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THE GENERATIVE DEVELOPMENT OF TRADITIONAL AND SELF-COMPLETING
(RESTRICTED BRANCHING) CULTIVARS OF WHITE LUPIN (*LUPINUS*
ALBUS L.), YELLOW LUPIN (*L. LUTEUS* L.) AND NARROW-LAFED
LUPIN (*L. ANGUSTIFOLIUS* L.) GROWN UNDER DIFFERENT
PHYTOTRON CONDITIONS

ABSTRACT

Increasing the number of flowers and pods set, as well as reducing the intensity of their abortion, is of crucial importance for the yielding of leguminous plants. This study examined the effects of the type of soil used and mineral fertilization applied on the generative development of the traditional and self-completing (restricted branching) cultivars of white lupin (*Lupinus albus* L.), yellow lupin (*L. luteus* L.) and narrow-lafed lupin (*L. angustifolius* L.) cultivated under controlled phytotron conditions. Experiments carried out under such conditions allow for the elimination of variable environmental factors affecting the course of plant ontogenesis in field cultivation, and enable unambiguous interpretation of the biochemical and molecular influence of a selected factor on the physiological process studied. For the first time, the influence of different cultivation factors on generative development of traditional and self-completing (restricted branching) cultivars of lupins under phytotrone was examined.

The research results presented here indicate that each of the selected lupin cultivars has its own characteristic cultivation conditions that are optimal for its generative development. The largest number of flowers were formed by the traditional cultivars of *L. luteus* and *L. angustifolius*, as well as the self-completing (restricted branching) cultivars of *L. luteus* and *L. albus* grown in class IIIa soil material. The lowest flower abortion rate was observed in *L. albus* grown in class V soil material, in *L. luteus* grown in class IIIa soil material, and in *L. angustifolius* grown in class IVa soil material. Regardless of the cultivation conditions applied, in all of the lupin cultivars examined the first pods to be set were characterized by the lowest abortion rate. The results obtained allowed for the development of lupin phytotron cultivation models for the purposes of research on generative development control.

Key words: fertilization, flower abortion, generative development, lupin cultivation, phytotron

INTRODUCTION

The most significant feature among the many desirable characteristics of leguminous plants, including lupins, is their symbiosis with bacteria allowing them to use atmospheric nitrogen for the purposes of growth and development, which also leads to soil enrichment with this extremely important for organisms macroelement, resulting in higher subsequent plant yields (Abd-Alla 1999). Additionally, post-harvest remains of lupin leave in the soil approx. 15–35 kg P $\times$ ha⁻¹, 80–110 kg K $\times$ ha⁻¹, 20–30 kg Ca $\times$ ha⁻¹ and 11–17 kg Mg $\times$ ha⁻¹, while the specific seed storage proteins are the reason for which lupins with low alkaloid contents are processed into fodder for monogastric farm animals. In Europe, three species of lupine are commonly cultivated: *Lupinus albus*, *L. luteus* and *L. angustifolius*. Despite numerous advantages of legumes, their cultivation area is small. This little interest in legumes results from their low cultivation profitability caused by, inter alia, the unwelcome phenomenon of generative organ abortion. In *L. luteus*, on the first and second verticiles most of the flowers set are abscised (Prusiński and Borowska 2007). This equals substantial production losses, the cause of which has not been fully explained, yet. As early as 1980s there were attempts at explaining the basis for this phenomenon and it was found to be of a complex nature. Hypotheses were put forward suggesting that the causes of generative organ abortion were: insufficient flower pollination (Rognli 2007), varied availability of assimilates and mineral substances (Bangerth 1989), diversified distribution and activity of natural plant hormones, or lethal or sublethal gene expression (Van Steveninck 1958). In the light of the latest research it is known that at the bottom of all the developmental changes observed in plants lie modulations of the activity of genes specific for these phenomena. Molecular biology techniques make it possible to define the mechanisms that determine both the formation and maintenance of generative organs. These mechanisms have been best identified in *Arabidopsis thaliana* and *Lycopersicum esculentum* (Burr et al. 2011, Giovannoni 2004). Apart from genes directly involved in flower development (Apetala, Pistillata, Agamous, Sepallata) (Jack 2004), there are also other essential regulatory factors, particularly phytohormonal, both at the level of their biosynthesis and signal transduction (Chandler 2011). The mechanisms regulating flower and fruit morphogenesis identified in *A. thaliana* also function in cereals, e.g. wheat, barley and rice (Hay and Ellis 1998). However, these phenomena have been poorly identified in legumes. In order to be able to take deliberate actions aiming to improve their yielding, it is essential that the mechanisms responsible for regulating the generative development of leguminous plants be defined. Due to the considerable variability of conditions, field or pot cultivations carried out so far do not allow for unambiguous interpretation of molecular research results.

