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EFFECT OF THE WATER STRESS ON THE PRODUCTIVITY OF SELECTED GENOTYPES OF PEA (*Pisum sativum* L.) AND YELLOW LUPIN (*Lupinus luteus* L.)

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ABSTRACT

The pot experiment investigated the effect of varied soil moisture (60-70% and 30-35% of capillary water capacity) from flowering through pod setting, on the intensity of photosynthesis, transpiration, intercellular CO_2 and stomatal conductance, some biometrics, seed weight per plant of different pea forms ('Jaspis', traditional cultivar and 'RRRbRb', homozygotic izoline) and yellow lupin ('Teo', traditional cultivar, and 'Markiz', self-completing cultivar). The research results showed that in the objects with a lowered moisture of 30-35% capillary water capacity of soil, the intensity of photosynthesis decreases, as well as that of transpiration, intercellular concentration of CO_2 and stomatal conductance in pea and yellow lupin. In the conditions of water deficit, the seed weight per plant in yellow lupin cultivars tested decreased significantly, while the seed weight per plant in the pea forms researched did not vary significantly.

Key words: pea, yellow lupin, water stress, gas exchange indicators

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INTRODUCTION

Plants growing in the natural environment and under greenhouse and/or tunnel conditions are always exposed to various abiotic and biotic stress conditions which can affect them unfavourably and result in a considerable decrease in yield [8]. One of the most dangerous abiotic stress factors deteriorating the plant productivity [15] and limiting the crop yield [7,16] is water deficit. Both water deficit and surplus create a considerable stress for the plant. In plants growing under stress conditions there were observed increasing levels of non-organic ions, organic acids, soluble carbohydrates and proteins as well as some of aminoacids and nitrogen compounds. A change in carbohydrates metabolism due to water stress increases the level of soluble sugars and results in changes in the proportion of monosaccharides to starch, which causes changes in the osmotic pressure of tissues [1]. Water deficit affects mostly the process of elongation growth [13]. Plants, in their defence against an excessive water loss close up their stomata, which can lead to a drastic increase in diffusion resistance to water and oxygen and carbon dioxide. A growth inhibition decreases the demand for products of CO_2 assimilation. There increases the consumption of substrates used to regenerate structures damaged due to stress and once the stress ceases to exist [16]. According to Kaiser [9], the decrease in the water potential in tissues, accompanied by a gradual dehydration of leaf cells, coincides with their decrease in turgor, which results in the shrinkage of cells, cell wall and protoplast, which, in turn, disturbs the vital activities of the plant.

Vital activities take a regular course when cell walls remain as a liquid mosaic, which depends also on the degree of hydration. Hydration causes changes in the structure of proteins and lipids as well as results in a considerable concentration of ions in vacuole and cytoplasm [16]. A high concentration of solution over dehydration disturbs the activity of enzymes in the Calvin cycle, which results from the accumulation of sulphates and phosphates [10,12] and can lead to an inhibited photosynthesis over drought [16].

Plants show a varied reaction to water deficit in their various development periods. That of the greatest sensitivity to water deficit has been defined as a critical period in the plant-water relations. Most often the critical period coincides with the generative stage of the plant and the beginning of flowering, if fruits and seeds constitute the yield [7,15]. However when yield consists of green matter, then the critical period coincides with the time of maximal vegetative growth in plants [7].

Water deficit disturbs basic physiological processes, photosynthesis especially, which is due to, on the one hand, a limited accessibility of CO_2 from the outside due to a decreased permeability of stomata, and, on the other hand, due to a decreased activity of enzymes in photosynthesis [15]. Drought damages photosystems, especially PSII, as well as membranes of tylacoids [16].

The photosynthetic efficiency is related to plant water relations, and especially with the process of transpiration. Open stomata make the penetration of CO_2 easier, however it coincides with a loss of considerable amount of water in plant. An increased water deficit results in a loss in plant turgor and disturbed basic metabolic processes in cell as well as photosynthesis. With an increasing water deficit, the photosynthesis slows down first and then it is completely inhibited [17]. The inhibited photosynthesis decreases the level of respiratory substrates and decreases the demand for products of CO_2 assimilation, which is due to an inhibited plant growth. However there increases the consumption of substrates used for the regeneration of damaged structures over stress and after the stress ceases to exist [16]. The water deficit may disturb the mobility of assimilates, which has an indirect effect on photosynthesis. If the drought coincides with the plant growth, then the meristems take away water and organic compounds from leaves placed in the lower plant part, which leads to lower leaf wilting, which, in turn, decreases the assimilation area and lowers the synthesis of organic compounds. A prolonged drought period results in an exhaustion of carbohydrate reserves, weakening the plant [15].

