THE IMPACT OF A PULSED ELECTROMAGNETIC FIELD ON THE SEED PROTEIN CONTENT OF SOYBEAN

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Abstract: Many studies show that in the last 20 years, the increase in production per hectare has been achieved mainly due to the creation of new varieties and the development of plant breeding. Innovations in plant breeding are the main way to find new traits, values and tolerances, which are the only ones that can respond to the increased demand for yield and more efficient production. In addition to high and stable yields, it is very important that the soybean seed has a satisfactory technological quality. Therefore, the aim of this study was to examine how the application of pulsed electromagnetic fields (PEMFs) affected the protein yield of soybean seed depending on the year, exposure time and frequency. The field trials were conducted in the experimental field of the Institute of Field and Vegetable Crops in Novi Sad, Serbia in 2010–2013. For this research, the seeds of a medium-sized variety Valjevka exposed to a pulsed electromagnetic field (PEMF) using a pulse generator and a strip applicator were used. A low frequency pulsed electromagnetic field (16, 24, 30, 72 Hz) was used at the exposure times of 0, 30, 60, and 90 minutes. The results of the research show that the application of this method can increase the yield of protein in soybean seed for more than 20%, which is a significant increase, especially in organic production, where the use of seed treatment agents is very restricted. However, this measure can also have an inhibitory effect if an adverse combination of exposure time and frequency strength is selected.

Key words: proteins, pulsed electromagnetic field, soybeans.

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Introduction

The magnetic field as an active factor in agriculture has more than 50-year history. Important applied investigations were made in Russia, whose results were the creation of technological lines of magnetic systems for pre-processing vegetative planting seeds (Ivanovich et al., 2013). Krilov and Tarakonova (1960) were among the first investigators to report the effect of magnetic field on plants. They found that their effect was similar to auxin in the seed germination process. Today, the magnetic field is an ecological technique used in sustainable agriculture, which has a little environmental impact, while contributing to an increased yield of cultivated plants (Bilalis et al., 2013). This has a better influence on seed germination (Djukic et al., 2017), absorption and assimilation of nutrients by plants (Bilalis et al., 2013), photosynthetic activity (Shine et al., 2011), enzymatic activity (Ramakrishna and Kumari, 2012) and in the second place ultimately aims to increase the yield of cultivated plants (Shine et al., 2011). Soybean is a crop of great world importance due to the widespread use of its products and their economic value (Filho et al., 2004). Seed protein and oil content are the two main seed quality traits in soybean. Soybean contains 40 to 42% of good quality protein and approximately 20 to 22% of oil, expressed on a dry matter basis (Bhangu and Virk, 2019).

Therefore, the aim of the study was to investigate the influence of pulsed yield electromagnetic fields on the protein content of soybean and whether their effect depended on the weather conditions during vegetation.

Materials and Methods

Weather conditions

In 2010, the lowest temperatures (18.4°C) and the highest rainfall were (684.4 mm) recorded during the soybean vegetation period with a favorable monthly distribution (Table 1). The year of 2011 was characterized by increased temperatures during the vegetation period (19.4°C), especially in August (23.1°C) and September (20.4°C), and with the least amount of precipitation (210.5 mm), as well as a marked deficiency in August (1.5 mm). In 2012, the highest average temperatures were recorded during the soybean vegetation period (20.5°C), with very high middle temperatures in May (17.5°C), June (23.0 °C), July (25.2°C), August (24.6°C) and September (19.8°C). There were 226.8 mm of rainfall during the soybean vegetation period this year, with very low amounts in June (27.5 mm) and August (3.5 mm). The average temperature in 2013 was 18.7°C and the precipitation amount was 448.2 mm, with pronounced deficiencies in July (34.1 mm) and August (26.7 mm).

Table 1. Average monthly temperatures and precipitation during the vegetation period of soybean (2010–2013).

