Research Article

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Influence of the Static Magnetic Field and Algal Extract on the Germination of Soybean Seeds

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Abstract: This study examines the effect of a separate static magnetic field (SMF) and algal extract and their synergistic effect on soybean seeds germination. To our knowledge, this is the first time these kinds of factors were used for the biostimulation of soybean seeds germination. Soybean – *Glycine max* (L.) Merrill variety ‘Merlin’ was used in the present study. The exposure of seeds to the magnetic field was applied for 3, 6 and 12 min. The algal extract, produced from a freshwater green macroalga – *Cladophora glomerata* using an ultrasonic homogenizer, was used directly to the paper substrate at a dose of 10%. The highest germination ability of soybean seeds was observed in a group, where the magnetic field (12 min.) was used together with 10% of algal extract. However, it was very low – only 21%, which may have resulted from the seed dormancy. Future experiments on soybean seeds are required to confirm the stimulation effect of the magnetic field (various induction values) and algal extract on seeds germination.

Keywords: soybean seeds; germination; static magnetic field; algal extract.

1 Introduction

The soybean plant *Glycine max* (L.) Merrill is a species of legume that produces pods containing beans. Current soybean cultivars are phenotypically distinct from their wild relative *Glycine soja* due to the selection pressures occurring over thousands of years of agricultural production [1] and ongoing plant breeding efforts [2]. The fresh beans from green pods can be eaten as a vegetable, and dry mature seeds are used not only in animal feed and human foods that contain soybean oil or meal, but also in industry (solvents, lubricants, inks, plastics, waxes, etc.) [3]. The market value of soybean stems largely from the significant oil and protein content of its seeds which accounts for approximately 40% and 20% of total dry weight, respectively, giving the seeds appreciable versatility [4,5]. Because of these attributes, soybean accounts for a significant amount of the world’s vegetable oil, animal fodder and food for human consumption [6,7]. Both breeding programs and genetic modification efforts are used for the purpose of creating specialized soybean lines [8–10]. But plant breeding and seed industry is a crucial segment in today’s modern economy of agribusiness. It is not only responsible for producing part of the agricultural production, but also affects its efficiency [11]. Additionally, farmers have been becoming more noticeably aware of the benefits and profits resulting from the use of high quality seeds [12].

Additional treatments to improve the quality of seeds are sought as they are an important means of production and their quality has an impact on agrotechnics which determines, to a large extent, the profitability of each crop.. The process of seed conditioning involves the hydration of seeds under strictly controlled conditions which to a degree allows them to stimulate their metabolic activity, but insufficient to initiate the growth of the embryo and the penetration of the seed coat through the germinal axis. After the conditioning treatment, the seeds are dried to the initial water content. Seeds prepared in this way may be stored and/or used as seed. As a result, the
conditioning improves the vitality of the seeds, which results in achieving improved effects during germination (increase in germination rate, T50 (reduced time taken to 50% germination) time reduction, increase in percentage of sprouted seeds, uniformity of germination) and seedling growth, especially under suboptimal environmental conditions. While normal seedlings further develop into full plants that grow in soil under favorable conditions, abnormal seedlings, classified as deformed, dwarf, albinotic, disproportionate rotten due to primary infection do not show the ability to develop into a normal plant (growing in soil under favorable conditions), which finally results in low yields [13]. Hence, it is necessary to find new methods, to enhance germination ability of seeds.

The soybean was used as a model plant because today it is considered an important crop which is cultivated worldwide because of its high protein and fat content and also other nutritional values. What is more, the world population is increasing and a sufficient supply of food is a fundamental issue for both the world and each individual country. Hence, a sufficient supply of sustainable food is essential. In order to increase the germination of soybean seeds, two factors were used – static magnetic field (SMF) and algal extract.

The exact mechanism behind the observable magnetically induced changes has not yet been fully explained although the research on the magnetic field’s influence on living organisms has been conducted for almost one hundred years. Krylov and Tarakonova were among the first scholars who described the influence of the magnetic field (MF) on plants [14]. They proposed the auxin-like effect of SMF on germinating seeds, calling this effect magnetotropism (SMF is a special case of MF). It has also been suggested that the auxin SMFs explain tomato ripening [15]. There is evidence that the response to root growth was not heliotropic, but rather magnetotropic or geotrophic. Observation of the roots of many other plants suggested that some innate factor within the species, and even within one species may also be necessary before tropism emerged [16,17]. Due to an insufficient understanding of the biological effects of the MF and its mechanism, the magnetic field is relatively rarely described as a controlled factor for a scientific experiment.

