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ORIGINAL RESEARCH PAPER

The effect of water shortage on pea (*Pisum sativum* L.) productivity in relation to the pod position on the stem

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Abstract

The literature contains few studies on the effect of temporary soil drought on the development and productivity of pea (*Pisum sativum* L.) pods in relation to their position in the fruiting part of the stem. The aim of this study was to evaluate pod productivity of various pea cultivars in relation to varied weather conditions. Differences in precipitation during two growing seasons resulted in a decrease in yield of 0.62 t ha^{-1} in a dry year in comparison to a year with better water availability. *Pisum sativum* 'Tarchalska' proved to be the most stable in terms of the number of pods produced, whilst 'Prophet' was the least. Weather conditions and cultivars were the determinants of pod production. Pea pods were distinguished by their position on the productive node. Larger and more productive pods were found on the lowest four productive nodes (which had a longer period of nutrient accumulation) resulting in higher seed mass. Productivity increased in the year with favorable weather conditions, as more of the upper nodes were reproductive. The first four nodes produced 45–91% of the yield. The number of seeds in the first three nodes was significantly cultivar-dependent, whereas the number of seeds in pods at all nodes was determined by weather conditions. Significantly more seeds were formed from each node in the wetter year. *Pisum sativum* 'Audit' was not sensitive to weather conditions, producing the same yield in the both years of the study.

Keywords

drought; productivity; pod position; pea

Introduction

Pulse crops provide us with many benefits by adding protein to the human diet and nutrients to the soil [1,2]. Production of sufficient protein to feed the growing human population, estimated to reach nine billion in 2050, is a major challenge for humanity [3]. This new challenge is closely linked to our changing weather patterns driven by possible climatic variation.

According to Olszewski [4], variable yield of pea in years with different weather conditions is due to the effect of various environmental stress factors. These may induce reversible disturbances, arresting or slowing plant development for a certain period of time, but may also induce irreversible changes leading to plant death thereby reducing the production potential of the crop. Bueckert et al. [5] analyzing the effect of weather conditions on pea productivity found that the yield and the length of the reproductive stage are indeed dependent upon weather conditions. Schneider et al. [6], as cited by Bénézit et al. [7], indicated that the new trend among European breeders is to generate cultivars that are better adapted to various environmental stresses. In the past, breeders greatly changed the morphological architecture of spring pea cultivars. They have increased resistance to lodging and the number of nodes, reduced the number of stems, and altered the shape of leaves. The changes introduced were aimed at improving yield but they did not take into account the changes in climate and resulting weather observed in recent years.

According to Dacko et al. [8], pea seed yield is determined by the number of fruiting nodes on the stem, which directly depends on weather conditions. This was confirmed by Westgate and Peterson [9] who studied the effects of drought on soybean growth. These authors demonstrated that a water deficiency at the flowering stage reduces pod set at high floral positions whilst improving basal pod set. French and Turner [10] further showed that soybean reacts differently to different drought stresses depending on their intensity. A mild water deficiency can even accelerate seed growth, because vegetative growth is severely constrained and photoassimilation is diverted to reproductive structures. If drought stress intensifies, carbon assimilation diminishes and stored reserves are then mobilized for seed growth. The seed growth rate is thus sustained, but the duration of setting can be shortened, so resulting in smaller seeds. Martin and Jamieson [11] demonstrated that pea productivity depends on the timing of the onset of drought; before flowering it reduces dry matter yield stronger than at maturity stage. For this reason, irrigation is crucial for reducing drought stress, as demonstrated by Podsiadło [12] who found that irrigation can increase pea yield by about 26%. Another solution, suggested by Bénézit et al. [7], is a change in the plant morphotype. This author showed some such differences between old and new pea cultivars can be a significant factor in plant adaptation to drought conditions, such as the length of the growing period and the number of reproductive nodes. Bénézit et al. [7] indicated that in cultivars with a high thousand seed weight and a low reproductive node number, the flowering period may be very short, whereas new cultivars require more weeks of flowering. Current knowledge of cultivar responses to water availability, however, remains limited.

The aim of the present study was to evaluate the productivity of selected pea cultivars in relation to the unpredictable nature of year-to-year weather conditions and the frequent random nature of precipitation during the growing season. The scope of the study was expanded to include a structural analysis of the pea stem in order to characterize the position of successive pods on the fruiting nodes.

Material and methods

Study conditions

A field trial was performed in 2012 and 2013 at the Experimental Cultivar Testing Station in Pawłowice (Gliwice County, Silesian Province, Poland), which is part of the National Research Centre for Cultivar Testing. The study was conducted using six multipurpose European pea cultivars: 'Batuta', 'Boruta', 'Tarchalska', 'Lasso', 'Audit', and 'Prophet'.