Therefore, in this study we defined the optimal conditions for phytotron cultivation of the traditional and self-completing (restricted branching) cultivars of white lupin, yellow lupin and narrow-lafed lupin (*L. albus* L., *L. luteus* L. and *L. angustifolius* L.), taking into account the type of soil and mineral fertilization. The results that we present herein are a starting point for further comprehensive studies aiming to learn the mechanisms of the generative development of these plants, and to determine the molecular basis for the formation and activation of the abscission zone.

MATERIALS AND METHODS

Plant material and growth conditions

Six commercial cultivars Butan and Boros of *Lupinus albus* (released by Plant Breeding Smolice Ltd. , Poland, Kadryl and Sonet of *Lupinus angustifolius*, Taper and Mister of *Lupinus luteus* (released by Poznan Plant Breeders Ltd Tulce, Poland) were used in the study. The seeds of *L. albus* and *L. angustifolius* were soaked in Vitavax 200 FS antifungal treatment (Chemtura Agro Solution) and H₂O (1 : 2, v/v) for one day, while the seeds of *L. luteus* were treated with Sarfun (250 cm³ × 100 kg⁻¹ seeds). Subsequently, the seeds were inoculated with *Bradyrhizobium lupini* (Nitragina 3 g × kg⁻¹ seeds) for 2 h. The seeds were sown in pots 11 dm³ (5 seeds per pot, with a spacing of 0.02 m) filled with class R IIIa soil material (53°06.003' N, 18°52.598' E, Szewa, Poland), class R IVa soil material (53°05.982' N, 18°52.525' E, Szewa, Poland) and class R V soil material (53°05.650' N, 18°53.112' E, Szewa, Poland). The seeds were planted at a depth of 0.03 – 0.04 m.

The lupins were grown in a growth chamber at a temperature of 22 ± 1°C under long day conditions (110 μmol × m⁻² × s⁻¹, cool white fluorescent tubes by Polam, Warsaw, Poland). The plants were watered with identical amounts of tap water, at least twice a week. In periods of crucial importance for plant development (germination, flowering, pod setting), watering was adapted to the current level of soil humidity. Nutrient solution (Polifoska 3, Police) was provided twice a week after emergence in doses recommended for lupines. Control plants were grown in non-fertilized soil.

The data presented are means of three independent experiments ± SE. The values determined were the average number of flowers and pods formed by the plant, the rate of flower and pod abortion, and a percentage of the number of pods set against the number of flowers formed by the plant. For 10 randomly picked pods, the average number and weight of seeds were calculated. In order to capture the variability resulting from the fruits' location on the stem, pods were picked randomly from different levels or branches, depending on the cultivar. For the purpose of determining

the weight of a thousand seeds, three series of 100 seeds each were weighed. The average value obtained was multiplied by 10. The difference in weight between subsequent series was less than 10 %.

RESULTS

The effects of the type of soil and fertilization on the generative development of lupines

Lupinus albus

The lowest flower abortion rate in the traditional cultivar Butan was found in control plants grown in class V soil material (Table 1). Applying a fertilizer did not considerably affect the number of flowers formed, and in plants cultivated in class IVa and V soils material it did not affect the rate of their abortion. However, it reduced flower abortion in plants grown in class IIIa soil material by 41% (Table 1) and increased, as compared to control plants, the ratio of pods to the number of flowers formed by the plants by 19 % (Table 4).

