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Influence of magnetic stimulation of seeds on the formation of morphological features and yielding of the pea**

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A b s t r a c t. Nowadays, when the rational usage of agricultural production space is promoted, the pre-sowing seed treatment with physical factors becomes more important. These factors, which are generally considered as harmless for the environment, most often modify the course of some physiological and biochemical processes in the seeds, increasing their vigour and ensuring better plant development at later stages. The magnetic field is especially worth our attention, since its impact on the seeds can change the course of some processes taking place in the seeds and so stimulates plant development. However, this issue can also be significant in the cultivation of leguminous plants as this group is characterised by low yields which vary considerably from year to year. The present study was carried out in the Institute of Soil Science and Plant Cultivation in Puławy, in the years 2000-2002. The factor of the 1st order were two varieties of the pea seeds, *ie*: Rola - a leafy type, and Piast – an afila type; whereas the factor of the 2nd order – 3 exposure doses of magnetic field: D_0 – without laser treatment (control), D_1 – 10 750 J m^{-3} s (B = 30 mT, s = 15 s) and D_2 – 85 987 J m^{-3} s (B = 85 mT, s = 15 s). Seed treatment was carried out in the Department of Physics of the University of Agriculture in Lublin. The study carried out proved a favourable influence of the magnetic treatment on the emergence, growth and development of both pea varieties. The pre-sowing treatment of the pea sowing material with a magnetic field resulted in a significant increase in the seed yield. The efficiency of the treatment applied depended on the variety, the exposure dose of the magnetic field and the course of weather conditions. The increase in the pea seed yield due to this treatment resulted from a higher number of pods per plant and lower losses of plants from a surface unit during vegetation.

K e y w o r d s: magnetic field, pea, development, emergence, yield

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INTRODUCTION

The application of high quality sowing material which has been properly pre-prepared is an important yield creating factor in plant cultivation. Most often, chemical methods consisting in seed dressing (pickling) with various chemical substances are used in the pre-sowing seed treatment (Górecki and Grzesiuk, 1994). Such methods are considered as very effective but not neutral for the environment. Nowadays, when the rational usage of agricultural production space is promoted, the pre-sowing seed treatment with physical factors becomes more important (Alexander and Doijode, 1995; Phirke *et al*., 1996; Pietruszewski, 1993; Podleśny, 1999; 2001). These latter factors, which are generally considered as harmless for the environment, most often modify the course of some physiological and biochemical processes in the seeds, increasing their vigour and ensuring better plant development at later stages (Galova, 1996; Grzesiuk and Kulka, 1986; Hirota *et al*., 1999; Podleśny *et al*., 2001). The magnetic field is especially worth our attention, since its impact on the seeds can change the course of some processes taking place in the seeds and so stimulates plant development (Phirke *et al*., 1996; Pietruszewski, 1999; Pittman, 1977). Only a few studies relating to this last issue have been carried out so far. They concentrated mainly on cereals and root crops. However, this issue can also be significant in the cultivation of leguminous plants, as this latter group is characterised by low yields which vary considerably from year to year (Jasińska and Kotecki, 1993).

The aim of the present study was to determine the influence of magnetic treatment of seeds on the emergence, growth, development and yield of pea cultivated under experimental conditions.