The trial was conducted on a Haplic Phaeozem soil type. This soil has a high content of phosphorus, potassium and magnesium and pH of 6.43. The preceding crop was winter wheat in 2012 and winter barley in 2013. The trial included four 15-m^2 replicate plots of each cultivar and rows spaced 18 cm apart. Mineral fertilizer was applied in the following amounts: 35 kg ha^{-1} of P, 74.7 kg ha^{-1} of K, and 32 kg ha^{-1} of N. The foliar fertilizer Basfoliar 36 Extra was applied at 8 L ha^{-1} in flowering stage. The seeds were inoculated with Nitragin. Herbicides [0.3 kg Senkor 70 WG (metribuzin); Fusilade 150EC at 1 L ha^{-1} (Fluazifop-P-butyl); Butoxone M400SL at 3 L ha^{-1} (MCPB)] and an insecticide [Karate Zeon 050 SC (lambda-cyhalotryn) at 0.15 L ha^{-1}] were applied during crop growth. Ten shoots of each cultivar were harvested from each plot at the fully ripe pod stage and biometric measurements were made. Parameters of yield structure were analyzed in each plant from the lowest node through each successive node, and included: number of pods, weight of pods, seed number, and individual seed weights.

The positions of the first and second pod in the node were determined as in the study by Dacko et al. [8].

Following combine harvesting of the plants, the yields per unit area and then the thousand-seed weights (TSW) were determined. Only an indirect method was used to evaluate a water deficit and Selyaninov's hydrothermal coefficient (k) [13] was used to analyze thermal conditions (soil drought and semi-drought) during the growth periods chosen for analysis: $k = P/0.1\ T_{sum}$, where P – monthly total of precipitation in mm; T_{sum} – daily sum of mean of air temperatures >0°C.

Monthly moisture levels were characterized according to Skowera and Puła [13], as follows: extremely dry – k ≤ 0.4; very dry – 0.4 < k ≤0.7; dry – 0.7 < k ≤ 1.0; fairly dry – 1.0 < k ≤ 1.3; optimal – 1.3 < k ≤ 1.6; fairly wet – 1.6 < k ≤ 2.0; wet – 2.0 < k ≤ 2.5; very wet – 2.5 < k ≤ 3.0; extremely wet – k > 3.0.

Statistical analysis

All data were analyzed using STATISTICA 10 software. Homogeneous groups were determined by Tukey's test at a significance level of α = 0.05.

Results

Weather conditions

Weather conditions significantly affected the length of the developmental stages of the pea crop (Tab. 1). In 2012, as compared to 2013, a longer period of plant growth from sowing to flowering was observed (9.2 days), a longer flowering period (3 days), and a longer crop growth period (7.5 days). Uniformity of maturity in the cultivars was similar in the 2 years (Tab. 2). However, weather was found to affect the degree of lodging before harvest. In 2012, less lodging was observed than in the rainy year of 2013.

Weather conditions differed substantially from the long-term averages (Tab. 3). The year 2012 was very dry. Drought was observed in March (k = 0.6), May (k = 0.7), July (k = 0.7), and August (k = 0.8). Only in April were precipitation levels high with respect to the requirements of the pea crop. A different precipitation regime was observed in 2013. Drought was observed in April (k = 0.7) and July (k = 0.6), whereas in May (k = 3.1) and June (k = 2.3) there was very heavy rainfall, with precipitation levels far exceeding the requirements of pea crops. Drought conditions were observed in both years in July during the critical time for pod and seed filling.

Tab. 1 Number of days of growth in selected periods in years differentiated by weather conditions.

Cultivar	Number of days from sowing to flowering		Number of days from beginning to end of flowering		Number of days from sowing to technical maturity	
	2012	2013	2012	2013	2012	2013
'Batuta'	73	60	14	15	109	100
'Boruta'	68	60	19	12	106	100
'Lasso'	68	59	17	14	107	98
'Tarchalska'	66	56	19	16	106	99
'Audit'	68	60	21	16	108	99
'Prophet'	68	61	17	12	106	101
Mean	68.5 ±2.3	59.3 ±1.7	17.8 ±2.4	14.2 ±1.8	107 ±1.3	99.5 ±1.05
CV (%)	3.42	2.95	13.47	12.95	1.18	1.05

Tab. 2 Comparison of uniformity of maturity and lodging in the pea crops.

Cultivar	Uniformity of maturity; 9-degree scale[a]		Lodging; 9-degree scale[b]	
	2012	2013	2012	2013
'Batuta'	8.00	7.75	4.00	3.50
'Boruta'	7.25	7.25	2.50	4.25
'Lasso'	7.25	7.25	1.50	4.00
'Tarchalska'	7.75	7.25	3.00	3.00
'Audit'	8.00	8.00	3.75	5.50
'Prophet'	8.00	7.00	2.75	3.00
Mean	7.71 ±0.4	7.42 ±0.4	2.92 ±0.9	3.87 ±0.9
CV (%)	4.77	5.07	30.98	24.40

[a] Uniformity of maturity scale. [b] Lodging scale: 1 – most favorable; 9 – least favorable.

