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Photosynthesis, yielding and quality of pea seeds depending on the row spacing and sowing density

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Abstract: Pea is one of the most important legumes grown in the world. The seeds are used for food production and animal feed. The problem with its cultivation is the low yield and sensitivity to the course of the weather. The important factor is to determine the optimal sowing rate and row spacing, especially for new cultivars of pea. Therefore, research was undertaken to assess the effect of row spacing and sowing density on selected physiological parameters, yielding, and structural elements of peas cv. 'Batuta' in Poland. The results of the research showed that the row spacing and sowing density determine the values of plant physiological parameters, yield of pea seeds and protein content. The increase in plant density in the canopy caused a decrease in the measured parameters of chlorophyll fluorescence, such as maximum quantum yield of photosystem II (F_v/F_m) and maximum quantum yield of primary photochemistry (F_v/F_0) and performance index (*PI*). The leaf area index (*LAI*) was lower with a wider row spacing. Row spacing and plant density determined yield of pea seeds, number of pods and seeds per plant and weight of seeds per plant. Wider row spacing resulted in a decrease in the protein content in seeds, while an increase in sowing density from 70 to 110 m^2 caused its increase. The course of the weather during the vegetation period of plants significantly influenced the obtained results.

Keywords: *Pisum sativum* L., photosynthesis efficiency, protein content, row spacing, sowing density

INTRODUCTION

Legumes account for about one-third of the world's direct protein consumption by mankind. They are an important source of animal feed as well as edible and industrial oils. One of the more important characteristics of legumes is their ability to symbiotically fix nitrogen, which underlines their importance as a nitrogen source in both natural and agricultural ecosystems [Karkanis *et al.* 2016; Philips 1980]. One of the popular legumes is pea (*Pisum sativum* L.). It is the third most important cultivated legume in the world and a valuable source of nutrients for humans [Bardaro *et al.* 2016; Karkanis 2016; Tayeh *et al.* 2015]. Peas play an important role in crop rotation as a plant that interrupts the frequent succession of cereals. It is a valuable phytosanitary plant [Małecka-Jankowiak *et. al.* 2016; Tan *et al.* 2012]. Pea plantation leaves the soil with crop residues containing about 20 kg P_2O_5, 25–60 kg K_2O, and 50–80 kg N per 1 ha, which results in a significant increase in the yield of succeeding crops without additional expenditure. The short growing season makes peas a good forecrop for winter species (rape, barley, wheat) [Boros 2016; Karkanis *et al.* 2016].

Peas are a valuable protein plant, it is characterised by a variety of cultivars and their suitability in terms of the direction of cultivation and use (edible, for fodder, as dry seeds, and green fodder) [Rutkowski *et al.* 2015; Smulikowska, Rutkowski 2005]. Genotypes, agronomical management, soil, and climate factors can affect plant growth, yield, and quality. Determining the optimal seeding rate is an important factor. Seeding rates can affect crop yield, competitive ability with weeds, soil surface evaporation, and light interception [Al-Rifaee *et al.* 2004; Armstrong *et al.* 2008; Bhutia, Saurabh 2017; Biswas *et al.*

2012. Johnston et al. 2002; Kosev et al. 2013; McMurray et al. 2011; Rasaei, Ghobadi 2012].

Chlorophyll fluorescence parameters are important tools to study the effects of different environmental stresses on photosynthesis [Allakhverdiev, Murata 2004]. It is one of the important methods to analyses the role of photosystem II (PSII) and its response to towards changes in the environment and growth conditions [Kalaji, Pietkiewicz 2004; Strasser et al. 2004]. The performance index (*PI*) and maximum quantum yield of primary photochemistry (F_v/F_0) are sensitive parameters related to PSII damage and efficiency. Photosynthesis activity can be determined by the measurement of chlorophyll fluorescence and the quantum yield of CO_2 uptake from gas exchange; however, both of them require an accurate assessment of leaf light absorption [Bauerle et al. 2004; Genty et al. 1989]. In the photosynthesis process, the photosynthetic pigments such as chlorophyll and accessory pigments absorb strongly the light in the visible range, minimising its reflectance. Stress factors alter the leaf reflectance in visible wavelengths (approx. 400–700 nm) that result in metabolic disturbance, causing a change in the leaf chlorophyll concentration [Carter, Knap 2001; Knipling 1970].

Therefore, research was undertaken to assess the effect of row spacing and sowing density on selected physiological parameters, yielding, and structural components of peas cv. 'Batuta' in Poland. The research hypothesis assumes that increasing the spacing and planting density per 1 m^2 will improve the physiological parameters of plants, increase the seed yield and have a positive effect on the chemical composition of seeds.

MATERIALS AND METHODS

The research was carried out from 2017–2019 years in Experimental Station for Cultivar Assessment (Stacja Doświadczalna Oceny Odmian) in Przecław (Poland 50°110' N, 21°290' E). The experiment was conducted as a two-factor split-plot method with four replications (24 plots). The area of each plot for harvest was 16.5 m^2. The row spacing (15 cm and 30 cm) was the first experimental factor and the second was the plant density (70, 90, and 110 plants per m^2). Pisum sativum cv. 'Batuta' as sown in variants: row spacing (cm) / seeding density (pcs·m^{-2}): 15/70, 15/90, 15/110 and 30/70, 30/90, 30/110. The forecrop of peas was: winter wheat (2017, 2018 years) and sugar beet (2019). Before sowing, soil mineral fertilisation was applied. Phosphorus, potassium, and nitrogen were applied in doses 35 kg P_2O_5·ha^{-1}, 95 kg K_2O·ha^{-1}, and 30 kg N·ha^{-1}, respectively. The sowing depth was 3–4 cm. The agrotechnical treatments carried out during the field experiment are presented in the Table 1.

The field research was situated in originating from clay loam classified as Fluvic Cambisol (CMfv), according to WRB FAO [IUSS Working Group WRB 2015]. The soil pH was slightly acidic in the years 2018 and 2019 and neutral in 2017. The phosphorus content and average potassium content in soil were characterised by high (2017 and 2018) and very high (2019). The content of magnesium was very high in 2017 and 2019, and in 2018 it was high. Micronutrients content (iron, manganese, and copper) was average in all research years. Zinc content was average in the years 2018–2019 and low in 2017 (Tab. 2).

The weather conditions were recorded at the Experimental Station for Cultivar Assessment in Przecław (Fig. 1).

Table 1. Agrotechnical treatments conducted in the experiment

Specification	2017	2018	2019
Sowing date	28.03.	09.04.	22.03
Herbicide	30.03. Afalon dispersive 450 SC (linuron) 1 dm^3·ha^{-1}	9.04; 27.04. Boxer 800 EC (prosulfocarb) 4 dm^3·ha^{-1}	26.04. Boxer 800 EC (prosulfocarb) 4 dm^3·ha^{-1}
Insecticide	5.06; 19.06 Mospilan 20 SP (acetampitite) 0.2 kg·ha^{-1}	23.05. Mospilan 20 SP (acetampitite) 0.2 kg·ha^{-1}	28.05. Mospilan 20 SP (acetampitite) 0.2 kg·ha^{-1}
Harvest date	24.07.	22.07.	08.07.