MATERIALS AND METHODS

The field experiment was carried out in the Institute of Plant Cultivation, Fertilization and Soil Science in Puławy in the period 2000-2002 in a split-plot-split-block design, in a good wheat complex soil. The mineral fertilization applied was as follows: P_2O_5 - 40 and K_2O - 60 and 20 kg N ha^{-1}. The plot surface area was 4 m^2. The factors of the 1st order were two varieties of pea sowing material: Rola – a leafy type, and Piast – an afila type, whereas the factor of the 2nd order – 3 exposure doses of magnetic field intensity: D_0 – without magnetic treatment (control), D_1 – 10 750 J m^{-3} s (B = 30 mT, s = 15 s) and D_2 – 85 987 J m^{-3} s (B = 85 mT, s = 15 s). The magnetic treatment of the seed was carried out in the Physics Department of the Agriculture University in Lublin by using a custom made device for the pre-sowing seed treatment by magnetic field equipped with an electromagnet with continuous adjustment of magnetic induction (Pietruszewski, 1999). Due to a special core design and an independent power supply for the 6 windings in the area of 144 cm^2, the change in the magnetic induction in the range from 30 to 100 mT was obtained. Then the seeds were sown at a depth of about 5-6 cm, with a density of 80 plants per 1 m^2. Two weeks before the sowing, the seeds were dressed with Funaben T and directly after sowing harrowing was used in order to cover the seeds with soil and to level the field surface. Weeds were controlled by using the Afalon preparation applied at a dose of 1.2 kg ha^{-1} to the soil, and in the later period of pea plants development weeds were destroyed mechanically. During vegetation, detailed observations of plant growth and of the occurrence of pest or fungal infestations, as well as plant measurements, were conducted. A few times during the emergence, and directly before harvest, plants in the surface area of 1 m^2 were counted. Dates of the occurrence of particular stages of plant development *ie* full emergence, initiation and end of flowering, browning of about 5 and 80% of pods were noted. Evaluation of the weed growth in the plot was also carried out using a 9^0 scale (1^0 – the biggest weed growth, 9^0 – no weed growth). During full flowering the measurements of 10 randomly selected plants were taken. The main measurements were: height up to the plant top and leaf surface by removing the leaves from the plant and measuring their surface area with the LI-3050A device made by LICOR. The data obtained were calculated for the surface area of 1m^2. Before the harvest 10 plants from each plot were selected at random to determine the following parameters: height to the first and last pod and to the plant top, number of pods per plant and number of seeds per plant. However, after the harvest the following parameters were determined: seed moisture content, weight of 1000 seeds and yield recalculated to 14% of moisture content. The results were statistically processed by using the method of variance analysis and the Statgraphics 4.0 software. Tukey's half-interval of confidence at the level of significance α = 0.05 was applied for the analysis.

RESULTS

The course of weather conditions in the years of the study was considerably differentiated. The amount of precipitation and the values of mean 24 h temperatures during the period of sowing-emergence had a big influence on the rate and evenness of emergence. The years 2001 and 2002 proved to be unfavourable in this respect due to precipitation deficit and considerable decrease of temperature during the period from sowing to emergence. In consequence, the beginning of emergence of pea was noted 24 days after sowing (Table 1). In the same period of 2000, precipitation was more abundant and the mean 24 h air temperature was higher than in both the following years, so pea emergence occurred just 16 days after sowing. Moreover, the emergence were earlier but more even. The influence of magnetic treatment of seeds on the date of first emergences was noted. In all the years of the study, emergence of plants which originated from seeds treated by magnetic field were about 2-3 days earlier than those from the control seeds. There were also differences in the dynamics of plant emergence between the seeds placed in the magnetic field and those without this treatment (Fig. 1).

On the other hand, no significant differences were observed between the D1 and D2 doses of magnetic field intensity in relation to the emergence date; hence the course of plant emergence was presented as one graph for both doses of magnetic field intensity.

In all the years of the study, more plants of the Piast pea variety emerged than of the Rola one. This was related to seed quality and sprouting capacity, since the energy and sprouting capacity of the Piast pea variety was 96 and 98%, respectively, and those of the Rola variety - 88 and 89%. The magnetic stimulation of seeds improved the emergence of the poorer sprouting pea variety, Rola, to a higher degree than in the case of the well sprouting Piast variety.

A significantly higher percentage of emerging plants grown from the stimulated seeds as compared to the plants grown from the non-stimulated seeds was found, especially in the initial stage of pea emergence.