Month	Average monthly temperatures (°C)				Precipitation (mm)			
	2010	2011	2012	2013	2010	2011	2012	2013
IV	12.3	13.2	13.0	13.4	63.7	22.8	82.8	35.8
V	16.9	16.8	17.5	17.4	113.7	62.4	52.2	118.1
VI	20.2	20.9	23.0	20.2	171.8	36.9	27.5	125.7
VII	23.1	22.1	25.2	22.3	99.0	61.5	47.7	34.1
VIII	21.9	23.1	24.6	22.8	168.5	1.5	3.5	26.7
IX	16.1	20.4	19.8	15.7	67.7	25.4	13.1	107.8
Average	18.4	19.4	20.5	18.7	684.4	210.5	226.8	448.2

Plant materials

In order to determine PEMF of soybean seed protein content, the field trials were conducted during four growing seasons (2010, 2011, 2012 and 2013) at the Rimski Šančevi experimental field (45°20′ N 19°51′ E) near Novi Sad, Serbia. The plant material used in this experiment was the medium early cultivar of soybean Valjevka. The trial was conducted on the humus soil type as a randomized block design with four replications under the conditions of dry farming. The plot size was 10 m^2. The inter-row spacing of 50 cm and the intra-row spacing of 5 cm were applied. There were no significant disease and insect attacks. The seed was exposed to a pulsed electromagnetic field (PEMF) using the impulse generator and strip. Low frequencies (16, 24, 30 and 72 Hz) of PEMF lasting for 0, 30, 60 and 90 minutes were used. Immediately after the seed exposure to the PEMF, sowing was carried out at the optimum time. After sprouting, seedlings were counted to determine the percentage of germinated seeds. Standard soybean cultivation practices were applied during the vegetation period. Harvesting was performed at the technological maturity stage. Samples and moisture were measured using a combine harvester for experimental plots with a small work operation (Wintersteiger elite), and yield was calculated at 14% moisture.

Protein yield was calculated based on the yield and protein content of the seed. The yield of soybean seeds obtained is expressed in kg ha^{-1} at 14% moisture. Protein content in the same seed was determined by the NMR method, according to Granlund and Zimmerman (1975). Protein yield was calculated as the product of the seed yield and protein content.

Statistical analysis

The experimental data were analyzed using the software STATISTICA 10, according to the completely randomized design. Analysis of variance (ANOVA) and comparisons of means were calculated using the least significant difference (LSD) test, at the 5% level of significance. Also, the correlation between the tested traits was determined.

Results and Discussion

The effect of PEMF on soybean seed protein content depended on the year (A), duration of exposure (B) and frequency (C), and year-by-duration of exposure interaction (A × B), year-by-frequency interaction (A × C) and exposure interaction-by-frequency interaction (B × C), as shown in Table 2.

Table 2. The effect of a pulsed electromagnetic field (PEMF) on protein yield in soybean seed (kg/ha).

Years A	Time B (min)	Frequency C (Hz)				Average AxB	Average A
		16	24	30	72		
2010	0	1464.2	1464.2	1464.2	1464.2	1464.20[c]	
	30	1830.3	1491.9	1433.9	1466.7	1555.70[ab]	
	60	1439.3	1778.3	1691.4	1509.0	1604.49[a]	1539.36
	90	1551.6	1731.1	1451.1	1398.4	1533.03[b]	
	Average AxC	1571.34[b]	1616.37[a]	1510.14[c]	1459.58[d]		
2011	0	1413.4	1413.4	1413.4	1413.4	1413.42[a]	
	30	1582.9	1427.0	1379.8	1419.8	1452.36[a]	
	60	1387.3	1544.4	1434.5	1455.6	1455.44[a]	1435.50
	90	1474.1	1548.7	1378.8	1281.5	1420.77[a]	
	Average AxC	1464.42[ab]	1483.39[a]	1401.62[b]	1392.56[bc]		
2012	0	908.5	908.5	908.5	908.5	908.54[b]	
	30	1078.6	941.5	895.4	917.9	958.35[ab]	
	60	926.5	1038.4	1022.7	995.7	995.85[a]	953.43
	90	1017.0	1050.5	891.0	845.4	950.97[ab]	
	Average AxC	982.66[a]	984.74[a]	929.42[b]	916.90[b]		
2013	0	1342.7	1342.7	1342.7	1342.7	1342.66[bc]	
	30	1482.7	1423.2	1300.5	1433.1	1409.86[b]	
	60	1387.3	1486.8	1476.0	1435.0	1446.29[a]	1391.31
	90	1456.8	1481.2	1298.6	1228.9	1366.41[bc]	
	Average AxC	1417.37[a]	1433.47[a]	1354.45[b]	1359.93[b]		
Average B*C	0	1282.21	1282.21	1282.21	1282.21	Average B	1282.21
	30	1493.60	1320.92	1252.38	1309.38		1344.07
	60	1285.10	1461.96	1406.16	1348.84		1375.52
	90	1374.86	1452.87	1254.89	1188.56		1317.80
	Average C	1358.94	1379.49	1298.91	1282.24		