Table 1

The effects of the type of soil and fertilization on the generative development of the traditional and epigonal cultivars Butan and Boros of *Lupinus albus* grown under phytotron conditions. For a detailed description of the cultivation conditions and fertilization, see Materials and Methods.

Cultivar and variant	Class IIIa soil material				Class IVa soil material				Class V soil material			
	A	B	C	D	A	B	C	D	A	B	C	D
Butan												
Con	13.3 (0.4)	45	7.3 (0.6)	72	15.0 (0.5)	16	12.5 (0.5)	64	10.0 (0.6)	13	8.7 (0.3)	84
Fer	13.6 (0.2)	26	10.0 (0.1)	75	13.1 (0.3)	24	9.9 (0.2)	64	12.1 (0.7)	16	10.1 (0.6)	77
Boros												
Con	11.0 (0.7)	9	10.0 (0.5)	65	8.3 (0.4)	28	6.0 (0.7)	50	8.7 (0.6)	11	7.7 (0.7)	52
Fer	11.9 (0.5)	25	8.9 (0.9)	46	11.7 (0.6)	19	9.4 (0.8)	53	10.2 (0.3)	21	8.0 (0.6)	58

A - No. of flower buds per plant ($\pm$ SE), B - Flower abortion rate [%], C - No. of pods per plant ($\pm$ SE), D - Pod abortion rate [%], Con – control, Fer - Fertilizer

In the control plants of the epigonal cultivar Boros grown in class V soil material, the flower abscission rate was similar to the one in plants grown in class IIIa soil material, but lower by 58% than in plants grown in class IVa soil material (Table 1). Fertilization increased the number of flowers formed by plants grown in class IIIa and V soils material by 8,5% and 17%, respectively, while this phenomenon was accompanied by an increased abortion rate of these organs. Fertilized plants cultivated in class IVa soil material formed an average of 2 pods more than the control plants. The ap-

plication of a fertilizer reduced the number of pods formed by plants grown in class IIIa soil material, and simultaneously reduced their abortion rate by an average of 29 %. Fertilizing plants grown in class V soil material increased the average number of pods set by 1, and raised their abscission rate by 6 %.

Lupinus luteus

The fertilized plants of the traditional cultivar Mister grown in class IIIa and V soils material formed an average of two and three flowers more than the non-fertilized ones (Table 2). In the control plants of this cultivar grown in class IIIa and V soils material, no flower abortion was observed. The ratio of the number of pods formed by the control plants to the number of flowers formed by them was for plants grown in class IIIa, IVa and V soils material 100 %, 91 % and 100 % respectively, and in fertilized plants 84 %, 82 % and 71 % (Table 4). The lowest pod abortion rate was observed in the fertilized plants of the cultivar Mister grown in class IVa soil material.

Table 2

The effects of the type of soil and fertilization on the generative development of the traditional and epigonal cultivars Mister and Taper of *Lupinus luteus* grown under phytotron conditions. For a detailed description of the cultivation conditions and fertilization, see Materials and Methods.

Cultivar and variant	Class IIIa soil material				Class IVa soil material				Class V soil material			
	A	B	C	D	A	B	C	D	A	B	C	D
Mister												
Con	5.0 (0.0)	0	5.0 (0.0)	65	5.5 (0.3)	22	2.5 (0.3)	50	5.0 (0.0)	0	5.0 (0.0)	60
Fer	6.9 (0.3)	16	5.8 (0.5)	52	4.4 (0.3)	17	3.6 (0.8)	45	8.3 (0.4)	28	6.0 (0.4)	64
Taper												
Con	10.5 (0.6)	33	7.0 (0.0)	57	7.0 (0.9)	25	5.2 (0.9)	66	8.0 (0.2)	6	7.5 (0.2)	60
Fer	9.2 (0.4)	18	7.5 (0.5)	71	5.7 (0.4)	2	5.7 (0.3)	69	11.3 (0.5)	23	8.7 (0.5)	69