The pre-sowing magnetic stimulation of seeds modified both pea growth and development. The plants grown from seeds treated with magnetic field were generally higher, especially during the period from emergence to flowering. The magnetic field caused a change in the height of both studied varieties of pea to a similar degree, but differences in plant height between the two pea varieties were observed. During the whole period of plant vegetation, plants of the

T a b l e 1. Weather conditions at different stages of pea plants growth

Year	Sowing - emergence			Emergence - flowering			Flowering - maturity			Sowing - maturity		
	number of days	sum of temperature (C)	precipitations (mm)	number of days	sum of temperature (C)	precipitations (mm)	number of days	sum of temperature (C)	precipitations (mm)	number of days	sum of temperature (C)	precipitations (mm)
Rola variety												
2000	16	202	69	38	544	42	43	936	65	97	1682	176
2001	24	204	8	40	586	53	42	813	96	106	1603	157
2002	24	210	15	34	539	44	40	868	99	98	1617	158
Piast variety												
2000	16	202	69	35	488	42	43	918	61	94	1608	172
2001	24	204	8	37	526	47	43	819	93	104	1549	148
2002	24	210	15	32	523	40	40	882	96	96	1615	151

Piast variety (afila type) were higher than the leafy variety, Rola. The plants height of the Piast and Rola varieties during maturation was 76 and 82 cm, respectively.

Differences in the leaf area between the plants grown from seeds treated by magnetic field and those that were not subjected to such a treatment were also observed (Fig. 2). The leaf surface area of the Rola and Piast varieties grown from the stimulated seeds, measured during flowering, was higher than in the case of plants grown from non-stimulated seeds by 31 and 36%, respectively. Significant differences in the leaf surface formation were also found between the studied pea varieties, which was the result of their different morphological structures.

The leaf surface area of one pea plant from the Rola variety was 0.24 10^{-2} m^2 during flowering, whereas the same area of the plant from the Piast variety was 0.06 10^{-2} m^2. The afila type variety, Piast, forms tenacious runners instead of leaves, and on the measured leaf surface there were also substantially enlarged attachments.

Plants grown from the stimulated seeds were characterised by a longer shoot with pods, which is sometimes called the fruiting part of the shoot (Table 2). The increase of this part of stem length was on average 22% for the two varieties. The length of this part of the pea stem is positively correlated with the seed yield. In the case of the leafy variety, Rola, more pods were placed on the longer part of the stem than in the case of the afila type variety, Piast.

Due to competition for light, water and nutrients, the plant complement during vegetation was undergoing substantial changes. The mean plant losses observed during the period from emergence to harvest were 22.9% for the leafy variety and 16.4% for the afila type of pea. Differences in the plant losses between the two pea varieties probably resulted from the different morphological plant structure. The mutual shading of the pea plants of the Rola variety (leafy type) was bigger than in the case of the Piast variety (afila type). So, the mutual plant competition for light in the canopy was different. The magnetic stimulation of the seeds clearly decreased the 'drop-out' of plants from the canopy. Both the doses of magnetic field applied had a favourable effect, *ie* resulted in a decrease of plant losses during the vegetation period.

The course of weather conditions exerted a significant influence on the level of pea yield in the particular study years. A sufficient amount of precipitation and relatively high temperatures during the period of flowering in 2001 and 2002 favourably influenced pod formation and seed filling, so the yield obtained was higher than in 2000 when, in the same period, there was a water deficit in the soil. High mean 24 h temperatures and a moderate amount of precipitation during maturation contributed to the obtaining of seeds which were less affected by fungal diseases than in 2000 when weather conditions favoured the development of fungal diseases on the ripening seeds. The treatment of the