Factory	Year (A)	Time (B)	Frequency (C)	AxB	AxC	BxC
	**	**	**	**	**	**

Factors	2010		2011		2012		2013	
	LSD$_{0.05}$	LSD$_{0.01}$	LSD$_{0.05}$	LSD$_{0.01}$	LSD$_{0.05}$	LSD$_{0.01}$	LSD$_{0.05}$	LSD$_{0.01}$
AxB	67.76	97.34	93.58	109.50	72.02	97.26	80.82	95.55
AxC	44.415	55.920	69.80	83.14	57.29	79.78	55.86	67.86

** – significance at 0.01, * – significance at 0.05, - ns (no significance) probability level.

Soybean meal is the most commonly used source of protein for poultry and swine feeds in the world, with 67% of the animal feed market (Pettigrew et al., 2002). In order for a feed ingredient to be considered an important component of an industry feeding program, it must have several fundamental qualities, and above all, it must contain a high proportion of protein. Therefore, the aim of breeding not only soybean but also other plants from the *Fabaceae* family is to produce varieties with the highest protein content in the grain (Jayalakshmi et al., 2018). Applied production technology also has an impact on the chemical composition of the grain (Dekhane et al., 2011; Kang et al., 2012). Various methods have been used to increase protein content. One of them is using the electromagnetic field (Crnobarac et al., 2002). The effect of PEMF on protein yield in soybean depended on year, exposure time, and frequency. The application of PEMF led to increasing the protein yield by 2.89–8.77%. The best effect was achieved in 2012. This year was characterized by water deficit and high temperatures at critical stages for soybean development. The beneficial effects of the electromagnetic field, especially in poor agro-meteorological conditions, can be attributed to their influence in increasing the root volume and surface area, which allows the crop to utilize more moisture during periods of active growth when water is often a limiting factor for successful crop production. Therefore, the seed treatment using the electromagnetic field before sowing can be considered as a pre-sowing measure in reducing the effect of water deficit in arid and semi-arid regions, thereby helping to increase production. Increases in root volume and surface area can reach up to 70% and 65% respectively, allowing the crop utilization for more than 60% of moisture during periods of active growth (Mridha and Nagarajan, 2014). In addition to agro-meteorological conditions, the success of this method depends on the exposure time and the frequency applied. The best results were obtained at the 60-min exposure time. On average, during investigation years, protein yield increased by 6.78% over a 60-minute exposure period, by 4.08% over a 90-minute exposure period, and by 2.18% over the 30-minute exposure time compared to the control. In terms of frequency, at the lowest frequency value of 16 Hz, the average increased the protein yield by 7.39% during the investigation years. With increasing radiation intensity at 24 Hz, the protein yield increased by 9.19%. A similar result was observed in the example of maize (Muraji et al., 1998). The best results were achieved with low frequencies, 10 and 20 Hz, respectively. Wang et al. (2006) concluded that low frequencies have the best impact on plant growth and development because they increase the intake of N, P, K and Mg chemical elements. Nitrogen can increase plant tolerance at high temperatures and water deficit. Potassium affects the water regime of plants while magnesium plays an important role in regulating protein biosynthesis. In the example of insufficient magnesium, the proportion of non-protein nitrogen compounds increases at the expense of the protein (Kastori et al., 1979). A further increase in the PEMF