A - No. of flower buds per plant ($\pm$ SE), B - Flower abortion rate [%], C - No. of pods per plant ($\pm$ SE), D - Pod abortion rate [%], Con – control, Fer - Fertilizer

The largest number of flowers set was in the control plants of the epigonal cultivar Taper grown in class IIIa soil material (Table 2). Fertilization only increased the number of flowers formed by 26.4 % in plants grown in class V soil and had no significant impact on the flowering of plants grown in class IIIa and IVa soils material. The lowest flower abortion rate in the cultivar Taper was observed in fertilized plants grown in class IVa soil material, with an average of 0.1 flowers abscised out of 5.7 flowers formed by the plant. The fewest pods were set by the control plants of this cultivar grown in class IVa soil material. Although fertilization increased the number of pods formed in plants grown in class V soil, still it did not reduce their abortion rate. The ratio of the number pods to that of flowers formed

by the plants reached the highest value in control plants grown in class V soil material, and fertilized plants grown in class IVa soil material (Table 4). The most pods remained in the control plants of the cultivar Taper grown in class IIIa soil material (Table 2).

Lupinus angustifolius

The most flowers and pods were formed by the control plants of the cultivar Kadryl grown in class IIIa soil material (Table 3). At the same time, these plants were characterized by the highest flower abortion rate. The largest number of pods were abscised by plants grown in class V soil material. The application of a fertilizer increased the number of flowers formed in plants cultivated in class IIIa, IVa and V soils material by 240%, 175% and 226% respectively and, simultaneously, increased the abortion rate of these organs in plants cultivated in class V soil material. The highest ratio of pods to flowers formed by the plants was observed both in control plants grown in class IVa and V soils material, and in fertilized plants grown in class IIIa soil material (Table 4).

Table 3

The effects of the type of soil and fertilization on the generative development of the traditional and epigonal cultivars Kadryl and Sonet of *Lupinus angustifolius* grown under phytotron conditions. For a detailed description of the cultivation conditions and fertilization, see Materials and Methods.

Cultivar and variant	Class IIIa soil material				Class IVa soil material				Class V soil material			
	A	B	C	D	A	B	C	D	A	B	C	D
Kadryl												
Con	3.0 (0.1)	8	2.7 (0.5)	9	2.2 (0.5)	0	2.2 (0.5)	0	1.7 (0.2)	0	1.7 (0.3)	20
Fer	7.2 (0.6)	0	7.2 (0.9)	30	3.9 (0.3)	2	3.9 (0.9)	34	3.8 (0.3)	14	3.2 (0.6)	20
Sonet												
Con	9.3 (0.1)	10	8.3 (0.3)	24	7.7 (0.9)	0	7.7 (0.9)	34	8.7 (0.6)	11	7.7 (0.7)	43
Fer	8.8 (0.1)	1	8.7 (0.3)	21	8.3 (0.7)	1	8.2 (0.6)	27	9.6 (0.5)	14	7.0 (0.6)	42

A - No. of flower buds per plant ($\pm$ SE), B - Flower abortion rate [%], C - No. of pods per plant ($\pm$ SE), D - Pod abortion rate [%], Con – control, Fer - Fertilizer

The control plants of the self-completing (restricted branching) narrow-lafed lupin cultivar Sonet formed a comparable number of flowers when grown in class IIIa and V soils material (Table 3). A slight drop in the number of flowers set was observed in plants grown in class IVa soil material. When compared to control plants, fertilization only increased by 10% the number of flowers formed by plants grown in class V soil material. The same agronomic practice reduced considerably the flower abortion rate in plants grown in class IIIa soil material, while it did not affect the number of pods formed by the plants, although at the same time it decreased the pod abortion rate in all of the plants examined.