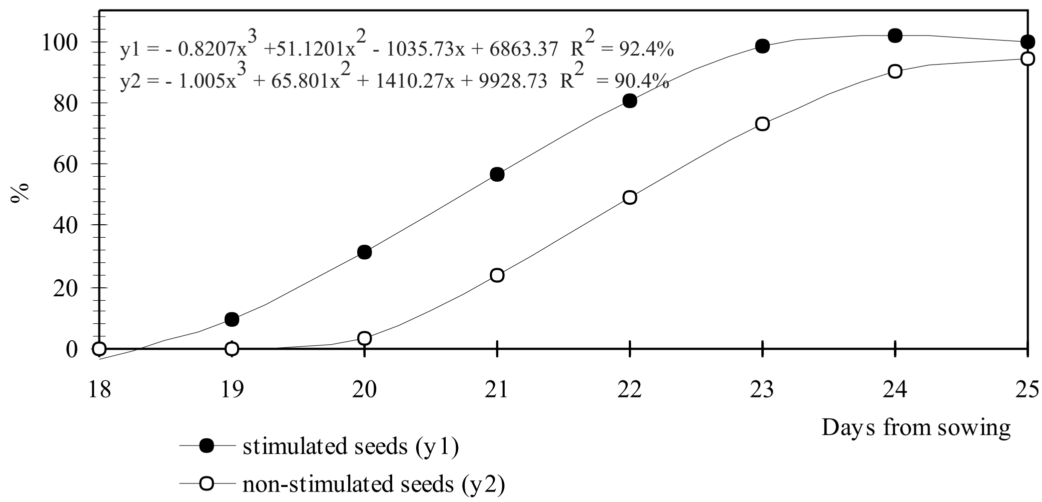

Fig. 1. Dynamics of pea emergence in field experiment conditions.

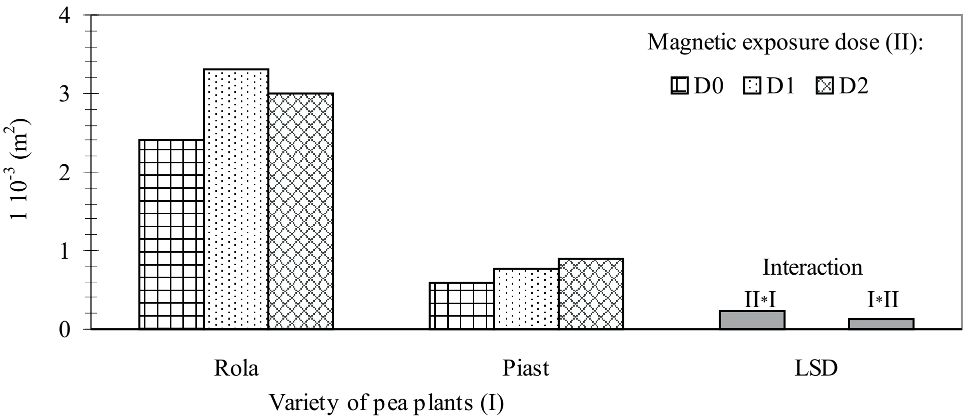

Fig. 2. Leaf area of pea plants grown from stimulated and control seeds.

T a b l e 2. Values of some morphological and functional features of pre-harvested pea plants

Description	Length of stem with pods (m)	Plant losses during vegetation (%)	Number of seeds per pods	Number of seeds per pods	Mass of 1000 seeds (g)
Magnetic exposure dose (II):					
D0	0.165a*	10.4a	3.3a	21.8a	261a
D1	0.204b	4.2b	3.1a	25.1b	263a
D2	0.199b	3.6c	3.3a	24.9b	264a
Standard error	0.0014	0.16	0.11	0.11	1.4
Variety (I):					
Rola	0.229a	9.2a	3.1a	24.8a	234a
Piast	0.164b	3.3b	3.2a	22.7b	292b
Standard error	0.0023	0.14	0.09	0.23	1.5

*values in columns marked with the same letters do not differ significantly.

sowing material of the two pea varieties favourably influenced the level of seed yield obtained, but the magnitude of this effect varied in the individual study years (Fig. 3). In each study year, there was a co-ordinated influence of the magnetic field exposure doses and the pea variety on the seed yield. Significant differences in the reaction of the pea varieties studied to the pre-sowing seed treatment with magnetic field were observed. In each study year, the afila-type Piast variety reacted more strongly to the pre-sowing seed stimulation than the leafy variety Rola. During the three years of the study, the increase in the seed yield of the two varieties, resulting from the pre-sowing seed stimulation, was on average 10.6 and 12.5%, respectively. Both the exposure doses of magnetic field, *ie* D1 and D2, favourably influenced the seed yield increase of the pea varieties studied, however, in 2000 the higher dose (D2) proved to be more favourable, while in 2001 and 2002 it was the lower dose (D1). The increase in the seed yield was the result of increased pod complement on the pea plants grown from biostimulated seeds (Fig. 4) and of lower plant losses from the canopy during vegetation.