Numerous hypotheses that attempt to explain the influence of the MF on changes in biochemical processes in cells have been developed. Some of them indicate, for example, the influence of the field on the ions of ferromagnetic elements found in the prosthetic groups of electron transport chain enzymes (e.g. some cytochromes) or enzymes involved in the H₂O₂ decomposition (catalases, peroxidases). Other researchers suggest changes in the functioning of whole protein structures and even tissues [18]. Many authors present hypotheses regarding changes caused by physical phenomena induced by MF, for example changes in liquid crystal properties (cell membranes exhibit many properties of liquid crystal structures), as well as Hall, Dorfman and Ettinghausen effects [19–24]. Furthermore, water treated with the MF changes its physicochemical properties, and this may influence the course of some biochemical reactions [25–31]. Even such a very simplified summary of hypothetical explanations of the magnetic biostimulation mechanisms of plant cells shows how complex this phenomenon is.

Most scientific papers conclude that the MF has a positive effect on better germination and plant growth, as well as on yield increase [32–38]. However, these works usually come down to the economic calculation. Response of plant organisms to the magnetic field was varied [39–41]. This answer depended not only on the plant species, but also on the time of exposure, intensity and nature of the MF used in the experiment. The exposure dose depends on two parameters: magnetic field density and exposure time. The density of magnetic field or electric field (ρ) is determined by the following formula:

\[ \rho = \frac{1}{2} \varepsilon_0 E^2 = \frac{1}{2} \mu_0 H^2 = \frac{1}{2} \mu_0 B^2 \]

where: \( \varepsilon_0 \) – vacuum permittivity [F/m; F · Farad (SI)], \( \mu_0 \) – vacuum permeability [H/m; H · Henr (SI)], \( E \) – electric field intensity [V/m], \( H \) – magnetic field intensity [A/m], \( B \) – magnetic induction [T].

The exposure dose (D) can be described using the following formula:

\[ D = \rho t \]

where: \( t \) – exposure time [s] [21, 42].

The MF is usually measured in terms of magnetic induction B, whose unit is given in Tesla [T], defined as:

\[ 1T = 1\frac{V \cdot s}{m^2} = 1\frac{Wb}{m^2} = 1\frac{N \cdot s}{C \cdot m} \]

where: \( V \) – volts, \( s \) – second, \( m \) – meter, \( N \) – newton, \( C \) – coulomb, \( Wb \) – Weber, dimension of “magnetic flux” in SI units [41].

The second factor, examined in the present study – algal extract was used as a biostimulant of plant growth. According to our knowledge, algal extracts produced from freshwater macroalgae have not been studied so far as...
biostimulants of plant growth. The biomass of freshwater *Cladophora glomerata* is a rich source of primary and secondary metabolites, such as amino acids and proteins, carbohydrates, carotenoids, minerals, vitamins, fatty acids, sterols, terpenes etc.\([43, 44]\). These compounds can be useful in the stimulation of plant growth. According to du Jardin\([45]\), algal extracts belong to the main categories of plant biostimulants, among others such as: humic and fulvic acids, protein hydrolysates and other n-containing compounds, chitosan and other biopolymers, inorganic compounds, beneficial fungi and beneficial bacteria. Seaweed extracts are known for their plant growth-promoting effects and moreover, they ameliorate the crop tolerance to the biotic and abiotic stress (nutrient deficiency, salinity, extreme temperatures, drought, etc.)\([46]\). The effects of seaweed extracts on crops (e.g., increased germination, plant nutrient uptake, chlorophyll content, antioxidant activity, phytohormone-like activity, yield etc.) was presented in detail in several reviews, e.g., \([46–48]\).

The purpose of this work was to test the effect of – static magnetic field and algal extract on the germination ability of soybean seeds and the uniform emergence of seedlings.

## 2 Materials and Methods

### 2.1 Soybean seeds

Soybean seeds *Glycine max* (L.) Merrill, cv. Merlin, (not genetically modified), were used in the present study. The origin of the seed material was obtained from an Austrian plant breeding station.