Source: own elaboration.

Table 2. Chemical properties of soil prior to pea sowing

Parameter	Value in the years of research		
	2017	2018	2019
Trait			
pH_{KCl}	6.92	6.03	7.0
Humus content (%)	1.16	1.16	1.18
Content (mg·kg^{-1})			
Mg	238.1	102.3	177.1
K	196.4	154.1	170.0
P	155.2	153.0	223.1
Zn	13.54	10.90	109.5
Fe	2885.3	1035.0	1079.3
Mn	370.4	116.0	119.9
Cu	11.43	3.79	7.21

Source: own elaboration.

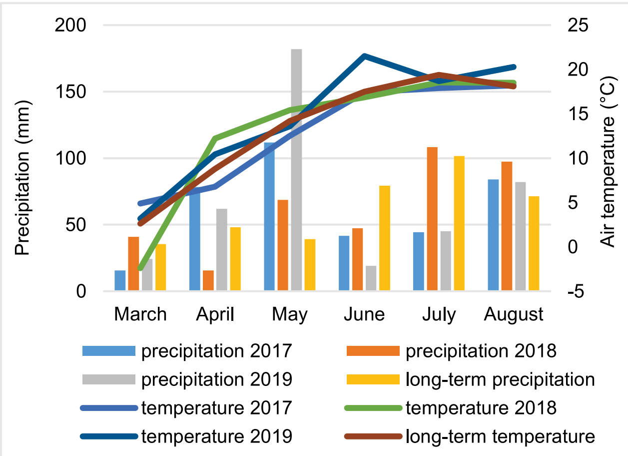

Fig. 1. Weather conditions during the vegetation period of plants in 2017–2019 (mean monthly); source: own elaboration

The growing seasons in terms of water and thermal conditions were characterised on the basis of the Sielianinov (*k*) hydrothermal coefficient [Skowera 2014] – Table 3, which was calculated according to the equation: $k = P/(0.1\Sigma t)$; *P* = sum of monthly precipitation (mm), Σt = sum of average daily air temperatures for a given month (°C).

Table 3. Sielianinov's hydrothermic coefficient (*k*) during the field experiment

Year	Coefficient's value in months					
	Apr	May	Jun	Jul	Aug	mean
2017	3.79 (eh)	0.88 (d)	0.80 (d)	0.80 (d)	1.50 (o)	1.79 (rh)
2018	0.42 (vd)	1.43 (o)	0.94 (d)	1.88 (rh)	1.70 (rh)	1.27 (rd)
2019	2.93 (vh)	4.63 (eh)	0.31 (ed)	0.82 (d)	1.47 (o)	2.03 (rh)
Longterm	1.75 (rh)	1.81(rh)	1.55 (o)	1.45 (o)	1.50 (o)	1.61 (rh)

Explanations: coefficient (*k*) value (for temperature above 8°C): ed = extremely dry, vd = very dry, d = dry, rd = rather dry, o = optimal, rh = rather humid, h = humid, vh = very humid, eh = extremely humid.
Source: own study.

Physiological measurements and leaf area index (*LAI*) on peas plants were conducted in the morning, twice during the growing season in phases: the beginning of flowering (BBCH[1] 59), the end of flowering (BBCH 69). Measurements of the relative chlorophyll content in leaves were conducted using SPAD 502 device. SPAD measurements were conducted on 20 randomly selected plants from each plot.

Measurements of chlorophyll *a* fluorescence were carried out using a portable fluorometer (Pocket PEA). The fluorescence signal was collected in red actinic light with a peak wavelength of 627 nm light diode source and applied for 1 s at the maximal available intensity of 3500 μmol of photosynthetically active radiation (*PAR*) $m^{-2}·s^{-1}$. Fluorescence measurements were carried out on fully expanded leaves of four randomly selected plants from each plot, after a 30 min dark adaptation, using leaf clips that were placed on the upper part of the leaf blades away from the main vein [Maxwell, Johnson 2000].

Leaf area index (*LAI*) measurements were performed with the use of an *LAI* 2000 device (LI-COR). In order to determine the LAI value, one measurement over the canopy and four measurements in the canopy were performed.

Before harvesting, a random 20 plants from each plot were collected in order to analyse the yield structure. Plant height (cm) was measured from the root crown to the tip of the shoot. The number of pods and the number of seeds in the technical maturity phase were determined. The weight of a thousand seeds has been determined with an accuracy of 0.1 g. The pea seeds were harvested at the full maturity phase (BBCH 89). The seed yield was converted into the yield per 1 ha at 15% humidity.

The protein content of peas seeds was determined by using near-infrared spectroscopy (NIRS) using an MPA FT NIR spectrometer. Protein yield was calculated acc. to PN-EN ISO 20483: 2014-02 from the product of the seed yield and the percentage of a protein in the seed.

The results of the study were performed using the statistical software TIBCO Statistica 13.3.0. The analysis of variance (ANOVA) was used to determine the significance of differences between treatments and verified by Tukey's test, at the significance level of $p \leq 0.05$.

[1] BBCH is derived from the Biologische Bundesanstalt, Bundessortenamt and CHemical industry and is the system used for uniform coding of phenologically similar growth stages of all mono- and dicotyledonous plant species.

RESULTS AND DISCUSSION

Chlorophyll is the most important pigment in plants. Its content is an important factor in determining the photosynthesis process and influencing the chlorophyll fluorescence [Mao *et al.* 2007]. The level of irradiance in plants modulates the anatomy and physiology of the leaf. In an environment where there is a high level of irradiance, the leaves are often thicker and have an increased level of mesophyll in proportion to the surface area [Terashima *et al.* 2006]. The content of chlorophyll in pea leaves measured by the SPAD value was higher in the BBCH 69 phase compared to BBCH 59 (Figs. 2, 3). A similar relationship was obtained by Hussain *et al.* [2019] who found a higher chlorophyll content under higher sunlight conditions. The highest SPAD-value was achieved by plants with a spacing of 15 cm and a sowing density of 70 cm in the BBCH 69 phase. SPAD-value was higher by 3.7% compared to the cast of 110 pcs.$·m^{-2}$. In the BBCH 59 phase, the highest SPAD value was recorded in 2019 and it was higher by 4.5% compared to 2017. In turn, in 2017, a significant increase in SPAD by 4.7% was observed between the BBCH 59 and BBCH 69 phases (Figs. 2, 3). Many authors claim (Nemeskéri *et al.* [2015], Prusiński [2022], Prusiński and Borowska [2022]) that the chlorophyll content in leaves is a genetic feature, but it is also conditioned by the course of the weather during the vegetation period and the plant density per 1 m^2. It is higher on the surface with less shade, which was demonstrated in the conducted studies. Higher chlorophyll content was observed with a lower plant density per unit area. Grabowska and Banaszkiewicz [2009], Podleśny [2009], Türk *et al.* [2011], Nemeskéri *et al.* [2015], Prusiński and Borowska [2022] also showed modification of chlorophyll content with the stage of plant development and abiotic factors. Drought reduces SPAD-values, which was shown in the conducted research. Lower SPAD-values were obtained in 2017 with low rainfall compared to 2019, which was confirmed by the performed statistical analysis (Fig. 3).