Table 4
The percentage of the number of pods set against the number of flowers form by the traditional and self-completing (restricted branching) cultivars white, yellow and narrow-lafed lupins grown under phytotron conditions. For a detailed description of the cultivation conditions and fertilization, see Materials and Methods.

Cultivar	Variant	Percentage of pod setting		
		Class soil material		
		IIIa	IVa	V
Butan	Control	55	83	87
	Fertilizer	74	76	83
Boros	Control	91	72	88
	Fertilizer	74	81	79
Mister	Control	100	91	100
	Fertilizer	84	82.5	71
Taper	Control	67	75	93.7
	Fertilizer	81	98	76
Kadryl	Control	92	100	100
	Fertilizer	100	98	85
Sonet	Control	89	100	88
	Fertilizer	99	99	73

The effects of the type of soil on the components of the yield of traditional and epigonal lupine cultivars

The plants of the self-completing (restricted branching) cultivar Boros grown in class IIIa soil material formed 92% more seeds per pod and 160% more seeds per plant than the plants of the traditional cultivar Butan, with their weight of seeds per plant larger by 0.0096 kg, as well (Table 5). Among the white lupin examined, a larger thousand seed weight was observed in the plants of the cultivar Boros grown in class IVa soil material.

The yellow lupin plants of the cultivar Mister formed more seeds per pod than the plants of the self-completing (restricted branching) cultivar Taper, at the same time producing a smaller number of seeds per plant and a lower weight of seeds per plant. This relationship was found in plants grown in all soil classes studied. The largest thousand seed weight was observed in the cultivar Mister grown in class IVa soil material.

In narrow-lafed lupin, the traditional cultivar Kadryl grown in class IIIa soil material formed more seeds per pod than the plants of the cultivar Sonet. However, its number of seeds per plant was 109% lower than that of the self-completing (restricted branching) form, which as a result gave a smaller weight of seeds per plant. This tendency was also maintained in

the plants of this cultivar grown in class IVa and V soil material. Regardless of the type of soil used, the thousand seed weight was larger in the self-completing (restricted branching) plants than in the traditional ones, with the largest difference of 22 % observed in plants cultivated in class IVa soil material.

Table 5

Components of the yield of selected cultivars of narrow-lafed, white and yellow lupins grown under phytotron conditions. For a detailed description of the cultivation conditions and fertilization, see Materials and Methods.

Cultivar	Class IIIa soil material				Class IVa soil material				Class V soil material			
	Average number of seeds		Weight [g]		Average number of seeds		Weight [g]		Average number of seeds		Weight [g]	
	per pod	per plant	seeds per plant	of 1000 seeds	per pod	per plant	seeds per plant	of 1000 seeds	per pod	per plant	seeds per plant	of 1000 seeds
Butan	2.6	19.1	6.8	321.7	3.01	37.6	13.5	301.2	2.4	20.8	7.4	334.6
Boros	5.1	50.2	16.8	317.3	4.43	26.6	8.9	357.6	4.6	35.7	11.9	326.0
Mister	4.0	20.0	2.5	119.3	4.25	10.6	1.7	127.8	4.4	21.9	1.4	122.6
Taper	3.5	24.5	3.3	113.5	3.65	19.2	2.6	110.8	3.2	24.3	3.3	109.4
Kadryl	4.5	12.4	2.2	110.4	4.01	9.0	1.6	112.5	3.5	5.8	1.1	118.1
Sonet	3.1	26.0	3.4	113.8	2.78	21.3	2.8	137.0	2.8	21.3	2.8	132.0

DISCUSSION

Plant development depends on the type of soil, weather conditions, fertilization, and more. These conditions are of particular significance in the cultivation of leguminous plants, including lupins. The most popular lupins are white, yellow and narrow-lafed lupins (*L. albus* L., *L. luteus* L. and *L. angustifolius*). Apart from the traditional cultivars, farmers grow determinate (self-completing (restricted branching) forms that are characterized by a large photosynthetic productivity potential and a higher – when compared to traditional forms – harvest index, more uniform ripening and a shorter vegetation period (Jarvis and Bolland 1991).