### 2.2 Freshwater macroalga

*Cladophora glomerata* – a freshwater macroalga was collected from the surface of the pond in Tomaszówek, Łódź Province, Poland (51°27′21″N 20°07′43″E) in October 2016. No specific permissions were required for this location/activity. The study was carried out on a private land, and the owner of the land gave permission to conduct the study. This study did not involve endangered or protected species. Then, the air-dried biomass was milled using a grinding mill (Retsch GM300, Haan, Germany). For the production of the algal extract, the biomass with the particle size lower than 400 µm (sieve analysis) was chosen \([49]\).

### 2.3 Production of the algal extract

The algal extract (E) was produced with the use of water as a solvent as it is safe for plants. Dry algal biomass (4 g) was mixed with 100 mL of distilled water, and the mixture was subjected to the ultrasound homogenizer (UP 50H; Hielscher Ultrasonics, Teltow, Germany) for 30 min. (50 watts, ultrasonic frequency 30 kHz, amplitude 100%). The beaker with algae and water during extraction with ultrasound was kept in a cold water tank. Then, the mixture was centrifuged (4000 rpm, 10 min.), and the supernatant was treated as a 100% algal extract. For the germination experiments, a concentration of 10% (E10%) was chosen, which was prepared by adding distilled water (on the basis of literature \([50,51]\)).

### 2.4 Physicochemical analysis of algal extract

The color of *C. glomerata* extract was evaluated visually. The pH of 10% algal extract was measured with a pH meter Mettler-Toledo (Seven Multi; Greifensee, Switzerland) equipped with an electrode InLab413 with temperature gauge, whereas the electrical conductivity (EC) used the conductivity meter CPC-505 (Elmetron; Zabrze, Poland). The measurements were performed in three replications. The multielemental analysis of 10% algal extract was performed using the ICP-OES technique (Inductively Coupled Plasma – Optical Emission Spectrometry) in the Chemical Laboratory of Multielemental Analysis at the Wrocław University of Science and Technology, accredited by International Laboratory Accreditation Cooperation Mutual Recognition Arrangement and Polish Centre for Accreditation (No AB 696).

### 2.5 The application of static magnetic field on soybean seeds

Generally, the magnetic field (MF) in literature is regarded as being friendly to the environment and humans; it improves seeds vigor, yield and tolerance to adverse environmental conditions. The positive effect of biostimulation with a static magnetic field depends on a minimum of two parameters: magnetic field intensity and exposure time. The prepared experiment will allow to verify the preliminary research hypothesis that the use of a SMF of moderate intensity will have a significant impact on the germination capacity of soybean seeds. In this research, a permanent magnet was used for presowing stimulation of soybean seeds. The induction of the
The magnetic field was 400 mT. The exposure time was 3, 6 and 12 min.

2.6 Germination tests

The germination test of soybean seeds was assessed according to the International Seed Testing Association (ISTA). A paper substrate was used to conduct the germination experiment which was carried out in 4 replications. One replication consisted of 100 soybean seeds. In the groups treated with the extract, a 10% algal solution (120 mL per each replication) was added directly to the paper substrate before soybean seeds were sown. The first counting of seedlings was conducted after 5 days and the second one after 8 days. The seedlings were stored in a growth chamber at a constant temperature of 25°C (Figure 1).

After 8 days, soybean seedlings were extracted from a paper substrate and then divided into two groups – normal and abnormal ones according to ISTA demands.

The germination ability was assessed and given in percentage. The minimum germination requirement according to ISTA demands is 80%. Soybean germination is referred to as epigeal because food storage structures (cotyledons) are pulled above the soil surface. Usually the differences between well-developed and abnormal seedlings are connected with the lack of chlorophyll (albinotic seedling), dwarfism, rotten due to primary infection, an irregular hypocotyl shape or its different defects. Abnormal seedlings simply do not show the ability to develop into a normal plant (growing in soil under favorable conditions).

Present research tested the following groups:

1. Control group – C (N=4)
2. SMF 3 (3 min.) (N=4)
3. SMF 6 (6 min.) (N=4)
4. SMF 12 (12 min.) (N=4)
5. SMF 3 (3 min.) + E10% – SMF 3-E10% (N=4)
6. SMF 6 (6 min.) + E10% – SMF 6-E10% (N=4)
7. SMF 12 (12 min.) + E10% – SMF 12-E10% (N=4)
8. E10% (N=4)

2.7 Statistical analysis

Results were elaborated statistically by Statistica ver. 12.0 StatSoft (Tulsa, OK, USA). Descriptive statistics (average, standard deviations) for all experimental groups was performed. The normality of the distribution of experimental results was assessed by the Shapiro–Wilk test and the homogeneity of variances by the Brown and Forsythe test. The differences between groups were determined with the one-way analysis of variance (ANOVA) using the Tukey multiple comparison test (for normal distribution and the homogeneity of variances). The results were considered significantly different when p<0.05.

