – statistically significant differences at $P=0.05$

Regarding seed number per plant, the genotypes with fewer pods compensated through more seeds per pod. Line №11 produced the highest seed number (28), followed by №8 (26) and №9A (24). Kristal and №29 had 20–21 seeds per plant, while №115 and Kerpo had 16–17.

All genotypes produced approximately three seeds per pod on average, except №9A (4 seeds per pod).

Seed weight per plant - trait closely correlated with grain yield was highest in Kristal (11.0 g) and №29 (10.9 g), followed by №8 (7.0 g) and №11 (7.4 g), with №9A showing the lowest (6.6 g).

The 1000-seed weight was highest for №29 (260 g) and Kristal (252 g), classifying them as large-seeded genotypes. Kerpo (230 g), №9A (215 g), and №115 (203 g) were medium-seeded, while №8 (129 g) and №11 (121 g) belonged to the small-seeded group.

Analysis of variance

The two-factor analysis of variance (Table 3) showed significant differences among genotypes for plant height, height of the first pod, number of seeds per pod, seed weight per plant, and 1000-seed weight. No significant differences were found for the number of pods and seeds per plant.

The environmental factor (years) significantly affected plant height, height of the first pod, number of pods per plant, seed weight per plant, and 1000-seed weight. Thus, longer-term studies are recommended for these traits.

Environmental conditions explained most of the total variation for the number of pods and seeds per plant, while genotype had a greater effect on plant height, first pod height, seeds per pod, seed weight per plant, and 1000-seed weight.

The coefficients of variation (CV, %) indicated that the number of pods (24.23%) and seeds per plant (25.08%) were highly dependent on environmental conditions. Medium variability was observed for plant height (17.75%), first pod height (13.95%), 1000-seed weight (13.57%), and seed weight per plant (11.77%), while the number of seeds per pod showed low variability (8.70%).

Table 3. Dispersion analysis of the investigated characters by genotypes (samples) and years (2016-2018)

Source of variation	DF	Mean square						
		Plant height, cm	Height on first pod, cm	Number of pods per plant	Number of seeds per plant	Number of seeds per pod	Seed weight per plant, g	1000 seeds weight, g
Years	2	1039.92*	237.94*	6.33*	96.37 ^{ns}	0.15 ^{ns}	0.74*	466.92 ^{ns}
Varieties (lines)	6	1174.10**	378.91**	5.60 ^{ns}	63.53 ^{ns}	0.466**	3.17**	5751.08**
Residuo	12	160.2956	46.1733	2.3544	29.6267	0.0827	0.1511	479.2082
CV (%)		17.75	13.95	24.23	25.08	8.70	11.77	13.57

Productivity breeding is complex, as it requires combining multiple valuable traits within a single genotype. In peas, key yield-related traits include the number of productive nodes, number of pods per plant, number of seeds per pod, and 1000-seed weight (Belyaeva and Naumkina, 2017; Likhacheva *et al.*, 2017). The investigated spring pea cultivars and lines were evaluated for grain yield (Figure 5).

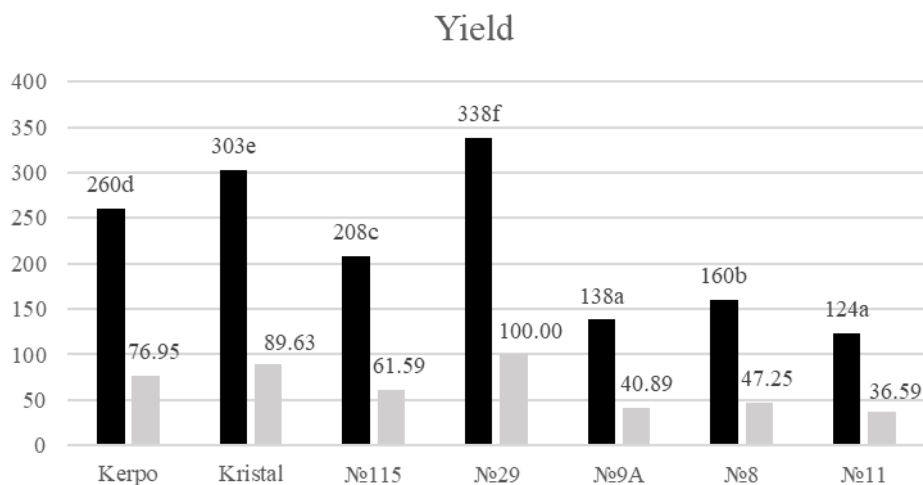


Figure 5. Grain yield (kg/ha) of the investigated pea varieties and lines (2016-2018); a, b, c, d, e, f – statistically significant differences at P=0.001

The investigated spring pea cultivars and lines were evaluated for grain yield (Figure 5). Line №29 consistently demonstrated the highest yield across all years. In the competitive variety trial (2016–2018), line №29 produced 338 kg/ha of grain - 20% higher than Kerpo and about 10% higher than Kristal. In most yield-related traits, except plant height and first pod height, line №29 was comparable only to Kristal.

The findings of the present study regarding the duration of the growing season are consistent with results reported by other researchers. Gul *et al.* (2005) observed a wide variability in this trait, ranging from 143 to 167 days, while Hussain *et al.* (2002) reported a range of 94 to 150 days among pea cultivars. These differences are primarily attributed to variations in environmental conditions affecting the phenological development of plants.

Similarly, variations in plant height observed in this study align with the reports of Hussain *et al.* (2005) and Bozoglu *et al.* (2007), who noted that although plant height is genetically determined, it is strongly influenced by climatic factors.

The number of seeds per pod, considered a relatively stable trait, also showed comparable results. Singh *et al.* (2015) reported a range of 4–5 seeds per pod, which is in agreement with our findings.

Our results regarding the number of pods per plant support the observations of Qasim *et al.* (2001) and Chadha *et al.* (2010), who suggested that smaller pods tend to produce more per plant due to lower nutrient requirements per pod.

Finally, as emphasized by Lysenko and Korobova (2019), detailed characterization of genotypes is essential for future breeding programs. Accumulated specific information facilitates the selection of forms not only with high productivity but also with optimal values of individual yield components, ensuring a more efficient breeding process.

CONCLUSIONS

Line №29 demonstrated the highest grain productivity among the studied genotypes. It is of medium height and has a short vegetation period (78–90 days), exceeding the control varieties in 1000-seed weight (209.88 g) and seed weight per plant (4.88 g). The varieties Kristal and Kerpo showed favorable characteristics in structural elements of seed productivity, making them suitable as parental components in combinatorial breeding for improving grain yield potential.

During the study period, line №29 produced 338 kg/ha of grain, which is 20% higher than Kerpo and 10% higher than Kristal. Lines №8 and №11 developed the tallest plants (91–101 cm), with well-developed foliage, making them suitable for forage purposes.

The coefficient of variation (CV%) indicated high variability for the number of pods per plant (24.23%) and number of seeds per plant (25.08%), moderate variability for plant height (17.75%), first pod height (13.95%), 1000-

seed weight (13.57%), and seed weight per plant (11.77%), and low variability for the number of seeds per pod (8.70%).

These findings highlight the potential of line №29 as a high-yielding genotype for grain production, while lines №8 and №11 may be recommended for forage purposes. The results provide valuable information for future breeding programs aimed at improving productivity and agronomic performance in spring forage peas.

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