The working hypothesis assumes that a lowered soil moisture from 60-70% down to 30-35% will decrease the intensity of vital activities of the pea and yellow lupin cultivars tested as well as the plant productivity. The aim of the present research was to evaluate the intensity of photosynthesis and transpiration, intercellular concentration of CO_2, stomatal conductance and productivity of varied pea and yellow lupin cultivars under water deficit.

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MATERIAL AND METHODS

The pot experiment in two series was carried out over 1999-2000 in the computer-managed glasshouse of the Olsztyn University of Warmia and Mazury. The experiment factors included the following pea cultivars:

- 'Jaspis' – Polish cultivar, traditional, white-flowering, mid-late, appropriate for dry seed harvest for animal feed and cooking; the seeds produced by the cultivar are spherical with a colourless coat, without a coloured eye,
- 'RRRbRb', a homozygotic isoline with dominating genes obtained from the John Innes Institute Norwich, England; the first R is responsible for generating ADP, while the other R stimulates the production of starch [18]. The white-flowering cultivar with smooth and spherical seeds,

and yellow lupin cultivars:

- 'Teo', a domestic cultivar, a fodder one with a traditional growth rhythm, useful for the seed plantation and green matter production; the cultivar is quite early, ripens evenly and with a little tendency to lodge. It reacts inconsiderably to a delayed sowing date. Plants are short with an average habit, pods are short with white seeds with no ornaments and with a light eye.
- 'Markiz', a self-completing cultivar, is destined for seed harvest to be used as fodder. A low plant with a determined growth rhythm and a small number of branches with pods. Resistant to lodging. Seeds with a beige coat with a dark eye.

Pea and lupin plants were cultivated in pots and treated with distilled water. The stress conditions were maintained from flowering to pod setting. The fertilisation with basic macro- and microelements was applied twice: prior to plant sowing and in the 3-4-leaf stage (Tables 1, 2). The plants were controlled with chemicals against pests and diseases with the following pesticides: AMISTSAR 250 SC (twice) and TALSTAR 100 EC (four times). The research defined the intensity of photosynthesis and transpiration, intercellular concentration of CO_2 and stomatal conductance of plants in the 3-7 leaf phase with mobile gas analyser LI-COR 6400 (DMP AG SA LTD); more essential biometrics and seed weight per plant were also evaluated.

Table 1. Doses of macroelements

Macroelement	N	P	K	Mg
Dose, mg ·1 kg^{-1} of soil	2.7	1.7	5.0	1.8
Salt form	NH_4NO_3	$Ca(H_2PO_4)_2 \cdot H_2O$	KCl	$MgSO_4 \cdot 7H_2O$

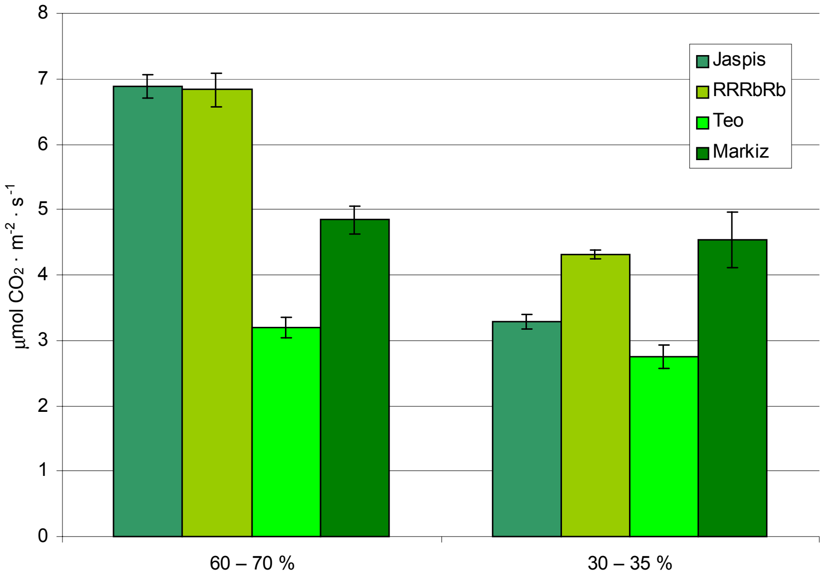
Table 2. Doses of microelements

Microelement	Dose, mg ·1 kg^{-1} of soil	Form
Fe	0.590	$C_{10}H_{12}FeN_2NaO_8$
Mn	0.056	$MnCl_2 \cdot 4H_2O$
Zn	0.057	$ZnCl_2$
Cu	0.011	$CuCl_2 \cdot 2H_2O$
B	0.027	H_3BO_3
Mo	0.0054	$(NH_4)_6Mo_7O_{24} \cdot 4H_2O$