Ethical approval: The conducted research is not related to either human or animal use.
3 Results and Discussion

The effectiveness of the applied conditioning methods (SMF, algal extracts and their combination) was assessed on the basis of the following results (1) germination ability and (2) the number of normal and abnormal soybean seedlings. In the present study we tested, which applied factors (SMF or algal extract or their both combination) had a more beneficial effect on the germination ability of soybean seeds. It should be also emphasized that we did not work on genetically modified seeds as there is a strict ban on GMO plants in Poland and in most European countries. This is an important stance from the viewpoint of humans and the environment. The biggest threat caused by GM foods is that they can have harmful effects on the human body. It is believed that consumption of these genetically engineered foods can cause the development of diseases which are immune to antibiotics. Besides, as these foods are new inventions, not much is known about their long term effects on human beings. As the health effects are unknown, many people prefer to stay away from these foods and are simply sceptical to GMO [52].

Figure 2 shows the process of soybean seed germination during the period of 8 days (a) and the example of soybean seedlings which were classified as normal (b) and abnormal (c).

In the present study we selected 10% of algal extract for testing its effect alone or in combination with SMF on the germination of soybean seeds. The literature depicts that, there are some papers concerned with the effects of the concentration of algal extract on seeds germination and parameters of plant growth. For example, Rathore et al. tested 2.5, 5, 7.5, 10, 12.5 and 15% algal extract [50], Lodhi et al. – 2.5, 5.0, 7.5, 10 and 15% [53]. In both cases, the highest yield was obtained for 15% of the algal extract. In our previous study it was shown that higher concentrations of C. glomerata extract (50 and 100%) inhibited the germination of soybean seeds [49].

The color of the obtained algal extract was light greenish-brown. The pH of the 10% C. glomerata extract was 7.92±0.10 (for 100% extract it was 7.58) and EC 284±6 mS/cm (for 100% extract it was 2.64 mS/cm). The concentration of macroelements in the 10% algal extract was as follows: K 85.2±1.2 mg/L, Ca 39.7±0.8 mg/L, S 22.6±0.04 mg/L, Mg 5.93±0.08 mg/L, Na 5.44±0.98 mg/L and P 0.770±0.086 mg/L. These results are in agreement with data published by Sivasankari et al. [54], who examined the properties of 100% extract obtained from a green seaweed – Caulerpa chemnitzia. The light yellow extract had a pH of 7.25 and the following concentration of macroelements: K 120 mg/L, Ca 192 mg/L, S 18.8 mg/L, Mg 115 mg/L, Na 176 mg/L. P was not detected in the extract. Taking into account that we tested a diluted extract (10%), the extract from C. glomerata was richer in K, Ca, S and P than extract from C. chemnitzia. The presence of macroelements in the algal extract was able to stimulate the plant growth.

In Table 1, the effect of the static magnetic field and Cladophora glomerata extract applied separately and in combination on the germination of soybean seeds is presented. The counting of soybean seedlings was done according to ISTA regulations. For each repetition (N=4 in each tested group), the number of germinated seeds after 8 days was counted. The mean value and standard deviation for 4 measurements is presented.

The results showed that both SMF, as well as the algal extract applied individually to the soybean seeds increased their germination percentage. However, the highest increase in the percentage of germinated seeds was observed for the synergistic action of physical (SMF)
Table 1: The effect of the static magnetic field and algal extract on the germination of soybean seeds.

| Group       | Germination (%) | Mean (N=4) | SD |
|-------------|-----------------|------------|----|
| C           | 9 abcd          | ±1         |    |
| SMF 3       | 11 a            | ±2         |    |
| SMF 6       | 14 b            | ±3         |    |
| SMF 12      | 14 c            | ±2         |    |
| SMF 3-E10%  | 16 c            | ±3         |    |
| SMF 6-E10%  | 19 b            | ±4         |    |
| SMF 12-E10% | 21 b            | ±3         |    |
| E10%        | 19 b            | ±5         |    |

- mean from 4 replications in each group ± standard deviation
- normal distribution, homogeneity of variances ANOVA (Tukey test)
- a, b, c... = statistically significant differences for p<0.05

Table 2: The effect of the static magnetic field and algal extract on the number of abnormal seedlings and dead seedlings.