White lupin, due to the large protein (36 % - 40 %) and fat (10 %) content in seeds, as well as its uniformly ripening and non-shattering pods, is a very valuable legume (Melo *et al.* 1994). An additional advantage is its yielding higher than in yellow lupin and narrow-lafed lupin. Under field conditions, this species is grown in class IIIa to V soils with a slightly acidic pH (pH 5.6 - 6.0). White lupin is also recommended for cultivation in better soils characterized by substantially diversified humidity. The seeds of yellow lupin contain more protein than those of white lupine (Gladstones

1998). Yellow lupin offers lower soil requirements and is successfully grown in class IVb, V and VI soils material. The best yield is obtained from class V soil with a pH of 5 - 6. Soil requirements place narrow-lafed lupin between yellow lupin and white lupin. Under field conditions, this species is grown in class IIIa, IIIb, IVa and IVb soils rich in magnesium and with a pH close to neutral. The fundamental condition for the correct growth and development of all lupine species is mineral fertilization with phosphorus and potassium. The size of fertilizer doses is determined based on analyses of the soil, depending on its nutrient content. The soil is fertilized prior to sowing, in autumn for heavy soils, and in early spring for lighter soils. Fertilization and class soil material are of crucial significance for lupine yields, but the effect of these factors on the yielding of lupins grown under phytotron conditions has not been identified successfully yet.

As particular species differ in respect of environmental requirements, this study focused on the optimization of phytotron cultivation conditions for the traditional and self-completing (restricted branching) cultivars of *L. albus*, *L. luteus* and *L. angustifolius*.

The results of the phytotron research performed on the traditional cultivar of white lupin showed that, similarly to field cultivation, it is the type of soil material used that is of the largest significance for flower formation and the flower abortion rate. In terms of these two physiological processes, the optimal cultivation results for the traditional cultivar Butan are obtained in class V soil material. The plants are characterized by the lowest flower abortion rate (Table 1) and the highest percentage of the number of pods set in comparison to the number of flowers formed (Table 4). Although, admittedly, mineral fertilization of plants grown in class V soil material increased the number of flowers and pods formed, it also raised the flower abortion rate and decreased the percentage of pods set against the number of flowers formed. This means that under phytotron conditions, the optimal soil material for the cultivation of the traditional cultivar of white lupine is the lowest of the soil classes examined. The result that we obtained for the self-completing (restricted branching) cultivar was different. In terms of flower and pod setting in the cultivar Boros, the most favorable soil turned out to be class IIIa soil material (Table 1). Although the plants were characterized by the lowest flower abortion rate, this result was accompanied by a high pod abscission rate. Despite this seemingly unfavorable relationship, the percentage of pods set against the number of flowers formed reached a maximum value in plants grown in class IIIa soil material (Table 4).

The weight of seeds per plant, the thousand seed weight, the number of seeds per pod and the number of pods per plant are the main parameters of the yield structure. The values of these parameters are affected by, inter alia, the species' cultivar features. Among all of the lupine species examined, the largest average number of seeds per pod and the weight of seeds

per plant, despite the highest flower abortion rate, were observed in both the cultivars of white lupin (Table 5). The factor that contributed to the improvement of this species' yield was its larger average number of pods formed per plant than in yellow lupin and narrow-lafed lupin.

The results presented show that the best cultivation results in terms of the number of flowers formed in the cultivar Mister of *L. luteus* were obtained in class IIIa and V soils material. Although fertilizing this cultivar grown in class V soil material increased the number of flowers formed by the plant, it failed to increase the number of flowers remaining on the plant (Table 2). Additionally, the more flowers were formed by the plant, the higher flower abortion rate was observed. The result was that the ratio of the number of pods set to the number of flowers formed was smaller than in plants grown in class IIIa and IVa soils material (Table 4). In turn, the self-completing (restricted branching) cultivar Taper formed the largest number of flowers when it was grown in class IIIa soil material. Although mineral fertilization did not raise the value of this parameter, and had only a slight impact on pod setting (Table 2), the yield of plants grown in this soil was larger than that of the plants cultivated in class IVa and V soils material (Table 5). Regardless of the cultivation conditions, in both the cultivars of *L. luteus*, flower and young pod abscission on the bottom verticiles of the fruiting zone was smaller than that on the upper nodes.