RESULTS

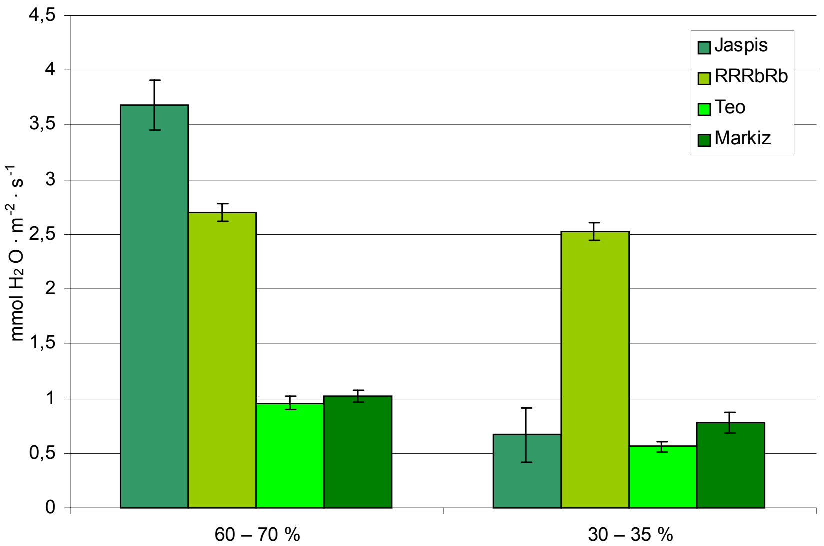
The present analysis of gas exchange parameters showed that a lowered capillary water capacity from 60-70% to 30-35% decreased the intensity of these processes. Yellow lupin cultivars revealed a lower intensity of, in particular, photosynthesis and transpiration under the optimal moisture conditions (Figs. 1, 2). As for the 'Jaspis' pea cultivar, the photosynthesis decreased by over 50%, while in the homozygotic isoline 'RRRbRb' – by over 36%, as compared with the control (60-70% of the capillary water capacity). In yellow lupin cultivars the differences were much smaller. A majority of cultivars researched under water deficit over flowering reacted with a lowered transpiration, intercellular CO_2 concentration (a lower rate of decrease in the 'RRRbRb' isoline – Fig. 3) and stomatal conductance (Fig. 4).

Fig. 1. Pea and yellow lupin photosynthesis intensity in 3-7–leaf phase under water stress



Capillary water capacity

Fig. 2. Pea and yellow lupin transpiration intensity in 3-7–leaf phase under water stress



Capillary water capacity

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Fig. 3. Intercellular CO_2 concentration in pea and yellow lupin leaves in 3-7–leaf phase under water stress