Light has a significant impact on the physiological processes taking place in plants. The presence of adjacent plants or self-shading within the canopy can reduce the availability of photosynthetic active radiation (*PAR*) and alter the quality of light for each plant [Valladares, Niinemets 2008]. Previous studies have shown that shading conditions in crops belonging to the *Fabaceae* family reduce the reaching of *PAR* run-in, which results in a significant reduction in the efficiency of the photosynthetic process [Yang *et al.* 2014; 2018]. According to Fan *et al.* [2019], shading conditions may affect the capacity

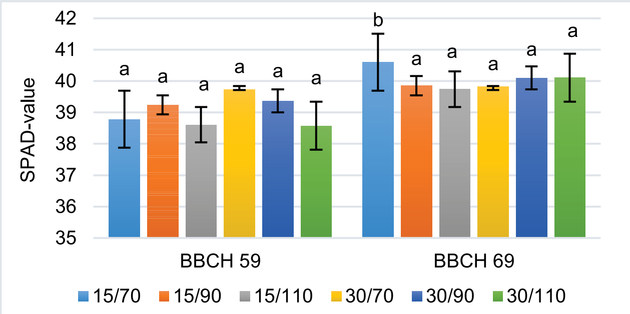

Fig. 2. Chlorophyll content (SPAD-value) depending on phenologic growth stages (BBCH) and row spacing (mean 2017–2019); different letters indicate a significant difference in the row spacing and sowing density according to ANOVA (followed by Tuckey's HDS test, $p \leq 0.05$); source: own study

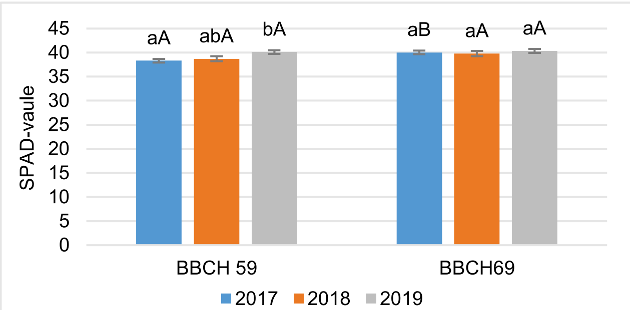

Fig. 3. Chlorophyll content (SPAD-value) depending on phenologic growth stages (BBCH) over the years; different letters indicate a significant difference in row spacing and sowing density, different lowercase letters indicate a significant difference among the means in the measurement phases and different capital letters indicate significant differences among means in the years of research according to ANOVA (followed by Tuckey's HDS test, $p \leq 0.05$); source: own study

decline in the transport of electrons from PSII to PSI. This can be explained by a reduction in the photosynthetic rate caused by a decrease in the availability of light as a result of the mutual overlapping of plants with an increased sowing density [Postma *et al.* 2021]. As the water content of the leaf decreases, reflectance increases and absorption decreases as a result of the radiative attributes of water [Bowman 1989]. Murchie and Lawson [2013] and Nemeskéri *et al.* [2015] showed that increasing the sowing density and row spacing causes the plants to shade each other, which reduces the availability of light, reduces photosynthesis, and causes a decrease in the maximum quantum yield of photosystem II (F_v/F_m) and maximum quantum yield of primary photochemistry (F_v/F_0) parameters. Similar relationships were shown in the conducted research (Fig. 4, 5). The significantly highest value of F_v/F_m was obtained for the row spacing of 15 cm and the density of 70 pcs.·m^{-2}. With the increase in the planting density, the F_v/F_m value decreased by an average of 8.6% (between 15/70 and 15/100 in the BBCH 59 phase) and by 10.8% (between the 30/70 and 30/100 variant in the BBCH 69). The analysis of variance showed significant differences (Fig. 4).

Similar relationships were obtained by analysing the F_v/F_0 and *PI* parameters (Figs. 5, 6). Along with the increase in plant density (regardless of the row spacing), the values of both parameters decreased in each of the analysed development stages. A significant decrease in F_v/F_0 was demonstrated between the 15/70 and 15/110 and 30/110 variants in the BBCH phase, which was

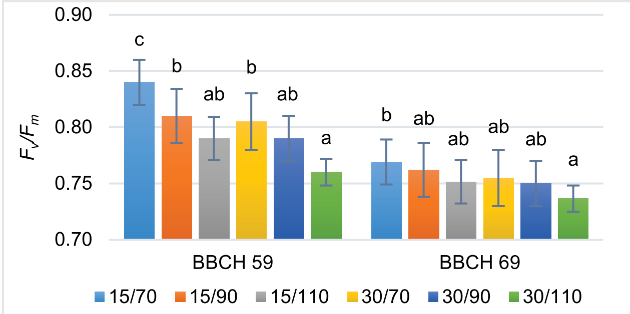

Fig. 4. The maximum quantum yield of photosystem II (F_v/F_m) in pea leaves depending on phenologic growth stages (BBCH) and row spacing (mean 2017–2019); explanations as in Fig. 2; source: own study

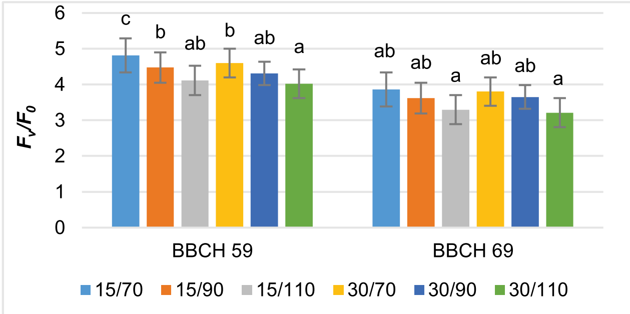

Fig. 5. The maximum quantum yield of primary photochemistry (F_v/F_0) in pea leaves depending on phenologic growth stages (BBCH) and row spacing (mean 2017–2019 years); explanations as in Fig. 2; source: own study

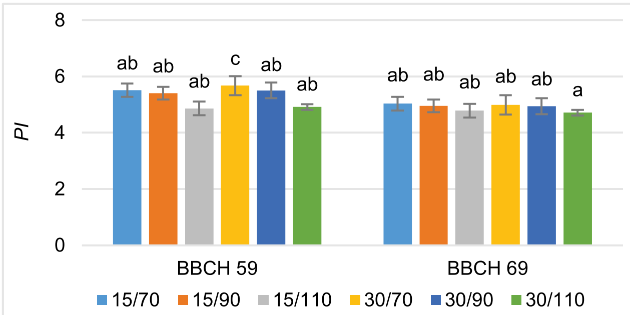

Fig. 6. The performance index (*PI*) in pea leaves depending on row spacing and plant density (mean 2017–2019 years); explanations as in Fig. 2; source: own study

confirmed by the performed statistical analysis The *PI* indicator was significantly the highest in the 30/70 variant. When assessing the years of the study, a decrease in the analysed indicators in 2017 was shown compared to 2018 and 2019, which was caused by the drought during the plant vegetation period in May and June (Tab. 3). The parameter values were lower in the BBCH 69 phase compared to BBCH 59 (Figs. 7, 8, 9).