Tab. 3 Weather conditions in successive months of the growing season in each year.

Item		March	April	May	June	July	August
Precipitation (mm)	2012	32.6	64.8	35.2	70.7	43.9	49.4
	2013	40.1	17.4	132.0	122.4	34.7	36.0
1999–2014		38.7	36.5	72.2	74.6	81.7	56.0
Precipitation requirements (mm)		-	32.5	50.0	81.3	87.5	56.3
Temperature (°C)	2012	5.0	9.0	15.9	17.8	20.7	20.0
	2013	−0.5	8.4	13.8	17.4	20.1	19.4
1999–2014		3.4	9.3	14.1	17.0	19.6	18.6
Selyaninov's hydro-thermal coefficient (k)	2012	0.6	2.4	0.7	1.3	0.7	0.8
	2013	-	0.7	3.1	2.3	0.6	0.6
1999–2014		-	1.3	1.6	1.5	1.3	1.0

The progression of pea growth

In 2012, peas were sown in the last 10 days of March (March 23), and in 2013 in the middle of April (April 16). In the first year of the study, the flowering stage was observed earlier, in the last 10 days of May, whereas in the following year it occurred before mid-June. Combine harvesting was conducted at the end of July 2012 and at the beginning of August 2013.

Statistical analysis shows that the choice of cultivars significantly determined the number of pods per plant, seed yield and harvest index – HI (Tab. 4). More pods were recorded in the lower part of the stem. Furthermore, more seeds were always counted in the first pod (Tab. 5). *Pisum sativum* 'Audit' formed significantly more pods on the stem (Fig. 1a), which was not confirmed by a higher seed yield (5.05 t ha^{-1}) or a high HI (0.46). The highest seed yield was noted for 'Batuta' (6.19 t ha^{-1}) and 'Tarchalska' (6.13 t ha^{-1}). *Pisum sativum* 'Tarchalska' also had the highest HI (0.57). The differentiation of characteristics in the cultivars found confirmation in the varied course of the developmental stages of the plants in different weather conditions.

Tab. 4 Yield components of the pea cultivars in two seasons.

Item	Pod number per plant	Seed number per pod	Seed weight per plant (g)	TSW (g)	Total plant weight (g)	Seed yield (t ha^{-1})	HI
'Audit'	13.55 [c]	35.65 [a]	7.71 [a]	271.52 [a]	16.59 [a]	5.05 [a]	0.46 [a]
'Batuta'	12.11 [bc]	43.00 [a]	9.40 [a]	271.22 [a]	20.05 [a]	6.19 [b]	0.45 [a]
'Boruta'	8.83 [a]	36.45 [a]	10.28 [a]	366.94 [a]	20.12 [a]	5.88 [bc]	0.50 [ab]
'Lasso'	13.10 [c]	47.05 [a]	8.82 [a]	285.30 [a]	19.42 [a]	5.54 [c]	0.46 [a]
'Prophet'	9.93 [ab]	41.40 [a]	10.91 [a]	321.50 [a]	21.43 [a]	5.69 [c]	0.51 [ab]
'Tarchalska'	9.92 [ab]	40.25 [a]	10.16 [a]	306.91 [a]	17.14 [a]	6.13 [b]	0.57 [b]
p value	0.0000**	0.063	0.11	0.672	0.17	0.0000**	0.0000**
2012	10.91 [a]	36.13 [a]	6.99 [a]	265.21 [a]	13.91 [a]	5.44 [a]	0.48 [a]
2013	11.52 [a]	45.13 [b]	12.10 [b]	342.62 [b]	24.34 [b]	6.06 [b]	0.50 [a]
p value	0.34	0.000*	0.0001**	0.046*	0.000**	0.0001**	0.43
p value (Years × Cultivar)	0.003**	0.042*	0.0001**	0.988	0.0032*	0.0001**	0.0001**

* Significant at 0.05 probability level. ** Significant at 0.01 probability level. Means with different letters denote a significant difference at the 5% probability level according to Tukey's test.

Less biomass was observed in 2012, a year characterized by periods of semi-drought, which negatively affected the entire yield structure (Fig. 1b). The reverse phenomenon was observed in the second year of the study. In 2013, it was very wet in May and June, which was conducive to an extreme biomass production. The greatest was attained by *Pisum sativum* 'Prophet' and 'Boruta' and the lowest by 'Audit'. In 2013, due to the high temperatures in June and July, a significant increase was observed in the productivity of the plants, including TSW, seed number, and weight per plant, and thus a significant increase in seed yield.