| Group       | Abnormal seedlings | Dead seedlings |
|-------------|--------------------|---------------|
|             | Means±SD           |               |
| C           | 33 ±4              | 58 ±4         |
| SMF 3       | 31 ±3              | 58 ±2         |
| SMF 6       | 28 ±3              | 58 ±4         |
| SMF 12      | 31 ±3              | 55 ±3         |
| SMF 3-E10%  | 26 ±3              | 58 ±3         |
| SMF 6-E10%  | 29 ±3              | 52 ±2         |
| SMF 12-E10% | 31 ±3              | 48 ±2         |
| E10%        | 35 ±2              | 46 ±7         |

- mean from 4 replications in each group ± standard deviation (SD)
- normal distribution, homogeneity of variances ANOVA (Tukey test)
- a – statistically significant differences for p<0.05

The effect of the static magnetic field and algal extract on the germination of soybean seeds.

Differences statistically significant (for p<0.05) were marked with letters a, b, c, etc. For example, symbol a in Table 1 signifies that the difference statistically significant was between C and SMF 3-E10% (p 0.0285), symbol b – difference between C and SMF 6-E10% (p 0.000653), etc. Statistically significant differences were observed between the control group (C) and all groups in which we applied the static magnetic field together with algal extract: SMF 3-E10% (p 0.0285), SMF 6-E10% (p 0.000653), SMF 12-E10% (p 0.000194) and algal extract alone E10% (p 0.000845). Moreover, we have determined statistically significant differences between groups SMF 3 and SMF 6-E10% (p 0.000880), SMF 3 and SMF 12-E10% (p 0.00112), SMF 3 and E10% (p 0.0119), SMF 6 and SMF 12-E10% (p 0.0214) and SMF 12 and SMF 12-E10% (p 0.0499).

In the case of dead seedlings, their number was much lower in the groups with algal extract when compared to the control group. Differences statistically significant were observed between the following groups: E10% and C (p 0.0210), E10% and SMF 3 (p 0.0144), E10% and SMF 6 (p 0.0119), E10% and SMF 3-E10% (p 0.0144) and SMF 12-E10% and SMF 6 (p 0.0439).

It is important to add that in none of the tested treatments was the required minimum germination percentage of 80% was not achieved. In laboratory conditions, Glycine max (L.) Merrill seeds revealed dormancy due to an impermeable seed coat. This is the main cause of poor germination under field conditions. As dormancy is the resting stage of plant or ripe seeds during which nearly all manifestations of life come to an almost complete standstill, new methods are sought to improve the germination phase. Very common is mechanical scarification – the process of slightly damaging or breaking the tough seed coat which allows water penetration into the seed. Rubbing the seeds in sand, have been suggested by Dempsey [55]. Sulphuric acid scarification has also been found successful in overcoming seed dormancy [56]. However, from research conducted on seed germination, it has been speculated that scarification of seeds is necessary to break seed dormancy [57]. Furthermore, stratification as a cold treatment process given to some seeds to complete ripening and overcome dormancy is also commonly known.

The cause of poor germination is the high levels of dormancy due to an impermeable seed coat. Hence, research is needed to better understand the seed biology of Glycine max (L.) Merrill by using different stimulation...
factors. A full knowledge about the environmental factors that affect the germination of soybean seeds may help in explaining its reaction in various ecosystems.

Taking into account the application only of algal extract, the germination percentage increased more than two times when compared with the control group. This is in accordance with literature data, which confirm the positive effect of algal extracts on the growth and performance of soybeans. Mathur et al. [58] tested the effect of green seaweed – Enteromorpha intestinalis derived liquid fertilizer as a biostimulant for Glycine max (L.) Merr. It was found that 60% of the algal extract (among tested concentrations – 20, 40, 60 and 100% and control groups – water and chemical fertilizer) positively influenced seed germination, root and shoot length, the content of carbohydrates, proteins and pigments. In the work of Rathore et al. [50], the effect of the foliar spray of seaweed extract prepared from red Kappaphycus alvarezii at concentrations 2.5, 5, 7.5, 10, 12.5 and 15% on the growth, yield and nutrient uptake (N, P, K and S) by soybean – Glycine max (L.) Merrill was tested. The concentrations of seaweed extract – 12.5% and 15% significantly enhanced the yield parameters. Anisimov and Chaikina and Chaikina et al. [59,60] examined the effect of water extracts obtained from red, green and brown marine algae on the root growth of soybean seedlings of the Primorskaya 81 variety. It was determined that the stimulatory effect of algal extracts was observed at low concentrations, and showed an inhibitory effect on the plant growth at higher concentrations. The increase of the aerial part of soybean seedlings and the length of the primary root was observed also by da Costa et al. [61], who examined an extract obtained from red seaweed – Kappaphycus alvarezii. Taking into account a positive effect of the Cladophora glomerata extract on the germination of soybean seeds, further analysis is necessary to indicate which compounds are responsible for the stimulation of plant growth.