In the conducted research, the *LAI* field architecture index was also analysed each year (Figs. 10, 11). A significantly higher *LAI* value was demonstrated for a higher plant density and a smaller row spacing. The significantly highest *LAI* parameters were obtained in the 15/110 variant compared to the 30/70 variant. Richard *et al.* [2013] showed that a higher planting density in a wet period causes an increase in the *LAI* value, which was demonstrated in their own research. In 2019, with higher rainfall, the *LAI* value was almost twice as high as in 2017, which

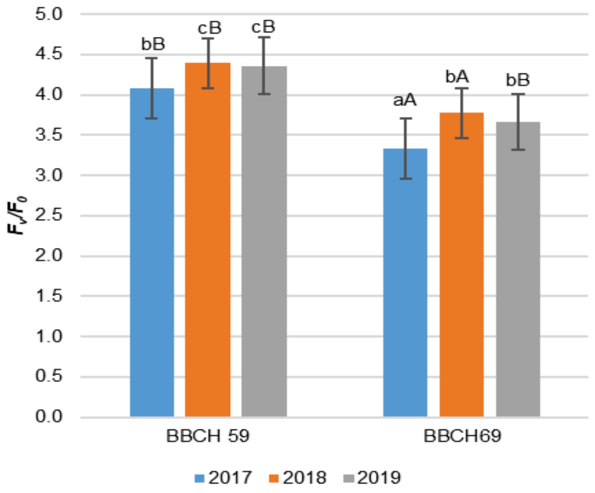

Fig. 7. The maximum quantum yield of primary photochemistry (F_v/F_0) in pea leaves depending on phenologic growth stages (BBCH) over the years; explanations as in Fig. 3; source: own study

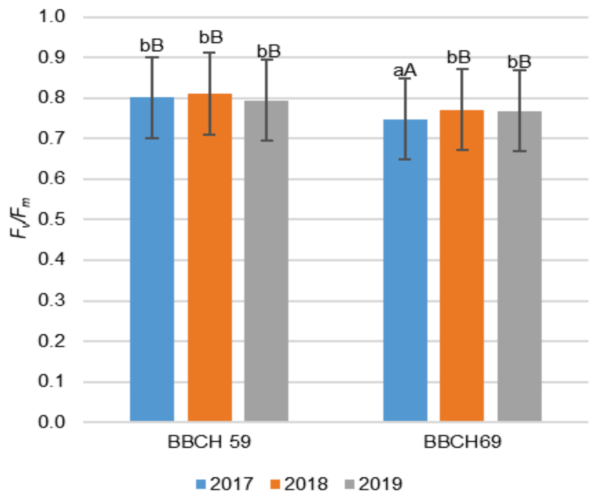

Fig. 8. The maximum quantum yield of photosystem II (F_v/F_m) in pea leaves depending on phenologic growth stages (BBCH) over the years; explanations as in Fig. 3; source: own study

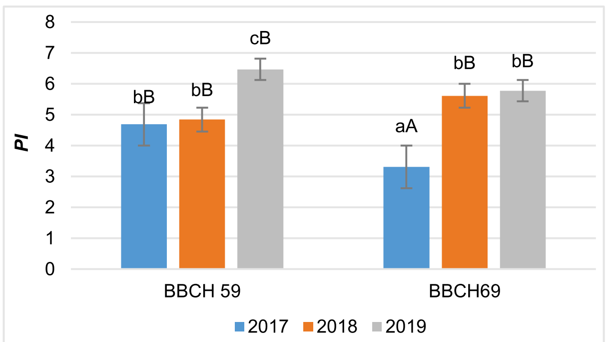

Fig. 9. Performance index (*PI*) in pea leaves depending on phenologic growth stages (BBCH) over the years; explanations as in Fig. 3; source: own study

was statistically confirmed. Podleśny [2009] indicates that in pea plants cultivated with a larger row spacing, the *LAI* value was lower, which was noted in this study, while Prusiński and Borowska [2022] showed no effect on row spacing and sowing density on the *LAI* value.

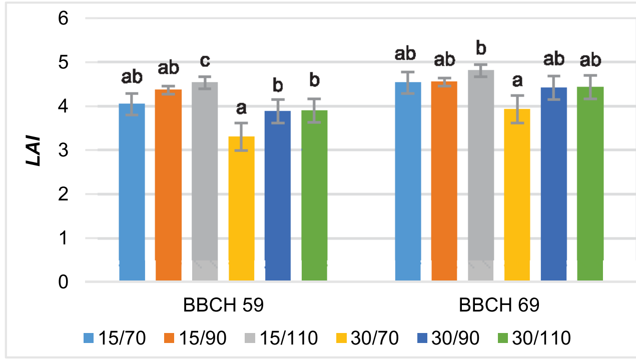

Fig. 10. The leaf area index (*LAI*) depending on phenologic growth stages (BBCH) and row spacing (mean 2017–2019 years); explanations as in Fig. 2; source: own study

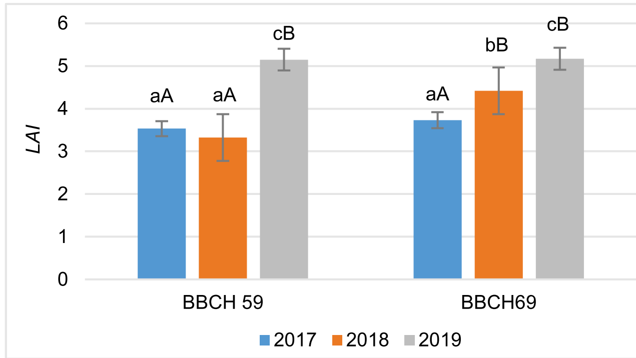

Fig. 11. The leaf area index (*LAI*) depending on phenologic growth stages (BBCH) of pea plants (mean 2017–2019 years); explanations as in Fig. 3; source: own study

The study also analysed the effect of row spacing and sowing density on plant morphological features, seed yield, and structure (Tabs. 4, 5). Podleśny [2009] believes that reducing pea row spacing causes an increase in the accumulation of biomass yield and a decrease in plant height. He showed that pea plants grown in a larger row spacing are taller and their leaf area is smaller. The conducted research showed no effect of the row spacing on the plant height and the height of the first pod placement. The varied plant density did not increase the plant height, but only increased the height of the first pod, on average by 4.97% for a density of 110 pcs.·m^{-2} compared to the density of 70 and 90 pcs.·m^{-2}. The highest plants were obtained in 2019, and the most favourable height of the first pod was in 2018, which was confirmed by the performed statistical analysis (Tab. 4).