frequency led to a sudden decrease in yield, so that at 72 Hz, there was no effect at all. However, for the successful application of this method, it is of great importance to find the right combination of the exposure time and frequency. In soybean studies, on average, the best combination was 16 Hz*30 minutes, increasing the yield by 14.15%. Marinkovic et al. (2006) point out that, in addition to the activation of the enzyme complex, electromagnetic rays have a beneficial effect on the structure of free water molecules and on the overcoming resistance in the transport of energy and matter in the plant. In this case, energy savings are achieved and the intensity of decomposition of the produced organic matter is reduced, which increases the yield and improves the quality of the plant products.

Observing the investigation, it can be established that the strongest linear dependence was determined at the frequency of 24 Hz, which means that with increasing the time of soybean seed exposure, this frequency achieved a favorable effect on protein yield (Figures 1, 2, 3, and 4).
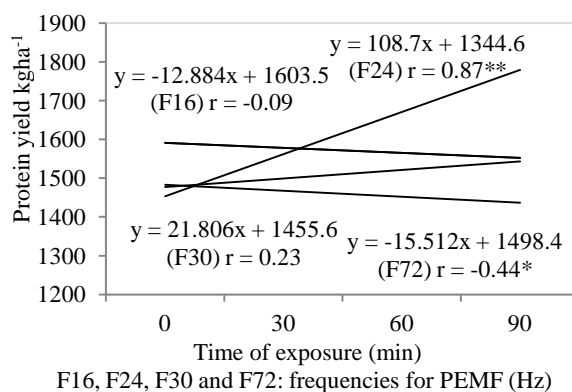
Figure 1. The effect of PEMF on soybean protein yield in 2010.
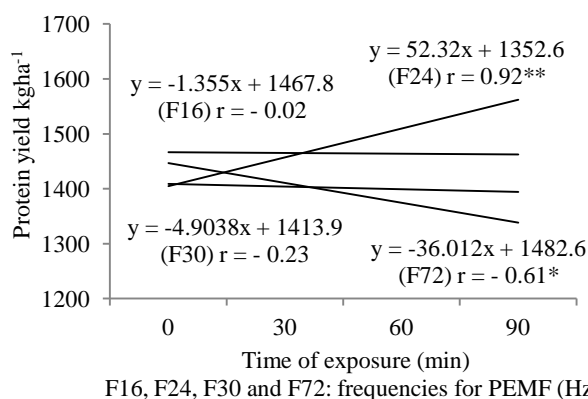

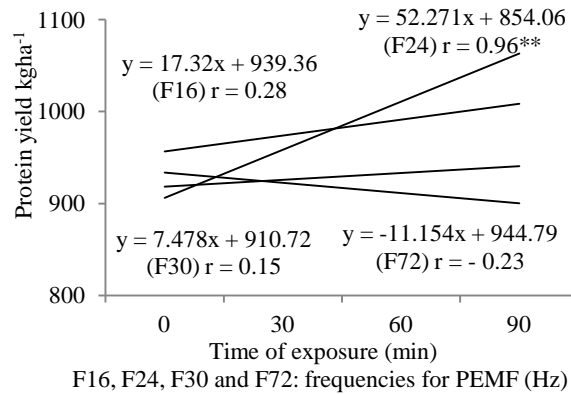Figure 2. The effect of PEMF on soybean protein yield in 2011.