Detailed plant measurements which were taken directly after harvest showed that the plants of the Piast variety grown from non-stimulated seeds had on average 6.4 pods and plants grown from the treated seeds 7.3 pods, and for the Rola variety these values were 7.4 and 8.2 pods, respectively. Each applied dose of magnetic field favourably influenced the pod complement on the plant in a similar degree for both varieties studied, but the lower dose (D1) gave slightly better effects than the higher dose (D2). No significant difference in the mean number of pods per plant in the individual study years was noted; hence the study results relating to this last feature have been presented as mean values for the three years.

A detailed analysis of the yield structure which were made after the harvest showed that the plants grown from stimulated seeds formed more seeds in comparison to plants grown from the non-treated ones (Table 2). The influence of magnetic field on the number of seeds per one pea plant was similar to the influence on the pod complement.

No influence of the treatment discussed on the number of seeds per pod and 1000 seeds weight was observed. Significant differences in relation to the number of seeds per pod and 1000 seeds weight were noted only between the pea varieties. The Rola pea variety formed more seeds than the plants of the Piast variety. However, the seeds of the Piast variety were characterized by a higher 1000 seeds weight (292 g) than the Rola variety (234 g).

Field observations showed an earlier maturation of plants grown from seeds treated with magnetic field, but clear differences in the course of other developmental phases, including flowering, were not observed. A lower water content in seeds, determined directly after their harvest (Table 3), was a confirmation of earlier plant drying.

Magnetic field had no influence on the degree of pea plant infestation with fungal diseases – differences were only related to the pea varieties studied. The afila type variety, Piast, was logged to a smaller degree and hence its seeds were healthier than the seeds of the traditional Rola variety. In the studies carried out, no significant influence of

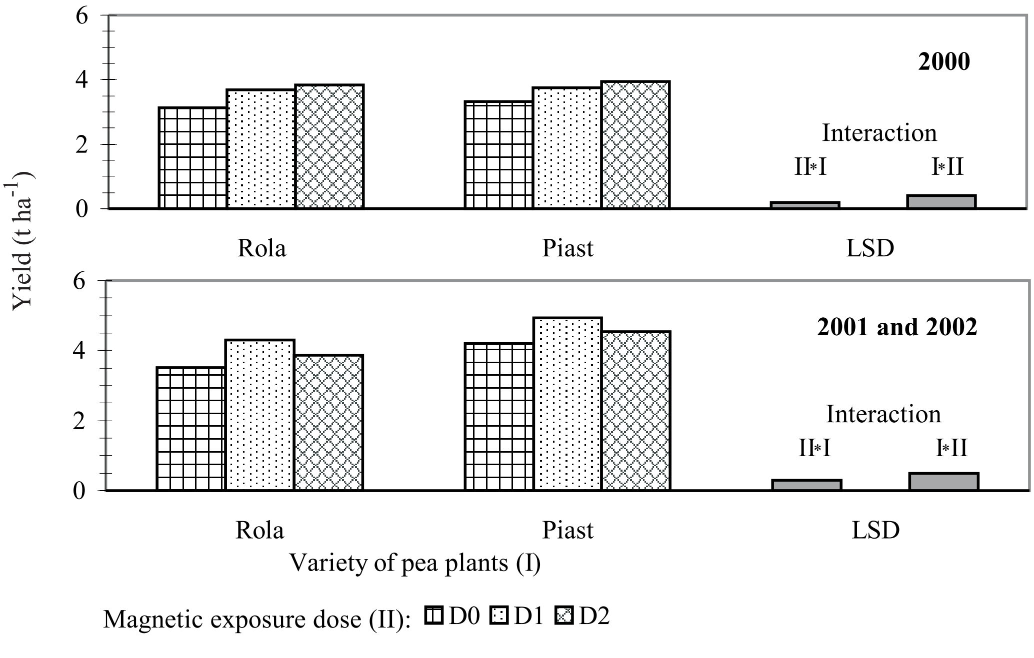

Fig. 3. Yield of pea seeds.