Many authors report that the most suitable planting density for peas is 40 pcs.·m^{-2}. A higher sowing density does not lead to an increase in the yield. Gugała and Zarzecka [2009] and Türk *et al.* [2011] obtained the highest yield from the planting stock of 125–150 pcs.·m^{-2}, and the lowest from the planting density of 75 pcs.·m^{-2}. Krizmanić *et al.* [2020] found that sowing peas at different densities significantly modified the seed yield, plant height, and the number of pods per plant, and did not affect the number of seeds in a pod or the weight of 1000 seeds. Spies *et al.* [2012] recommended a pea sowing density in the range of 59–88 pcs.·m^{-2}. Authors report increasing pea plant density reduces the branching of plants. In the conducted research (Tab. 5), the row spacing and sowing density modified the pea seed yield and its structure. A significant increase in the yield was found by 7.8%

Table 4. Morphology trains depending on the research factors of pea plants in the years of experiment

Factor		Plant height (cm)	1st pod height (cm)
row spacing (cm) (X)	plant density (pcs.·m^{-2}) (Y)		
15	70	92.1a ±21.3	70.1a ±13.4
	90	97.5a ±17.0	70.0a ±11.5
	110	99.0a ±14.1	73.2a ±10.4
30	70	94.6a ±21.7	67.6a ±12.3
	90	94.0a ±17.5	68.1a ±12.2
	110	94.4a ±18.4	71.8a ±12.2
15	mean	96.2a ±17.5	71.1a ±11.6
30		94.4a ±18.7	69.1a ±12.0
Mean	70	93.4a ±21.1	68.8a ±12.6
	90	95.8a ±17.0	69.0a ±11.6
	110	96.7a ±16.2	72.5b ±11.2
Year (Z)	2017	73.5a ±7.8	56.1a ±5.2
	2018	98.4b ±7.7	81.7b ±4.6
	2019	113.9c ±4.0	72.6c ±5.3
Mean		95.3 ±18.0	70.1 ±11.8
X		ns	ns
Y		ns	*
Z		***	***
X×Y		ns	ns
X×Z		ns	ns
X×Z×Y		ns	ns

Explanations: different letters indicate a significant difference in row spacing and sowing density according to ANOVA (followed by Tuckey's HDS test, $p \le 0.05$); significance level: *** $p \le 0.001$, ** $p \le 0.01$, * $p \le 0.05$, ns = not-significant.
Source: own study.

with a wider row spacing (30 cm) compared to a narrower one (15 cm). A significantly higher yield was demonstrated for the stocking density of 90 and 110 pcs.·m^{-2} by 2.6% on average compared to the stocking density of 70 pcs.·m^{-2}.

The meteorological conditions during the vegetation period influenced the size of the seed yield. In the analysed growing seasons, favourable weather conditions prevailed in 2018 and 2019 (Tab. 3). April 2018 and June 2019 were dry. Particularly high rainfall was recorded in May 2019, which improved the vegetation of plants (Sielianinov's hydrothermic coefficient – 4.63). The least favourable hydrothermal conditions were recorded in June and July 2017. During this period, the drought decreased the yield and the protein content of seeds. The highest yielding peas in 2019, with well-distributed rainfall during the growing season. Lowest in dry, 2017 year. The difference was 34.8%. PRUSIŃSKI and BORKOWSKA [2022], as well as GRABOWSKA and BANASZKIEWICZ [2009], found that the air temperature and rainfall total determined 84.5% of the pea seed yield. Therefore, favourable rainfall conditions influenced the yield of pea seeds more than the other yield elements, which was also demonstrated in the conducted research. Yield structure elements (with the exception of 1000 seeds weight) depended on the row spacing. With a narrower row spacing (15 cm), there was a significantly greater number of pods and seeds per plant as well as the weight of seeds per plant than with the spacing (30 cm). Similarly, at a lower plant density of 70 pcs.·m^{-2}, a significant increase in the number of pods and seeds per plant was observed in relation to the stocking density of 90 and 110 pcs.·m^{-2} and the weight of seeds per plant in relation to the stocking density of 110 pcs.·m^{-2}. The weight of 1000 seeds was significantly the highest in the density of 90 pcs.·m^{-2}. TÜRK *et al.* [2011] showed that the number of seeds per plant depended on the cultivar and sowing density. The highest number of seeds was developed by plants with a density of 75 pcs.·m^{-2}. Increasing the density reduced the number of seeds per plant. In own research, the most seeds were also obtained from plants at a similar plant density (70 pcs.·m^{-2}) – Table 5. KRIZMANIĆ *et al.* [2020] stated instead the planting density per m^2 had no significant effect on the number of pods or the

Table 5. Pea yield and yield components depending on the research factors in the years

Factor		Seed yield (Mg·ha^{-1})	Number of pods per plant (pcs.)	Number of seeds per plant (pcs.)	Seed weight per plant (g)	Weight of 1000 seeds (g)
row spacing (cm) (X)	plant density (pcs.·m^{-2}) (Y)					
15	70	4.43abc ±0.58	7.5b ±2.6	32.8c ±11.5	7.29cd ±2.51	224ab ±26
	90	4.70bc ±0.64	7.1b ±2.6	30.4bc ±10.4	7.32d ±3.76	233c ±24
	110	4.75c ±0.58	6.4ab ±1.4	27.8ab ±6.6	5.71ab ±1.38	208a ±21
30	70	4.31ab ±0.72	7.6b ±2.4	33.2c ±11.4	7.45d ±2.63	222ab ±17
	90	4.24a ±0.75	6.4 ab ±2.0	27.5ab ±8.9	6.25bc ±2.32	224ab ±18
	110	4.26a ±0.60	5.6a ±1.7	23.3a ±6.4	5.12a ±1.46	219ab ±21
15	mean	4.63a ±0.69	7.0b ±2.3	30.3b ±9.7	6.77b ±2.76	222a ±26
30		4.27b ±0.70	6.5a ±2.1	28.0a ±9.8	6.27a ±2.34	221a ±18
Mean	70	4.37a ±0.64	7.5c ±2.4	33.0c ±11.2	7.37b ±2.51	223ab ±22
	90	4.47b ±0.72	6.8b ±2.3	28.9b ±9.6	6.79b ±3.10	228c ±21
	110	4.50b ±0.67	6.0a ±1.6	25.6a ±6.8	5.42a ±1.42	213a ±21

cont. Tab. 5

Factor		Seed yield ($Mg \cdot ha^{-1}$)	Number of pods per plant (pcs.)	Number of seeds per plant (pcs.)	Seed weight per plant (g)	Weight of 1000 seeds (g)
row spacing (cm) (X)	plant density ($pcs. \cdot m^{-2}$) (Y)					
Year (Z)	2017	3.84 a ±0.32	5.6 a ±1.0	24.4a ±3.8	4.81a ±0.98	205a ±5
	2018	4.33 b ±0.49	5.4 a ±1.4	22.8a ±4.8	5.32 a±1.07	236c ±28
	2019	5.18 c ±0.29	9.3 b ±1.5	40.3b ±7.7	9.44b ±2.12	224b ±12
Mean		4.45 ±0,67	6.82 ±3.2	29.2 ±9.7	6.52 ±2.55	222 ±22
X		***	***	*	*	ns
Y		***	ns	***	***	***
Z		***	***	***	***	***
X×Y		***	ns	ns	ns	ns
X×Z		***	ns	ns	ns	ns
Y×Z		***	ns	ns	ns	ns
X×Z×Y		***	ns	ns	ns	ns