All cultivars produced different numbers of seeds per plant in the 2 years of the study (Fig. 1c). More seeds per plant were obtained in 2013. *Pisum sativum* 'Lasso' produced the highest number, but their weight was low. The fewest were recorded for 'Audit', but it produced significantly more in 2012. This is indicative of the differences in the water requirements of these two cultivars. *Pisum sativum* 'Audit' produced longer pods in 2012 and was the only cultivar to produce pods on all 10 nodes. The share of seeds from the first four nodes in the total seed yield was significant but varied between cultivars and with weather conditions (Tab. 5, Fig. 2). *Pisum sativum* 'Prophet' had the highest percentage of seeds from the first four nodes (91.9%) in the dry year, and the lowest in the wet year (8.06%). *Pisum sativum* 'Tarchalska' was the most uniform in seed production, attaining a high percentage of the total yield (about 74%) from the first four nodes in the 2 very different years. The variation in number of seeds from the first four nodes ranged from low (13.7%) to intermediate (43.9%), depending on the cultivar and the year. The remaining nodes were characterized by variation ranging from intermediate (34%) to very high (>60%).

Variation was observed in the number of fruiting nodes between years and cultivars (Tab. 5). In 2012 (the dry year), *Pisum sativum* 'Audit' and 'Batuta' produced fruit on 9–10 nodes. In 2013, 'Prophet' and 'Lasso' had more favorable conditions. In 2013, although fewer pods were produced per plant, the fruits formed more seeds. The seed number per pod was determined by the position of the fruits on the stem (Fig. 2). The number of seeds from the first three nodes varied significantly between the cultivars, whereas the years significantly differentiated Nodes 3 and 4. The highest seed number per pod was noted for 'Prophet' and the lowest for 'Audit'. All cultivars were found to be more productive in the wet year (2013). An increase was observed in variation in the number of seeds per pod between years for flowering Nodes 3 and 4.

Tab. 5 Number of total seeds in pods of pea cultivars in relation to the position of the fruiting nodes and the year.

Location of fruiting nodes and pods in the node		'Audit'		'Batuta'		'Boruta'		'Lasso'		'Prophet'		'Tarchalska'	
node No.	pod No.	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
Lower 1–4	1	14.3	14.4	16.4	19.3	17.2	22.6	16.9	18.5	18.8	18.7	16.9	21.2
	2	8.4	8.1	12.0	15.3	12.9	14.9	15.5	13.9	15.4	15.9	13.7	18.0
A*		45.8	55.2	56.3	62.1	78.4	53.3	64.7	49.9	91.9	46.9	74.6	74.3
CV (%)		30.84	38.55	20.03	21.00	43.94	28.82	13.72	20.98	26.90	24.30	25.13	15.15
Upper 5–10	1	17.4	11.8	14.7	11.1	6.7	19.2	11.1	20.6	3.0	25.6	6.1	8.5
	2	9.5	6.5	7.4	10.1	1.6	13.6	6.7	12.1	0	14.9	4.3	5.1
B**		54.2	44.8	43.7	37.9	21.6	46.7	35.3	50.1	8.1	53.8	25.4	25.7
CV (%)		34.54	110.65	66.11	82.88	175.76	80.35	80.79	52.51	331.66	30.89	129.64	146.22
No. of fruiting node		10	7	9	8	6	7	8	9	5	10	7	6

* A – percentage of seeds from first four nodes in total seed number per plant. ** B – percentage of seeds from remaining nodes in total seed number per plant.

Marked differences were noted in the length of pods on successive nodes of the stem (Tab. 6). The first four nodes generated the longest pods, and the higher ones were usually longer. The longest pods were noted for *Pisum sativum* 'Boruta' in 2012 and the shortest for 'Batuta'. In addition, low (5.9%) to intermediate (36.3%) variability in pod length was observed. Shorter pods were recorded at the remaining nodes.

Seed weight per plant was determined by the interaction of growing season and cultivar (Fig. 3a). All cultivars produced significantly greater unit seed weight in the wet year (2013). *Pisum sativum* 'Prophet' produced the greatest seed weight per plant (16 g) and 'Audit' produced the lowest (8 g). *Pisum sativum* 'Prophet' was also the most sensitive to weather conditions; the difference between years in seed weight was as high as 10 g. The least sensitive cultivar was 'Lasso'.

Seed yield was also influenced by cultivar and weather conditions (Tab. 4, Fig. 3b). Cultivars 'Batuta', 'Tarchalska', and 'Boruta' produced significantly greater seed yield in 2013. These cultivars were sensitive to weather conditions during the growing season. They had a shorter flowering time in 2013, leading to a prolonged ripening stage and a high seed yield. Only *Pisum sativum* 'Audit' produced stable but very low yield during 2 years of the trial. The harvest index was influenced by cultivar and the interaction of cultivar and weather conditions (Fig. 3c). The highest HI was noted for *Pisum sativum* 'Tarchalska' (0.6) and the lowest for 'Lasso' (0.5) in 2013.