The most favorable cultivation conditions for the growth and generative development of the traditional cultivar Kadryl of narrow-leafed lupin are offered by class IIIa soil material. The application of a fertilizer not only increased the number of flowers formed by the plants by over 50%, but it also stopped the flower abortion process (Table 3). Additionally, all of the flowers set formed pods that resisted abscission, which contributed to yield improvement.

Our observations showed that phytotron cultivation shortened the flowering time and changed the plant habitus (data not shown). Mature plants were smaller than those grown under field conditions, but the yields obtained were comparable. Similarly to field conditions, in all of the lupin cultivars examined the pods formed in later stages of the generative development were characterized by a much higher abortion rate. In traditional cultivars, the pods formed on lateral stems were aborted more frequently than those formed on the main stem. Additionally, pods formed on the same verticiles, developing simultaneously, were larger than single pods and usually resisted abscission.

The results presented in this study allowed us to set up optimal models for the phytotron cultivation of lupines, which will be used in research on the control of generative development and on flower and pod abscission.

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REFERENCES

- Abd-Alla M.H. 1999. Nodulation and nitrogen fixation of *Lupinus* species with *Bradyrhizobium* (lupin) strains in iron-deficient soil. *Biol. Fertil. Soils*. 28: 407-415.
- Bangerth F. 1989. Dominance among fruits/sinks and the search for correlative signal. *Physiol. Plant*. 76: 608-614.
- Burr C.A., Leslie M.E., Orlowski S.K., Chen L., Wright C.E., Daniels M.J., Liljegren S.J. 2011. CAST AWAY, a membrane-associated receptor-like kinase, inhibits organ abscission in *Arabidopsis*. *Plant Physiol*. 156: 1837-1850.
- Chandler J.W. 2011. The hormonal regulation of flower development. *J. Plant Growth Regul.* 30: 242-254.
- Clements J., Atkins C. 2001. Characterization of a non-abscission mutant in *Lupinus angustifolius*. I. Genetic and structural aspects. *American Journal of Bot.* 88: 31-42.
- Giovannoni J.J. 2004. Genetic regulation of fruit development and ripening. *Plant Cell* 16: 170-180.
- Gladstones J.S. 1998. Distribution, origin, taxonomy, history and importance. In: Gladstones JS, Atkins CA, Hamblin, J. (ed.): *Lupins as crop plants: biology, production and utilization*. Pp. 1-37. CAB International Wallingford, UK
- Hay R.K.M., Ellis R.P. 1998, The control of flowering in wheat and barley: what recent advances in molecular genetics can reveal. *Ann. Bot.* 82: 541-554.
- Jack T. 2004. Molecular and genetic mechanism of floral control. *Plant Cell*, 16: 1-17.
- Jarvis R.J., Bolland M.D.A. 1991, Lupin grain yields and fertiliser effectiveness are increased by banding superphosphate below the seed. *Aust. J. Exp. Agr.* 31: 357-366.
- Melo T.S., Ferreira R.B., Teixeira A.N. 1994, The seed storage proteins from *Lupinus albus*. - *Phytochem.* 37: 641-648.
- Prusiński J., Borowska M. 2007, Degree of success of legume cultivars registered by the center for cultivar testing over the period of market economy. *Acta Sci. Pol., Agricultura* 6: 3-16.
- Rognli O.A. 2007, GMOs and the role of seed yield capacity in herbage breeding programs. *Biofork Fokus*, 12: 13-21.
- Steveninck van R. F. M. 1958, Factors affecting the abscission of reproductive organs in yellow lupins (*Lupinus luteus* L.). II. Effect of growth substances, defoliation, and removal of lateral growth. *J. Exp. Bot.* 9: 372-383.