Explanations as in Tab. 4.
Source: own study.

number of seeds per plant; SALTER and WILLIAMS [2015] observed in their research that the weight of pea seeds systematically decreased with increasing planting density. Similarly, in this study, a decrease in seed weight per plant with an increase in seeding density and row spacing was noted (Tab. 5). However, no significant relationships were found between the elements of the structure of the seed yield in the research years and the row spacing and sowing density, which was also demonstrated in their research by PRUSIŃSKI and BOROWSKA [2022].The protein content in the seeds depended on the research factors as well as the course of the weather during the period of seed yielding (Tab. 5). Wider row spacing caused a decrease in the protein content in the seeds as compared to the narrower spacing, while the increase in the plant density resulted in an increase in the amount of protein in the seeds as compared to the lower sowing density, which was confirmed by the variance analysis (Tab. 6).

In 2017, with higher rainfall in June and July, pea seeds contained less protein than in 2018 and 2019 (Tab. 6). In the conducted research, the protein yield depended only on the row spacing and the years of the research. In the narrower spacing (15 cm), the protein yield was significantly higher by 9.7% compared to the wider spacing (30 cm), which was caused by the higher seed yield in this row spacing. The highest protein yield was obtained in 2019 and the lowest in 2017. SHAUKAT [2012] found no effect of row spacing on the protein content in seeds. Similarly, PRUSIŃSKI and BOROWSKA [2022] did not show a significant effect of row spacing, sowing density, and their interaction on the protein content in pea seeds. These authors, analysing the influence of weather conditions on the seed yield and the protein content in seeds, indicated that the decrease in precipitation and the increase in temperature in June and July caused a significant increase in the protein content in pea seeds and a decrease in the seed yield, which was confirmed in the study. In June 2019, there was a drought (0.31), which contributed to the accumulation of more protein in pea seeds, which resulted in a higher seed yield compared to 2017. MARTIN

Table 6. Yield and protein content depending on the research factors across in pea in the research years

Factor		Protein content (% dry matter)	Protein yield ($Mg \cdot ha^{-1}$)
row spacing (cm) (X)	plant density ($pcs. \cdot m^{-2}$) (Y)		
15	70	22.0bc ±2.00	98.4ab ±20.3
	90	21.9bc ±2.23	104.4b ±22.9
	110	21.9bc ±2.49	105.1b ±21.6
30	70	21.2a ±2.11	92.0a ±19.1
	90	21.7b ±2.30	92.9a ±22.4
	110	22.2c ±2.67	95.8ab ±25.0
15	mean	22.0b ±2.19	102.7b ±21.2
30		21.7a ±2.34	93.6a ±21.7
Mean–	70	21.6a ±2.05	95.2a ±19.6
	90	21.9b ±2.22	98.7a ±22.9
	110	22.1c ±2.53	100.5b ±23.4
Year (Z)	2017	18.8a ±0.32	72.2a ±6.4
	2018	23.5b ±0.44	101.8b ±11.5
	2019	23.2b ±0.99	120.3c ±8.2
Mean		21.9 ±2.25	98.1 ±21.8
X		***	***
Y		***	ns
Z		***	**
X×Y		***	ns
X×Z		**	ns
X×Z×Y		***	ns

Explanations as in Tab. 4.
Source: own study.

et al. [1993] and Grabowska and Banaszkiewicz [2009] claim that water stress is the key cause of a decrease in pea yield in a temperate climate.

CONCLUSIONS

The results of the research showed that the row spacing and sowing density determine the values of plant physiological parameters, yield and protein content in pea seeds. The increase in plant density in the canopy caused a decrease in the measured parameters of chlorophyll fluorescence, such as maximum quantum yield of photosystem II (F_v/F_m) and maximum quantum yield of primary photochemistry (F_v/F_0) and performance index (*PI*). This relationship was observed in both development phases in which the measurements were made. The lowest values were recorded for the row spacing of 30 cm and the plant density of 110 pcs.$\cdot$m^{-2}. The leaf area index (*LAI*) was lower with a wider row spacing (30 cm). With the increase of the sowing density from 70 to 110 pcs.$\cdot$m^{-2}, it increased. Wider row spacing (30 cm) and increased plant density (90 and 110 pcs.$\cdot$m^{-2}) resulted in an increase in the yield of pea seeds, while with a narrower row spacing (15 cm), a higher number of pods and seeds per plant and a higher weight of seeds per plant were noted. The use of sowing density – 70 and 90 pcs.$\cdot$m^{-2} had a positive effect on the measured features of the crop structure. Increasing the row spacing from 15 to 30 cm resulted in a decrease in the protein content in seeds, while an increase in sowing density from 70 to 110 pcs.$\cdot$m^{-2} resulted in its increase. The course of the weather during the vegetation period of plants significantly influenced the differentiation of the values of the examined parameters. The highest yield and protein content in seeds were obtained in 2019, which was characterised by the most favourable weather conditions during the growing season.

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REFERENCES

Allakhverdiev S.I., Murata N. 2004. Environmental stress inhibits the synthesis de novo of proteins involved in the photodamage-repair cycle of Photosystem II in *Synechocystis* sp. PCC 6803 Biochimica et Biophysica Acta – Bioenergetics. Vol. 1657(1) p. 23–32. DOI 10.1016/j.bbabio.2004.03.003.

Al-Rifaee M., Turk M.A., Tawaha A.R.M.A. 2004. Effect of seed size and plant population density on yield and yield components of local faba bean (*Vicia faba* L. Major). International Journal of Agriculture & Biology. Vol. 6(2) p. 294–299.

Armstrong E.L., Matthews P.W., Fettell N.A., Holding D.J., Gaynor L.G., Lisle C.J., Cullis B.R. 2008. Effects of plant density on the yield of field pea and faba bean varieties across southern and central NSW preliminary findings. In: Global issues, paddock action. Ed. M.J. Unkovich. Proceedings of 14th Agronomy Confererence. 21–25.09.2008. Adelaide, South Australia. Australian Society of Agronomy pp. 4.

Bardaro N., Marcotrigiano A.R., Bracuto V., Mazzeo R., Ricciardi F., Lotti C., Pavan S., Ricciardi L. 2016. Genetic analysis of resistance to *Orobanche crenata* (Forsk.) in a pea (*Pisum sativum* L.) low-strigolactone line [online]. Journal of Plant Pathology. Vol. 98(3) p. 671–675. [Access 15.04.2022] Available at: https://www.jstor.org/stable/44280520

Bauerle W.L., Weston D.J., Bowden J.D., Dudley J.B., Toler J.E. 2004. Leaf absorptance of photosynthetic active radiation in relation to chlorophyll meter estimates among woody plant species. Scientia Horticulturae. Vol. 101 p. 169–178.