Discussion

Two different strategies of plant adaptation to abiotic stress conditions have been distinguished. According to a classification created by Levitt [14], the self-defense mechanisms developed by plants are avoidance of drought or delay of its consequences and tolerance to the effects of the stress factor. Avoidance of drought involves the development of morphological or physiological adaptations to the conditions of a habitat deficient in water, such as shortening of the life cycle before drought, water accumulation, or development of a large root system. The second strategy is linked to osmoregulatory processes which enable a plant to bind and retain water during the growing period. Farooq et al. [15], on the basis of existing references, presented various characters for screening grain legumes for drought resistance. These authors demonstrated that legumes can shorten their growth period to avoid stress by maintaining high tissue water potential through reduced water loss and/or improved water uptake

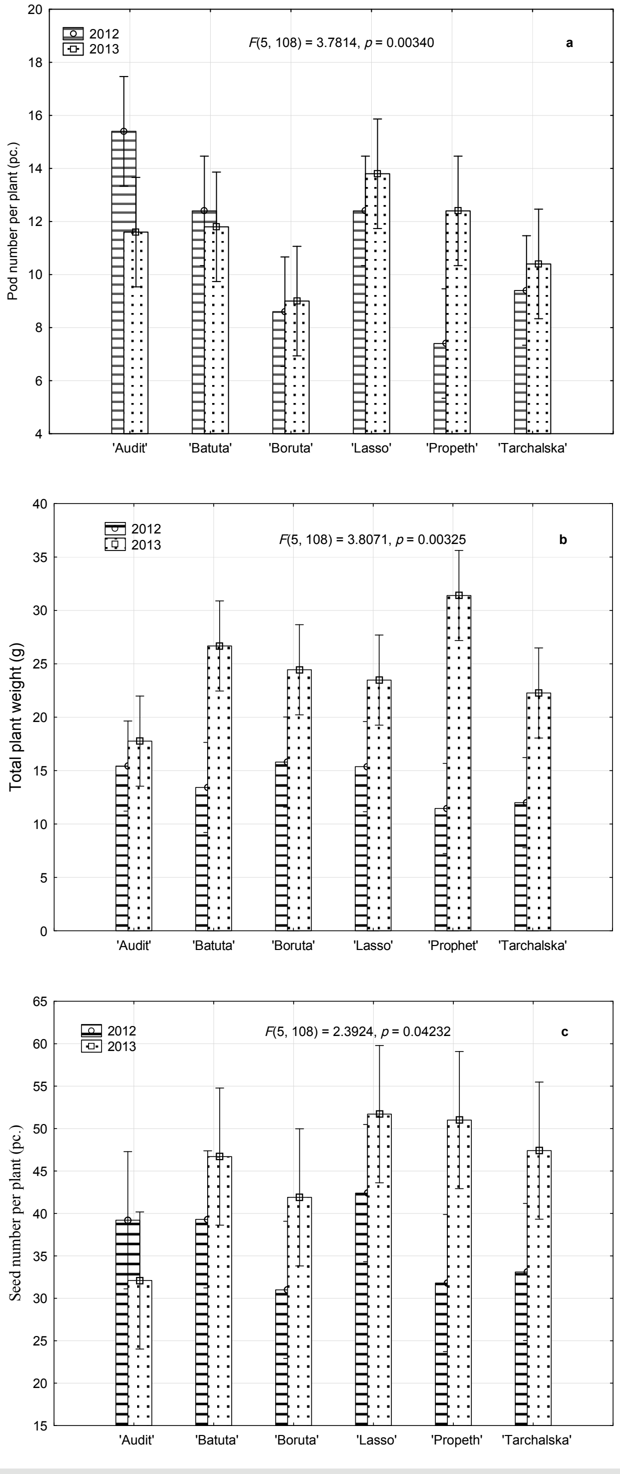

Fig. 1 Interaction of growing seasons and cultivars on (**a**) pod number per plant, (**b**) total plant weight, and (**c**) seed number per plant.