Nevertheless, the influence of SMF is important regarding the germination ability of soybeans. The positive effect of the static magnetic field is consistent with the literature data. Pietruszewski [62] described pre-sowing stimulation with a static magnetic field of cabbage and onion seeds. The seeds were stimulated with a magnetic field with induction values: for cabbage at – 70, 120 and 210 mT and for onions at – 40 and 80 mT. Cabbage seeds germinated at the same rate, regardless of the value of the magnetic induction used for pre-sowing stimulation. Contrary, onion seeds reacted differently to stimulation. Earlier and better germination was recorded for seeds stimulated with an 80 mT magnetic field. The obtained results showed that the influence of the magnetic field depended not only on the value of the magnetic induction used, but also on the type of seeds subjected to stimulation.

In another article [63], Pietruszewski et al. presented the influence of a static magnetic fields on the relative germination capacity of wheat (germination capacity of stimulated seeds/germination capacity of control seeds). Different magnetic induction values were used. The best germination capacity was obtained for shorter exposure times and for magnetic induction: 100 and 180 mT.

Similarly, the effect of a static magnetic field of 150 mT at four exposure times on the lentil seed germination process showed better germination of seeds [64]. Research on rice and barley seeds was carried out in Spain. The applied magnetic fields with 150 and 200 mT inductions resulted in faster germination of rice seeds [65], as did the yield for barley with a 125 mT field [66]. Martinez et al. [67] used a magnetic field of 125 and a 250 mT induction, produced by means of permanent magnets, to investigate its effects on the germination of tomato seeds. Positive effect of this stimulation type was observed for the exposure times used.

Static magnetic fields with different magnetic induction values: 50, 100, 150, 200 and 250 mT for presowing stimulation of chickpea seeds were used by Vashisth and Nagarajan [33]. The positive effect of this stimulation applied to not only the germination capacity, but also to the development of the roots and leaves. The same authors applied a static magnetic field of 250 mT to determine its effect on the germination and growth of sunflower seedlings [68]. The research confirmed that pre-sowing stimulation with a permanent magnetic field caused not only faster germination, but also an increase in the weight of the seedlings.

Static magnetic fields with a low induction value (2.9-4.6 mT) was used on soybeans [69]. There was no effect on the germination due to the value of these fields. However, such stimulation had a significant positive effect on the development of the roots and on the content of chlorophyll a and b.

The presented research results show a wide variety of seeds that were investigated with applied magnetic fields and selected exposure times. It is difficult to compare the results obtained in our work with previously published ones. Martinez et al. [70] and Ashgaripour and Omrani [71] works are the closest to our experimental setting. The interaction of different magnetic fields induction values and exposure times indicates that certain combinations, such as 0.3, 0.6 and 1.5 T for 10 min., were highly effective in improving the germination capacity and germination energy. This general observation showed that the internal
energy of the seeds reacted positively when there was a suitable combination of magnetic fields induction and exposure time [32,72,73]. This selective effect of various stimulus combinations (magnetic fields and time) can be explained by the properties of ions. The ions in the cell have the ability to absorb energy coming from the magnetic field, which corresponds to specific parameters related to their vibration and rotation energy sublevels [64]. This phenomenon represents some kind of resonance absorption, and this may explain the powerful effect of using certain magnetic field induction values (at a given exposure time), which were closely observed by Aladjadjiyan [74] as well as in our research.

4 Conclusions

This paper shows that soybean seeds were characterized by a low germination percentage, generally below 21%. This could be the result from seed dormancy. Nevertheless, it was shown that the applied static magnetic field and algal extract stimulated the germination of the dormant seeds. The combination of the stimulation of seeds by a magnetic field in conjunction with the algal extract, as well as algal extract alone, gave the best results. These natural extracts, rich in bioactive compounds, are known to positively affect the metabolism of plants, their growth and development. However, further research is needed to determine the presence and concentration of these compounds.

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