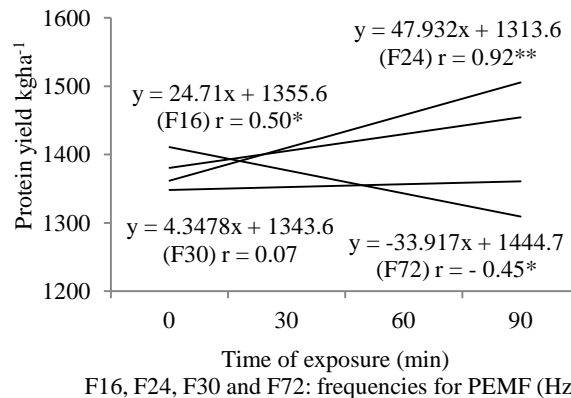Figure 3. The effect of PEMF on soybean protein yield in 2012.

Figure 4. The effect of PEMF on soybean protein yield in 2013.

The value of the correlation coefficient ranged from 0.87 to 0.96, which means that with increasing the exposure time at this frequency, the protein yield increased significantly. In 2012 and in the year with the most unfavorable agro-ecological conditions, the highest linear dependence ($r^2 = 0.96$) was achieved, while in 2013 and in the year with the best agro-ecological conditions, the highest negative linear dependence ($r^2 = -0,45$) was achieved. Failure to choose the right combination can result in a significant decrease in yield. With a combination of 72 Hz*90 min, the protein yield was reduced by 7.88%. Djukic et al. (2017) point out that the application of PEMP, in addition to the positive, can have an inhibitory effect if a favorable combination of the exposure time and frequency strength is not chosen. Attention must also be paid to the trait of the plant being observed. For example, regarding soybean, it was found that the combination of 16 Hz*30 min had the best effect on seed germination, while the best effect was obtained by using the combination of 24 Hz*30 min.

Conclusion

The results show that the use of the pulsed electromagnetic field as a pre-sowing treatment can increase the yield of protein in soybean. This is a good basis for this measure to be used, especially in organic production, where the use of seed treatments is very restricted. However, in addition to its positive impact, this measure can also have an inhibitory effect resulting in decreasing the yield.

Acknowledgements

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UTICAJ PULSIRAJUĆEG ELEKTROMAGNETNOG POLJA NA SADRŽAJ PROTEINA U SEMENU SOJE

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R e z i m e

Mnoga istraživanja pokazuju da se u poslednjih 20 godina povećanje proizvodnje po hektaru ostvaruje uglavnom zahvaljujući stvaranju novih sorti i razvoju oplemenjivanja biljaka. Inovacije u oplemenjivanju biljaka su glavni put za iznalaženje novih osobina, vrednosti i tolerantnosti, koje jedine mogu da odgovore povećanom zahtevu za prinosom i efikasnijom proizvodnjom. Osim visokih i stabilnih prinosa, veoma je važno da seme soje poseduje i zadovoljavajući tehnološki kvalitet. Zbog toga je cilj ovog istraživanja bio da se ispita kako primena pulsirajućeg elektromagnetnog polja (PEMP) deluje na sadržaj proteina u semenu soje u zavisnosti od godine, vremena trajanja ekspozicije i jačine frekvencije. Poljski ogled je izveden na eksperimentalnom polju Instituta za ratarstvo i povrtarstvo u Novom Sadu u periodu od 2010. do 2013. godine. Za ovo istraživanje korišćeno je seme srednjerane sorte Valjevka koje je izlagano pulsirajućem elektromagnetnom polju (PEMP) pomoću generatora impulsa i trakastog aplikatora. Korišćeno je pulsirajuće elektromagnetno polje niskih frekvencija (16, 24, 30, 72 Hz) u vremenu ekspozicije od 0, 30, 60 i 90 minuta. Rezultati istraživanja pokazuju da primena ove metode može povećati prinos proteina u semenu soje do 20%, što predstavlja značajno povećanje i dobru osnovu da se ova mera počne koristiti, pre svega u organskoj proizvodnji, gde je primena sredstava za tretiranje semena veoma ograničena međutim, ova mera može imati i inhibitorni efekat ako se izabere nepovoljna kombinacija vremena ekspozicije i jačine frekvencije.

Ključne reči: proteini, pulsirajuće elektromagnetno polje, soja.

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