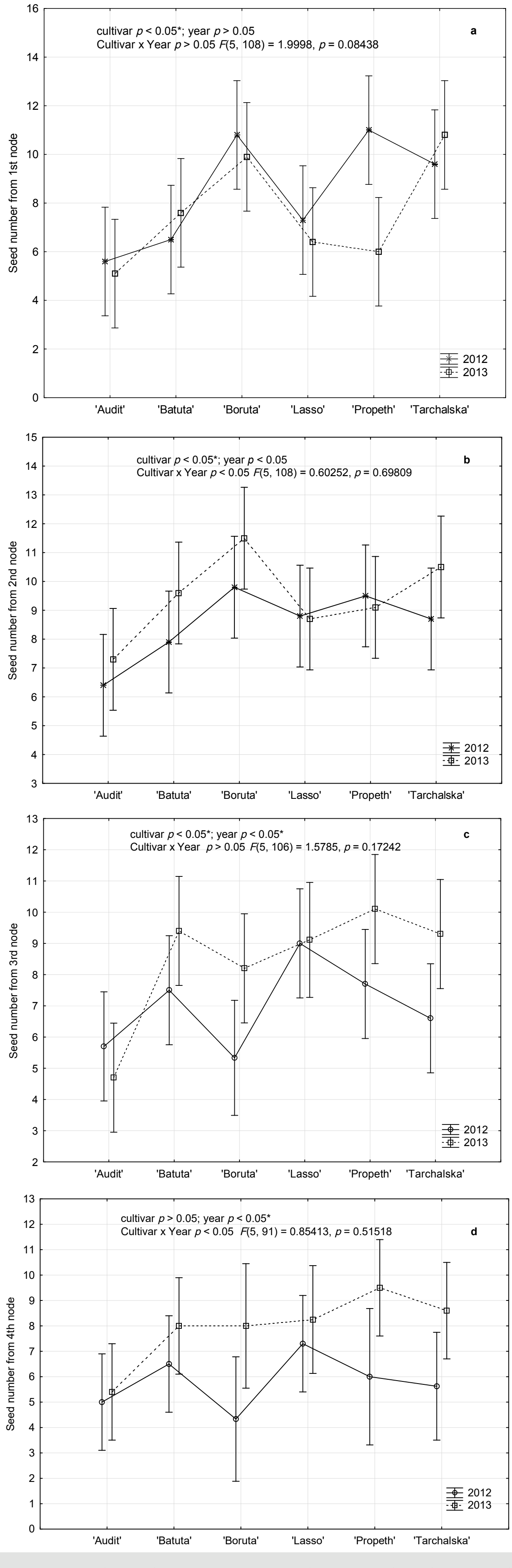

Fig. 2 Seed number per (**a**) 1st node, (**b**) 2nd node, (**c**) 3rd node, (**d**) 4th node, in relation to cultivar and weather conditions.

Tab. 6 Pod length (cm) in relation to position on the stem.

Location of fruiting nodes and of pods in the node		'Audit'		'Batuta'		'Boruta'		'Lasso'		'Prophet'		'Tarchalska'	
node No.	pod position	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
Lower 1–4	1	5.88	5.39	5.71	5.20	6.90	6.80	6.22	5.52	6.34	5.34	6.02	5.93
	2	3.76	2.85	4.63	4.46	5.48	4.79	5.84	3.85	6.19	4.48	4.76	5.18
CV (%)		28.4	36.3	13.6	17.2	21.1	23.4	5.9	24.7	20.9	21.3	20.7	11.7
Upper 5–10	1	5.05	5.03	4.53	4.16	5.35	5.60	4.78	4.89	4.45	5.15	4.52	5.07
	2	3.07	2.99	2.40	3.43	1.56	5.33	3.48	3.41	0.00	3.56	2.95	3.10
CV (%)		115.2	210.6	80.0	123.7	189.3	117.2	76.4	121.1	297.8	93.2	184.0	163.0