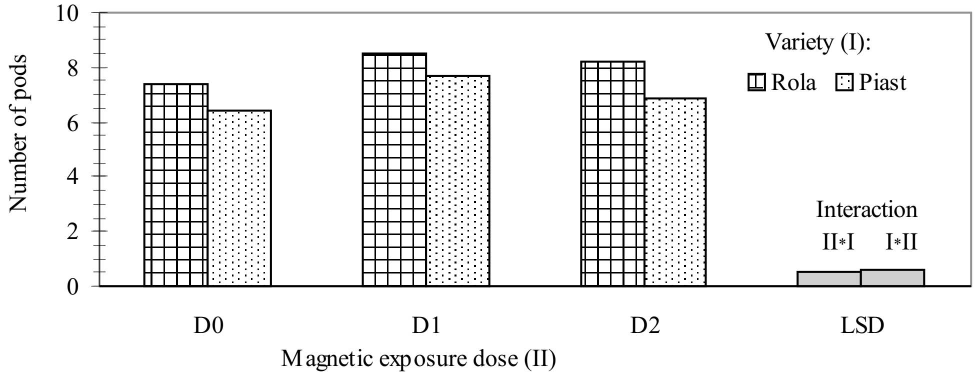

Fig. 4. Number of pods per plant.

T a b l e 3. Parameters of chemical analysis of pea seeds (means from 3 years)

Description	Moisture content of seeds at harvest (%)	Percent of plants infested by during vegetation	Protein content (%)	Fat content (%)
Magnetic exposure dose (II):				
D0	14.4a*	5.7a	21.4a	1.53a
D1	12.6b	6.2a	22.0a	1.59a
D2	12.8b	5.4a	21.5a	1.58a
Standard error	0.15	0.25	0.27	0.044
Variety (I):				
Rola	11.9a	2.1a	20.6a	1.74a
Piast	14.8b	8.3b	23.4b	1.22b
Standard error	0.23	0.13	0.29	0.018

*values in columns marked with the same letters do not differ significantly.

the pre-sowing seed treatment with magnetic field on the protein and fat content in the seeds was observed. Significant differences in the content of these elements occurred only in the pea sowing material.

DISCUSSION

In the field studies carried out, a favourable influence of the pre-sowing seed treatment with magnetic field on the emergence, growth and yield of pea plants was observed. The opinion that physical factors influence the initial growth and development of plants, especially plant sprouting and emergence, is predominant. In the field studies presented, an acceleration of emergence of the two pea varieties was observed. Moreover, emergence was more even and the seedlings grown were better formed. This showed the high usefulness of magnetic field in improving the sowing quality of pea seeds. An earlier sowing date and an increase in plant emergence due to the influence of magnetic field on the seeds of vegetables and cereals were also observed by Chao and Walker (1967), Hirota *et al*. (1999) and Pittman and Ormrod (1971).

The effects obtained in the present study, which were measured by the seed yield, ranged from 10 to 12% and were slightly lower than the results found in experiments with other varieties of cultivated plants. However, the obtained yield increase was very significant for the improvement of pea yielding because this species is characterised by low reliability and variation of yields in different years. The pre-sowing treatment of seeds with the magnetic field, as one of the physical methods for the improvement of sowing material quality, had a varied impact on pea yielding – better effects were obtained in 2000 than in 2001 and 2002. It showed a dependence between the effect of the treatment applied and the course of the weather conditions, which was suggested by Pittman (1977) in his studies on some cereal varieties.

It can be assumed that apart from the weather conditions, other factors, *eg* seed moisture level, influence sprouting and, later, the development of plants grown from seeds subjected to the influence of magnetic field. Pietruszewski (1999) observed better sprouting of spring wheat seeds which had been soaked in water before they were placed in magnetic field, in comparison to dry seeds. He explained this phenomenon by the higher mobility of ions in more humid seeds. Reports in domestic and foreign literature show that the seeds of cultivated plants react more strongly to the impact of physical factors when the optimum exposure dose has been applied (Gieroba *et al*., 1995); Inyushin *et al*., 1981; Phirke *et al*., 1996; Pietruszewski, 1999; Wilde *et al*., 1969). Small doses of the factor usually stimulate seed sprouting and further development, whereas big doses can sometimes cause mutations. Results of studies by Rybiński *et al*. (1993) on the application of laser light on barley proved that there exists a limit value of the energy dose up to which seed stimulation takes place; when this dose has been exceeded, mutations and a reduction of the morphological features and yield structure are observed. In the present studies, both doses of the magnetic field applied favourably influenced the size of the pea seed yield, but in the first study year, the higher exposure dose of magnetic field proved to be better, and in the following year, the lower dose was better. It follows from the studies of Phirke *et al*. (1996) and Pietruszewski (1999) that the exposure dose of magnetic field exerts a big influence on the course of growth, development and yielding of some cereal plants. An increase in the pea yield in the present study resulted from a higher number of pods per plant and lower plant losses from the surface unit during vegetation. These results have been confirmed by the studies of Gurusama and Kalavathi (1998) which showed an increase in the number of pods per plant of cowpea grown from seeds pre-treated with magnetic field before sowing.