Bhutia T.R., Shivani, Saurabh K. 2017. Evaluation of different varieties of pea (*Pisum sativum* L.) for yield and quality under late sown conditions in the Eastern region. Crop Research. Vol. 52(4 & 5) p. 176–179. DOI 10.5958/2454-1761.2017.00014.6.

Biswas D., Haque M., Rahman M. 2012. Influence of plant population density on growth and yield of two black gram varieties. Journal of Agronomy. Vol. 1(2–3) p. 83–85.

Boros L. 2016. Groch siewny: charakterystyka odmian i elementy agrotechniki [Pea seeds: characteristics of varieties and elements of agrotechnics]. Agroserwis. Nr 3 p. 35.

Bowman W.D. 1989. The relationship between leaf water status, gas exchange, and spectral reflectance in cotton leaves. Remote Sensing of Environment. Vol. 30(1) p. 249–255. DOI 10.1016/0034-4257(89)90066-7.

Carter G.A, Knap A.K. 2001. Leaf optical properties in higher plants: Linking spectral characteristics to stress and chlorophyll concentrations. American Journal of Botany. Vol. 88 p. 677–684. DOI 10.2307/2657068.

Fan Y., Chen J., Wang Z., Tan T., Li S., Li J., …, Yang F. 2019. Soybean (*Glycine max* L. Merr.) seedlings response to shading: Leaf structure, photosynthesis and proteomic analysis. BMC Plant Biology. Vol. 19, 34. DOI 10.1186/s12870-019-1633-1.

Genty B., Briantais J.M., Baker N.R. 1989. The relationship between the quantum yield of photosynthetic electron transport and quenching of chlorophyll fluorescence. Biochimica et Biophysica Acta. Vol. 990 p. 87–92. DOI 10.1016/S0304-4165(89)80016-9.

Grabowska K., Banaszkiewicz B. 2009. Wpływ temperatury powietrza i opadów atmosferycznych na plonowanie grochu siewnego w środkowej Polsce [Effect of air temperature and atmospheric precipitation on yielding of sowing pea in central Poland]. Acta Agrophysica. Vol. 13 p. 113–120.

Gugała M., Zarzecka K. 2009. Wpływ gęstości siewu i sposobów pielęgnacji na plonowanie grochu siewnego (*Pisum sativum* L.) [The influence of sowing rate and weed control methods on the yielding of field pea (*Pisum sativ*um L.)]. Fragmenta Agronomica. Vol. 26 p. 64–71.

Hussain S., Iqbal N., Brestic M., Raza M.A., Pang T., Langham D.R., ..., Yang W. 2019. Changes in morphology, chlorophyll fluorescence performance and Rubisco activity of soybean in response to foliar application of ionic titanium under normal light and shade environment. Science of the Total Environment. Vol. 658 p. 626–637. DOI 10.1016/j.scitotenv.2018.12.182.

IUSS Working Group WRB 2015. International soil classification system for naming soils and creating legends for soil maps. Word Reference Base for Soil Resources 2014, update 2015. Word Soil Resources Reports. No. 106 pp. 192.

Johnston A.M., Clayton G.W., Lafond G.P., Harker K.N., Hogg T.J., Johnson E.N., May V., McConnell J.T. 2002. Field pea seeding management. Canadian Journal of Plant Science. Vol. 82 p. 639–644. DOI 10.4141/P02-001.

Kalaji M.H., Pietkiewicz S. 2004. Some physiological indices to be exploited as a crucial tool in plant breeding. Plant Breeding and Seed Science. Vol. 49 p. 19–39.

Karkanis A., Ntatsi G., Kontopoulou Ch., Pristeri A., Bilalis D., Savvas D. 2016. Field pea in European cropping systems: Adaptability, biological nitrogen fixation, and cultivation practices. Notulae Botanicae Horti Agrobotanici Cluj-Napoca. Vol. 44 (2) p. 325–336. DOI 10.15835/nbha44210618.

Knipling E.B. 1970. Physical and physiological basis for the reflectance of visible and near-infrared radiation from vegetation. Remote Sensing of Environment. Vol. 1 p. 155–159. DOI 10.1016/S0034-4257(70)80021-9.

Kosev V., Pachev I., Mikić A. 2013. Assessing the breeding value of nine spring field pea (*Pisum sativum* L.) cultivars. Plant Breeding and Seed Science. Vol. 68 p. 55–64. DOI 10.2478/v10129-011-0080-4.

Krizmanić G., Tucak M., Brkić M., Marković M., Jovanović V., Cupić T. 2020. The impact of plant density on the seed yield and the spring field pea's yield component. Poljoprivreda. Vol. 26(1) p. 25–31. DOI 10.18047/poljo.26.1.4.

Małecka-Jankowiak I., Blecharczyk A., Swędrzyńska D., Sawińska Z., Piechota T. 2016. The effect of long-term tillage systems on some soil properties and yield of pea (*Pisum sativum* L.). Acta Scientiarum Polonorum. Sect. Agricultura. Vol. 15(1) p. 37–50.

Mao L.Z., Lu H.F., Wang Q., Cai M.M. 2007. Comparative photosynthesis characteristics of *Calycanthus chinensis* and *Chimonanthus praecox*. Photosynthetica. Vol. 45(4) p. 601–605. DOI 10.1007/s11099-007-0103-4.

Martin I., Tenorio J., Ayerbe L. 1993. Yield, growth and water use of conventional and semi-leafless peas semiarid environments. Crop Science. Vol. 34 p. 1576–1583. DOI 10.2135/cropsci1994.0011183X003400060029x.

Maxwell K., Johnson G.N. 2000. Chlorophyll fluorescence – a practical guide. Journal of Experimental Botany. Vol. 51, 345 p. 659–668. DOI 10.1093/jexbot/51.345.659.

McMurray L.S., Davidson J.A., Lines M.D., Leonforte M.A., Salam U. 2011. Combining management and breeding advances to improve field pea (*Pisum sativum* L.) grain yields under changing climatic conditions in south-eastern Australia. Euphytica. Vol. 180 p. 69–88. DOI 10.1007/s10681-011-0362-9.

Murchie E., Lawson T. 2013. Chlorophyll fluorescence analysis: A guide to good practice and understanding some new applications. Journal of Experimental Botany. Vol. 13 p. 3983–3998. DOI 10.1093/jxb/ert208.

Nemeskéri E., Molnár K., Vígh R. 2015. Relationships between stomatal behaviour, spectral traits, and water use and productivity of green peas (*Pisum sativum* L.) in dry seasons. Acta Physiologiae Plantarum. Vol. 37, 34. DOI 10.1007/s11738-015-1776-0.

Phillips D.A. 1980. Efficiency of symbiotic nitrogen fixation in legumes. Annual Review of Plant Biology. Vol. 31 p. 29–49. DOI 10.1146/annurev.pp.31.060180.000333.