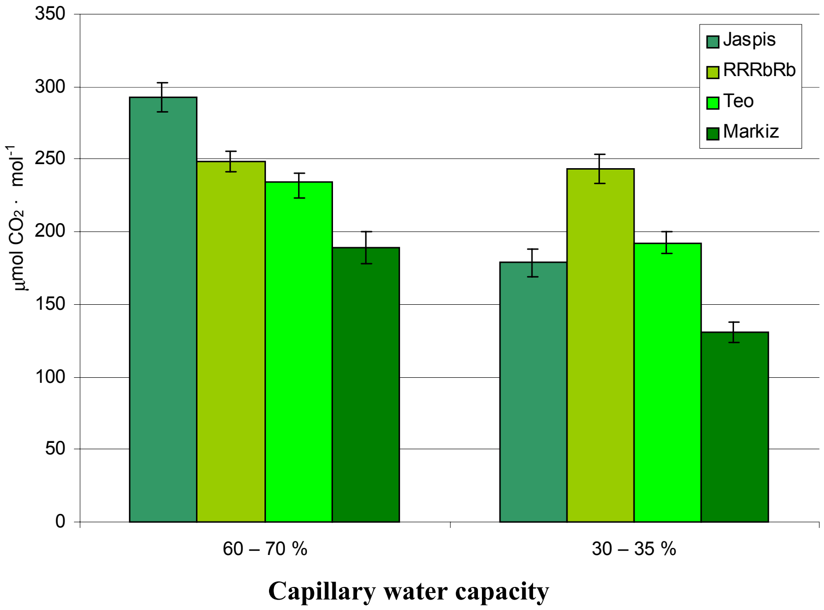
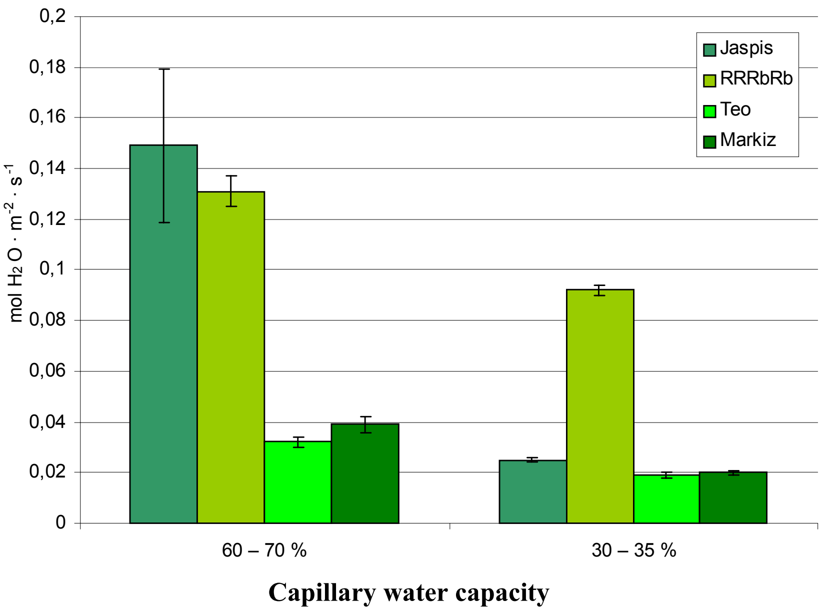


Fig. 4. Pea and yellow lupin stomal conductance in 3-7–leaf phase under water stress



The present results obtained showed that the decreased soil water capacity from 60-70% to 30-35% did not result in significant changes in the values of the yield components biometrics studied and the seed weight per plant (Table 3). Out of all the pea cultivars researched, a significantly higher seed weight per plant was recorded in 'Jaspis', while its first pod was set lower. As for the other indicators researched, no significant differences were shown.

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Table 3. Some biometrics and seed weight per plant in the pea cultivars studied exposed to water stress

Cultivar/ isoline	Water capacity	Plant height cm	Setting height of the first pod, cm	Number of pods per plant	Number of seeds per plant	1000 seed weight g	Weight of seeds per plant g
Jaspis	60-70% 30-35%	49.5 A 50.3 A	42.6 A 46.1 AB	2.4 B 1.8 AB	3.9 A 4.3 A	268 A 288 A	2.57 AB 2.61 B
RRRbRb	60-70% 30-35%	52.4 A 56.2 A	52.0 B 53.1 B	1.9 AB 1.3 A	4.7 A 4.2 A	255 A 253 A	2.15 AB 1.94 A
Mean for cultivars							
Jaspis RRRbRb		49.9 A 54.3 A	44.3 A 52.6 B	2.1 A 1.6 A	4.1 A 4.4 A	278 A 254 A	2.59 B 2.05 A
Mean for water capacity							
60-70% 30-35%		50.9 A 53.3 A	47.3 A 49.6 A	2.1 A 1.5 A	4.3 A 4.3 A	261 A 270 A	2.36 A 2.27 A

A, AB, B – homogenous groups according to the Fisher test

Table 4. Some biometrics and seed weight per plant in the yellow lupin cultivars studied exposed to water stress

Cultivar	Water capacity	Plant height cm	Setting height of the first pod, cm	Number of pods per plant	Number of seeds per plant	1000 seed weight g	Weight of seeds per plant g
Teo	60-70% 30-35%	51.0 AB 49.8 AB	47.7 AB 44.5 A	2.7 A 2.2 A	3.1 A 2.4 A	126 C 115 BC	1.20 B 0.55 AB
Markiz	60-70% 30-35%	55.8 B 48.4 A	50.4 B 44.2 A	3.8 A 2.8 A	3.1 A 2.0 A	93 AB 73 A	0.88 AB 0.40 A
Mean for cultivars							
Teo Markiz		50.4 A 52.1 A	46.0 A 47.3 A	2.5 A 3.3 A	2.8 A 2.6 A	120 B 83 A	0.87 A 0.64 A
Mean for water capacity							
60-70% 30-35%		53.4 A 49.1 A	49.0 B 44.3 A	3.3 A 2.5 A	3.1 A 2.2 A	109 A 94 A	1.04 B 0.47 A

A, AB, B, BC, C – homogenous groups according to the Fisher test

Water stress very clearly modified the seed weight per plant in both genotypes of yellow lupin (Table 4). In the object of 30-35% of soil water capacity a 56% lower seed weight per plant was obtained as compared with the combination with the optimal water capacity (60-70%). The differences in the seed weight per plant across the cultivars researched were non-significant. Water deficit over flowering did not result in any differences in most biometrics and yield components. Both 'Teo' and 'Markiz' in stress conditions showed a lower 1000 seed weight and seed weight per plant.