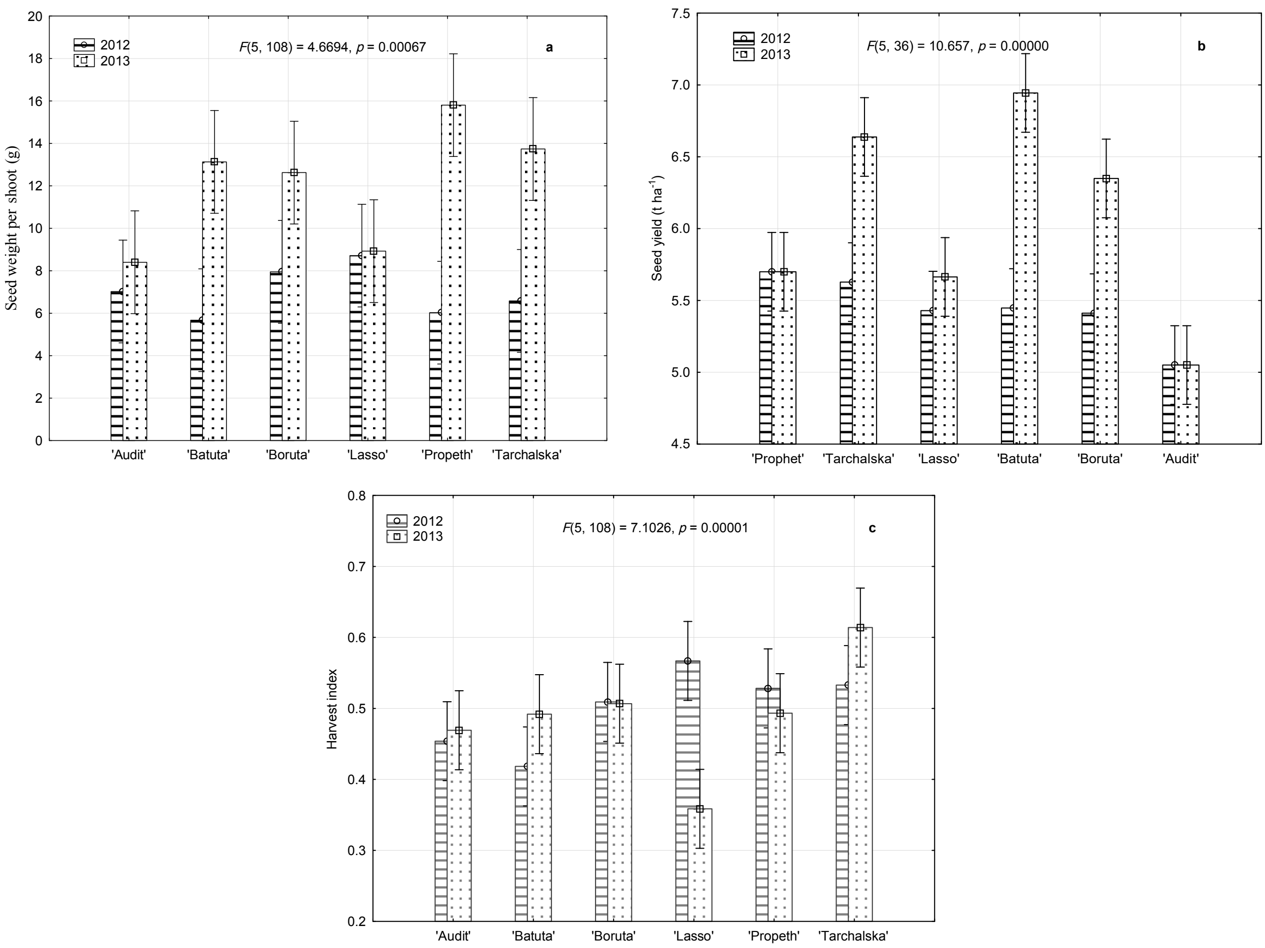

Fig. 3 Seed weight per plant (**a**), seed yield (**b**), and HI (**c**) depending on cultivar and weather conditions.

(chickpea, cowpea, and pea). Another adaptation to drought conditions is associated with root system adjustment, which was tested in chickpea, common bean, lentil, and pea [15–17]. However, according to recent studies [18], trait selection for better drought resistance is not essentially dependent on the root system, but rather on other characteristics such as stomatal conductance, canopy spectral reflectance, and biomass accumulation at different growth stages, all of which were shown to be highly correlated with seed yield [19]. Physiological attributes such as canopy structure (number of reproductive nodes, leaf structure) may be useful in screening grain legume cultivars for drought resistance.

Our research has shown that the varying reactions of pea plants to temporary water stress during growth, characterized by the formation of different numbers of reproductive nodes, had a crucial impact on yield. The study showed that the contribution of seeds from the first four nodes to the total seed yield was significant, but varied depending on the cultivar and on water availability. *Pisum sativum* 'Prophet' had the highest percentage of seeds from the first four nodes (92%) in the dry year and the lowest in the wet year (8%). *Pisum sativum* 'Tarchalska' was the most uniform in seed productivity from nodes, producing a high percentage of seeds from the first four nodes – about 74% in extremely different years. Variation in the number of seeds from the first four nodes was low (13.7) to intermediate (43.9) and depended on the cultivar and the year. The remaining nodes on the stem were characterized by variation ranging from intermediate (34%) to very high (>60%). Our study confirmed earlier findings of Zając et al. [20], who found that the first four nodes contribute about 97% of the seed yield.

The production potential of available pea cultivars is exploited in practice at a level of only about 40%. This is not only due to unfavorable weather conditions but also to limited exploitation of new cultivars with greater yield potential. Our analysis revealed important differences in the productivity of pea depending on weather conditions and the morphotype of the cultivar. Cultivars 'Batuta', 'Tarchalska', and 'Boruta' produced significantly greater seed yield in the wetter year. These three cultivars had a shorter flowering period, which resulted in a prolonged ripening stage and greater seed yield. Cultivar 'Prophet' was highly sensitive to semi-drought. Shortage of water led to a substantial reduction in biomass, the number of pods and seed weight per plant. This was also confirmed by Annicchiarico and Iannucci [21] who found that seed yield and aboveground weight of pea plants are clearly determined by both habitat conditions and variable weather conditions. Olszewski [4] suggested that variability in pea yield in different growing seasons is the result of interactions between various environmental stress factors which may cause reversible changes in plant growth rate, as well as irreversible changes resulting in the death of plants, thereby reducing the production potential of the crop.

Our study has shown high variability of yield elements in *Pisum sativum* 'Tarchalska'. Despite a strong stability in the number of pods formed on stems in different years of the study, very high variation was noted for seed number per plant as well as seed weight and seed yield per plant. This cultivar had a significantly better yield in the year with more rainfall. Similar results were obtained by Zając et al. [20] who found that the productive potential of 'Tarchalska' shows low stability in different years. For the narrow-leaved 'Tarchalska' in the cold and very wet year (683.8 mm rainfall from March to August), it was only the green area index that was higher than in the dry year, whereas the seed yield was higher in the year with optimal rainfall distribution (472 mm). Chmura et al. [22] reported that pea requires from 260 to 300 mm of rainfall during the growing season. Shortages or excesses of water reduce crop yields. Yield is reduced by 16–20% in the case of higher precipitation levels and by 26–28% in the case of low precipitation. In our study, temporary semi-drought reduced yield on average by 10%.