PN-EN ISO 20483: 2014-02 wersja polska. Ziarno zbóż i nasiona roślin strączkowych – Oznaczanie zawartości azotu i przeliczanie na zawartość białka – Metoda Kjeldahla [Cereal grains and pulses – Determination of nitrogen content and conversion to protein – Kjeldahl method].

Podleśny J. 2009. Wpływ struktury przestrzennej łanu na wzrost, rozwój i plonowanie wąsolistnej odmiany grochu siewnego [The effect of spatial structure of stand on growth, development and yielding of pea]. Fragmenta Agronomica. Vol. 26 p. 140–149.

Postma J.A., Hecht V.L., Hikosaka K., Nord E.A., Pons T.L., Poorter H. 2021. Dividing the pie: A quantitative review on plant density responses. Plant, Cell & Environment. Vol. 44 p. 1072–1094. DOI 10.1111/pce.13968.

Prusiński J. 2022. Effect of row spacing and plant density on the yield of *Faba bean* L. under very differentiated humidity conditions. Journal of Agricultural Science. Vol. 14(1) p. 1–10. DOI 10.5539/jas.v14n1p1.

Prusiński J., Borowska M. 2022. Effect of planting density and row spacing on the yielding and morphological features of pea (*Pisum sativum* L.). Agronomy. Vol. 12, 715. DOI 10.3390/agronomy12030715.

Rasaei A., Ghobadi M.-E. 2012. Effect of supplemental irrigation and plant density on yield and yield components of peas (*Pisum sativum* L.) in Kermanshah region. African Journal of Agricultural Research. Vol. 7(15) p. 2353–2358. DOI 10.5897/AJAR11.1559.

Richard B., Bussière F., Langrume C., Rouault F., Jumel S., Faivre R., Tivoli B. 2013. Effect of pea canopy architecture on microclimate and consequences on ascochyta blight infection under field conditions. European Journal of Plant Pathology. Vol. 135 p. 509–524. DOI 10.1007/s10658-012-0132-0.

Rutkowski A., Hejdysz M., Kaczmarek S., Mikuła R., Kasprowicz-Potocka M., Zaworska A. 2015. Możliwości wykorzystania roślin strączkowych w żywieniu zwierząt monogastrycznych. Wersja uzupełniona i poprawiona [Possibilities of using legumes in the nutrition of monogastric animals. Updated and revised version]. Warszawa. FAPA. ISBN 978-83-62282-84-5 pp. 83.

Salter J., Williams J.B. 2015. The effect of irrigation on pea crops grown at different plant densities. Journal of Horticultural Sciences. Vol. 42 p. 59–66. DOI 10.1080/00221589.1967.11514193.

Shaukat S.A., Ahmad Z., Choudry Y.A., Shaukat S.K. 2012. Effect of different sowing dates and row spacing on the growth, seed yield, and quality of off-season pea (*Pisum sativum* L. cv. Climax) under temperate conditions of Rawalakot Azad Jammu and Kashmir. Scientific Journal of Agricultural. Vol. 1(5) p. 117–125.

Skowera B. 2014. Zmiany warunków hydrotermicznych na obszarze Polski (1971–2010) [Changes in hydrothermal conditions in the Polish area (1971–2010)]. Fragmenta Agronomica. Vol. 31(2) p. 74–87.

Smulikowska S., Rutkowski A. 2005. Zalecenia żywieniowe i wartość pokarmowa pasz – normy żywienia drobiu [Nutritional recommendations and nutritional value of feed – poultry nutrition standards]. Ed. 4th. Jabłonna. IFiŻZ PAN. ISBN 8391709779 pp. 156.

Spies J.M., Warkentin T., Shirtliffe S.J. 2010. Basal branching in field pea cultivars and yield-density relationships. Canadian Journal of Plant Science. Vol. 90 p. 679–690. DOI 10.4141/CJPS09195.

Strasser R.J., Tsimilli-Michael M., Srivastava A. 2004. Analysis of the chlorophyll a fluorescence transient. In: Chlorophyll a fluorescence. Eds. G.C. Papageorgiou, Govindjee. Ser. Advances in Photosynthesis and Respiration. AIPH. Vol. 19. Dordrecht. Springer p. 321–362. DOI 10.1007/978-1-4020-3218-9_12.

Tan M., Koc A., Dumlu Gul Z. 2012. Morphological characteristics and seed yield of East Anatolian local forage pea (*Pisum sativum ssp. arvense* L.) ecotypes [online]. Turkish Journal of Field Crops. Vol. 17(1) p. 24–30.[Access 10.05.2022]. Available at: https://www.field-crops.org/assets/pdf/product512cbc43287a3.pdf

Tayeh N., Aubert G., Pilet-Nayel M.-L., Lejeune-Hénaut I., Warkentin T.D., Burstin J. 2015. Genomic tools in pea breeding programs: status and perspectives. Frontiers in Plant Science. Vol. 6, 1037. DOI 10.3389/fpls.2015.01037.

TERASHIMA I., HANBA Y.T., TAZOE Y., VYAS P., YANO S. 2006. Irradiance and phenotype: Comparative eco-development of sun and shade leaves in relation to photosynthetic CO_2 diffusion. Journal of Experimental Botany. Vol. 57(2) p. 343–54. DOI 10.1093/jxb/erj014.

TÜRK M., ALBAYRAK S., YÜKSEL O. 2011. Effect of seeding rate on the forage yields and quality in pea cultivars of different leaf types. Turkish Journal of Field Crops. Vol. 16 p. 137–141. DOI 10.17557/tjfc.312335.

UZUN A., BARIS B., ACIKGOZ E. 2017. Effects of different seeding rates on forage yield and quality components in pea. Turkish Journal of Field Crops. Vol. 22(1) p. 126–133. DOI 10.17557/tjfc.312335.

VALLADARES F., NIINEMETS Ü. 2008. Shade tolerance, a key plant feature of complex nature and consequences. Annual Review of Ecology, Evolution, and Systematics. Vol. 39 p. 237–257. DOI 10.1146/annurev.ecolsys.39.110707.173506.

YANG F., FENG L., LIU Q., WU X., FAN Y., RAZA M.A., CHENG Y., CHEN J., WANG X., YONG T. 2018. Effect of interactions between light intensity and red-to-far-red ratio on the photosynthesis of soybean leaves under shade condition. Environmental and Experimental Botany. Vol. 150 p. 79–87. DOI 10.1016/j.envexpbot.2018.03.008.

YANG F., HUANG S., GAO R.C., LIU W.G., YONG T.W., WANG X.C., WU X.L., YANG W.Y. 2014. Growth of soybean seedlings in relay strip intercropping systems in relation to light quantity and red:far-red ratio. Field Crops Research. Vol. 155 p. 245–253. DOI 10.1016/j.fcr.2013.08.011.

YUKSEL O., TURK M. 2019. The effects of phosphorus fertilization and harvesting stages on forage yield and quality of pea (*Pisum sativum* L.). Fresenius Environmental Bulletin. Vol. 28(5) p. 4165–4170.