In the experiments presented, differences in height between the plants grown from seeds treated and not treated with magnetic field were observed. These differences were not very big or especially visible during the period of the main shoot flowering. The magnetic field modified the height of the pea more in the case of the Piast variety than of the Rola variety. It can be generally assumed that plants grown from stimulated seeds are taller than plants grown from the control seeds. The literature data does not point to any unambiguous influence of magnetic stimulation of seeds on the height of plants grown from them. Remarks on a quicker height increase of plants grown from seeds subjected to magnetic field in comparison to the control object could also be found. However, they concern mainly the initial stages of plant development (Alexander and Doijode, 1995).

In the studies carried out, no significant influence of seed magnetic stimulation on the acceleration of plant flowering was observed. It can probably be attributed to difficulties in carrying out these types of observations in field conditions where a lot of other factors, like weather conditions, exerted an influence on the course of plant growth and development. However, a few days' acceleration of pea maturation was observed. Data from literature confirm accelerated plant maturation due to the impact of some physical factors on the sowing material. For example, Boe and Solunkhe (1963) showed earlier maturation of tomatoes, and Pittman (1977) an acceleration of the maturation of some varieties of cereals grown from seeds pre-treated with magnetic field before sowing. A disturbance in the 'biological clock' manifested in accelerated flowering of maize plants and their earlier maturation was observed by Gieroba *et al*. (1995) in their studies on laser stimulation of maize seeds.

The chemical analysis of pea seeds after harvest did not show any significant influence of magnetic field on the content of fat and protein. Literature provides data showing favourable influence of some physical factors on the quality of harvested yield. For example, studies carried out in recent years by Pietruszewski (1999) and Pietruszewski and Wójcik (2000) showed an increase in the sugar content of sugar beet roots and gluten in the wheat kernels grown from eeds subjected to the pre-sowing stimulation with magnetic field. It cannot be excluded that magnetic field exerts an influence only on the chemical composition of seeds in some plant species. There were only a few studies which were carried out on this latter problem, but their results are ambiguous.

CONCLUSIONS

1. The magnetic stimulation of seeds favourably influenced the sprouting and emergence of both pea varieties, Rola and Piast. As a result of the application of this treatment, plant emergence was more uniform and took place 2-3 days earlier than the emergence of plants in the control object.

2. The exposure doses of magnetic field applied positively influenced the development and growth of the pea plants studied. Pea seedlings grown from seeds treated with magnetic field were better formed and the plants grown from them produced a temporarily bigger leaf surface.

3. The pre-sowing treatment of pea seeds with magnetic field produced a significant increase in the seed yield. The efficiency of the treatment applied was different in the individual years of study – a bigger dose (D2) gave better effects in the year 2000, and a lower dose in 2001 and 2002, which points to the fact that the effect of this treatment depends on the course of the weather conditions.

4. An increase in the seed yield due to the pre-sowing stimulation of the sowing material with magnetic field resulted, in the case of both the pea varieties studied, from a bigger pod complement and lower plants losses from the surface unit during vegetation.

5. There were no significant differences in the course of most developmental phases of plants grown from the stimulated and not stimulated seeds. The observed phenomenon was only a few days' acceleration of plant maturation in the case of plants grown from seeds treated with the magnetic field in comparison to the plants from the control objects.

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