Bueckert et al. [5] analyzed the effect of weather conditions on pea productivity. Seed yield and the length of the reproductive stage were found to be dependent on weather conditions and to be increased by rainfall. Tolerance of pea for drought can be improved by an earlier or longer flowering period. We believe that it is essential to conduct further research on the development and abortion of pods on successive nodes on the stem in varied habitat conditions and in different cultivars. Our study showed that pod formation depends on the cultivar and on the interaction of years and cultivars. In the dry year, *Pisum sativum* 'Audit' had a prolonged flowering stage, resulting in the greatest number of pods. Unfortunately, pod formation on all 10 nodes did not translate into high productivity in this cultivar, resulting in a low seed number, seed weight and final seed yield.

The water stress observed in the dry year before the flowering stage did not significantly affect the number of pods formed in the cultivars 'Audit' and 'Batuta' as these cultivars formed the most pods. However, water stress before the flowering period was found to affect yield in *Pisum sativum* 'Batuta'. A similar phenomenon is described by Farah et al. [23], who showed that water stress should be minimized in pulses (pea, lentil, fava bean, and chickpea) during the flowering and pod-forming stages. These authors demonstrated that among the pulse species tested, pea and lentil are most sensitive to drought stress before the flowering period.

Morison et al. [24] report that in conditions of water shortage plants adopt a variety of strategies for efficient water use: reducing soil evaporation, deeper root growth, improving biomass/water ratio by more efficiently exchanging transpired water for CO_2 and converting it into biomass, and converting more biomass into harvestable yield (HI). Our study has shown that *Pisum sativum* 'Tarchalska' attained the highest HI of all the six cultivars tested. Zając et al. [20] showed that HI is determined by both site conditions and weather. In the case of optimum soil moisture, the HI is higher, whereas an excess of water in the soil reduces it. We found that generative development of pea was more effective in the warmer growing season, which resulted in higher seed yield and number of seeds. Pod length and weight and seed number per pod depended on the position on the stem. The longest pods, characterized by greater weight and higher seed number, were formed by the lowest nodes, i.e., the first two. In pods positioned higher, beginning with the third node, the number of seeds and weight of a single seed were lower. The shortest pods were formed on Nodes 5 and 6.

Conclusions

Two types of morphotypes were distinguished in the cultivars compared in this study. The first comprised local cultivars, i.e., 'Batuta', 'Boruta', and 'Tarchalska', which were characterized by higher productivity per unit area and a smaller number of reproductive nodes. Only *Pisum sativum* 'Tarchalska' formed a stable number of reproductive nodes (6–7) irrespective of weather conditions. Moreover, the four lowest nodes accounted for 74% of the yield. The second morphotype was represented by the foreign cultivars 'Audit', 'Prophet', and 'Lasso', which were less productive (5.05–5.69 t ha^{-1}). However, these cultivars developed more reproductive nodes (9–10). Special attention should be paid to *Pisum sativum* 'Audit', which had the most stable yield in unpredictable weather conditions, but the lowest among all tested cultivars. Breeders should focus primarily on two cultivars: 'Audit', which was characterized by stable yield, and 'Tarchalska', which formed a stable number of reproductive nodes. The challenge is to create new cultivars that combine these two features. However, a new morphotype with high productivity in unpredictable weather conditions will increase the potential of pea cultivation all over Europe.

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Wpływ zmiennych opadów na produktywność strąków z uwzględnieniem ich położenia na pędach grochu (*Pisum sativum* L.)

Streszczenie

W piśmiennictwie spotyka się mało pozycji literatury dotyczącej wpływu okresowej suszy i posuchy na rozwój i produkcyjność strąków grochu w zależności od biosocjalnego położenia w części owocującej pędu. Dlatego celem przeprowadzonych badań była ocena produktywności różnych odmian grochu na tle zróżnicowanych warunków pogody. Zróżnicowanie opadów w sezonach wegetacyjnych skutkowało zmniejszeniem plonowania w roku suchym o 0.62 t ha^{-1}. Najbardziej stabilna w ilości wykształcanych strąków była odmiana 'Tarchalska', a najmniej odmiana 'Prophet'. Warunki pogody miały wpływ na biosocjalne położenie strąków na pędzie, a w konsekwencji na potencjał produkcyjny strąków. Cztery pierwsze okółki zapewniały od 45 do 91% plonu. Właściwości botaniczno-rolnicze odmian decydowały o liczbie nasion pochodzących z dolnych okółków (1–4). Liczba nasion w strąkach zawiązanych z kwiatów wyższych okółków była determinowana warunkami pogody. W roku bardziej wilgotnym formowało się istotnie więcej nasion z każdego okółka. Odmiana 'Audit' odznaczała się wysoką stabilnością plonowania w latach badań.