DISCUSSION

Legumes represent species which are sensitive to periodical water deficits. However they show varied water requirements across cultivars [6]. A plant demand for water changes over its development. The plants are most exposed to water deficit over seed germination, over juvenile development, period of intensive growth and vegetative development. The critical period, as far as water requirements are concerned, in legumes coincides with flowering and pod-setting [2,15]. Disturbed photosynthesis due to water deficit results from a limited access of CO_2 from the outside due to decreased stoma permeability and the activity of enzymes participating in the photosynthesis [15]. The present research showed that plants of pea and yellow lupin cultivated under water deficit over flowering reacted with a decreased intensity of photosynthesis. Similar reactions were recorded by Gej et al. [4] in their research into physiological reactions of faba bean plants to water deficit in soil. The authors

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showed that drought resulted in a varied lowering of the intensity of photosynthesis, and at the same time limited the increase in weight in vegetative parts of the plant and in seeds. The limits coincided especially with the first half of plant flowering. An unfavourable effect of drought was also observed for the gas exchange in faba bean leaves, which was due to decreased diffusion resistance in stomata to CO_2 and water vapour. Grzesiak [5] reports on a short-term drought in resistant corn forms decreasing the photosynthesis and increasing the intensity of transpiration and stomatal resistance. The analysis of the photosynthesis intensity course in the present research showed that 'Jaspis' cultivar showed a slightly higher level of this process than 'RRRbRb' isoline at an optimal capillary water capacity of soil. Similarly the reports by Fordoński et al. [3] who investigated the intensity of photosynthesis of a few forms of pea, show that photosynthesis in the Polish cultivar, 'Jaspis', was higher and amounted to 4.8 μmol $CO_2 \cdot m^{-2} \cdot s^{-1}$, while that of pea isoline with round seeds, 'RRRbRb', amounted to 3.3 μmol $CO_2 \cdot m^{-2} \cdot s^{-1}$. The present results showed that drought resulted in a varied effect on the intensity of transpiration. The 'Jaspis' pea cultivar reacted with a clear lowering of this process, while the values obtained for the isoline, 'RRRbRb', and yellow lupin genotypes did not show considerable differences. The reports by Gej at al. [4] indicate that drought lead to a decrease in the level of daily and seasonal transpiration.

The present research carried out when exposed to water deficit over plant flowering did not show a significant effect on the decrease in the seed weight of the pea cultivars and the values of biometrics studied. However, the seed weight of yellow lupin cultivars was much and significantly lower under water deficit. The results reported by Koczowska et al. [11] showed that drought significantly decreased the number of flowers per plant and the number of set and ripe pods. Prusiński [14] reports that the number of pods per plant under water deficit over early seed development phases as usually decreases, while over the later stages the photosynthetic activity decreases, which decreases the supply of assimilates and has an unfavourable effect on the seed weight and seed biological value. Żuk-Gołaszewska et al. [19] investigating the reaction of white and narrow-leaf lupin cultivars to water stress over flowering did not show a significant decrease in the seed weight, while the results obtained by Grzesiak et al. [6] showed that pea and yellow lupin cultivars researched were less resistant to drought than faba bean and soybean.

CONCLUSIONS

1. Water stress due to water deficit decreased the intensity of photosynthesis, transpiration, intercellular concentration of CO_2 and stomatal conductance in pea 'Jaspis' and 'RRRbRb'.
2. The intensity of photosynthesis decreased slightly only (insignificant differences) under water deficit in the yellow lupin cultivars researched.
3. It was observed that lowered soil moisture from 60-70% to 30-35% significantly decreased the values of gas exchange parameters (transpiration, intercellular concentration of CO_2 and stomatal conductance) in both, the traditional 'Teo' and self-completing 'Markiz' yellow lupin cultivars.
4. Water deficit over flowering significantly decreased the seed weight per plant in the yellow lupin cultivars studied.
5. There were recorded no significant differences in the seed weight per plant in the pea cultivar tested.

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