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Influence of 340 mT Static Magnetic Field on Germination Potential and Mid-Infrared Spectrum of Wheat

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In a number of studies, a static magnetic field was observed to positively influence the growing process of various plants; however, the effect has not yet been related to possible structural changes. We investigate if the static magnetic field that improves germination of wheat also alters wheat's near-infrared spectrum. Two groups of seeds were exposed to 340 mT for 16 h cumulatively. The first group was exposed 8 days for 2 h per day, while the second group was exposed 4 h per day for 4 consecutive days. One half of each of the exposed seed groups as well as of the unexposed control groups was sown, and the other half was used for mid-infrared spectra measurements. The sown seeds were monitored for 3 weeks after sowing. Germination of the groups exposed to the magnetic field was faster compared to corresponding non-exposed groups that were grown under the same conditions. The magnetic field exposure caused the enhancement of one O—H peak at 3,369 $\mathrm{cm^{-1}}$ and two C═O peaks at 1,662 $\mathrm{cm^{-1}}$ and 1,740 $\mathrm{cm^{-1}}$ in the mid-infrared spectrum. The effect was more pronounced for the 4 day, 4 h/day exposure. Bioelectromagnetics. 38:533–540, 2017. © 2017 Wiley Periodicals, Inc.

Keywords: strong static magnetic field; wheat; infrared peaks intensity change; growing enhancement; hydroxyl and carbonyl groups

INTRODUCTION

Rapid technological advances in the last few decades have established electromagnetic radiation as inevitably surrounding the entire planet. Numerous studies related to the influence of electromagnetic radiation on humans and life in general have been conducted. In particular, a static magnetic field of various intensities and homogeneities has been shown to affect humans, animals, insects, and bacteria, as well as plants. For example, it was shown that 5 min exposure to a static magnetic field of 0–192 mT peak-to-peak magnetic induction and 19 T/m lateral gradient could potentially help stomatologists as a drug-free, fast, and easy-to-use alternative method of local anesthesia [László et al., 2012]. An inhomogeneous static magnetic field of 31.7–232.0 mT was shown to have a cytoprotective effect on low-cisPt-concentration-treated SH-SY5Y cells, suggesting that exposure to various sources of static magnetic field in cancer patients under a cisPt regimen should be strictly controlled [Vergallo et al., 2014]. Milovanovich et al. [2016] reported that an upward and downward-oriented homogeneous static magnetic field of 128 mT affected spleen, brain, kidney, and liver in mice after 1 h/day exposure during a 5 day period. The subacute exposure to the homogeneous static magnetic field of 128 mT for 1 h per day in 15 consecutive days induced a pseudoanemia status with an increase in MCT4 and Glut4 proteins in glycolytic muscle of rats [Elferchichi et al., 2016]. A strong, homogeneous static magnetic field of 2.4 T was reported to be a potential stressor influencing fitness components and antioxidant defense

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in *Drosophila* flies after 2 h of exposure [Todorović et al., 2015]. The investigation of secondary structures of protein in *Escherichia coli* (*E. coli*) and *Staphylococcus aureus* (*S. aureus*) exposed to an ultra-strong static magnetic field of 10 T for 5–60 min revealed little impact on *S. aureus*, but strong impact on *E. coli* [She et al., 2009].

There are also numerous studies that address the influence of magnetic fields on plants. The removal of local geomagnetic field for the whole growth period under laboratory conditions was shown to negatively affect the reproductive growth of *Arabidopsis*, which further affected the yield and harvest index [Xu et al., 2013]. On the contrary, Pietruszewski and Martinez [2015] reviewed studies that applied various magnetic fields and achieved improved quality of sowing material. For example, exposure of irrigation water for 6 s or of snow pea (*Pisum sativum* L var. macrocarpon) and Kabuli chickpea (*Cicer arietinum* L) seeds for 10 s to an inhomogeneous static magnetic field with peak magnetic field intensity of 136 mT led to a significant increase in the emergence rate index, shoot dry weight, and contents of N, K, Ca, Mg, S, Na, Zn, Fe, and Mn in both seedling varieties [Grewal and Maheshwari, 2011]. Jan et al. [2015] conducted a standard 7-day test in a reduced and enhanced geomagnetic environment of 4 and 100 μT as well as in a strong static magnetic field environment of 150 mT. The results showed that the 4 μT field significantly stimulated growth rate, and the 150 mT field seemed to have the potential to increase initial Chl *a* fluorescence and energy dissipation in *Lemna minor* plants. Shine et al. [2011] reported a beneficial effect of pre-sowing magnetic treatment for improving germination parameters and biomass accumulation in soybean. Several magnetic field strengths ranging from 0 to 300 mT in 50 mT steps as well as exposure times of 30, 60, and 90 min were shown to improve germination-related parameters like water uptake, speed of germination, seedling length, fresh weight, dry weight, and vigor indices of soybean seeds under laboratory conditions. In 1-month-old treated plants, leaf area and leaf fresh weight showed more than twofold enhancement, polyphasic chlorophyll *a* fluorescence transients gave a higher fluorescence yield, and total soluble protein map of leaves showed increased intensities in two bands. Pre-sowing exposures of spring wheat seeds to two values of a magnetic dose, a parameter defined to be proportional to exposure time and square of the magnetic induction, were observed to cause dose-dependent increase in germination and yield [Pietruszewski and Kania, 2010]. Vashisth and Nagarajan [2008] exposed seeds of chickpea (*Cicer arietinum* L.) to static magnetic fields with strengths of 0–250 mT in steps of 50 mT for 1–4 h and obtained significantly enhanced laboratory germination, speed of germination, seedling length, and seedling dry weight. In soil, seeds exposed to the three most efficient treatments produced significant increase in seedling dry weights, root length, root surface area, and root volume of 1-month-old plants. These three magnetic fields also improved coat membrane integrity as it reduced seed leachate electrical conductivity.

Infrared spectroscopy is commonly used to identify and study non-organic as well as organic chemicals. The peaks in an infrared spectrum correspond to various types of oscillations within a molecule and are mapped into functional groups and chemical bonds. A number of studies applied this technique to analyze wheat. For example, near infrared spectroscopy was used for wheat quality testing [Delwiche et al., 2011], and for predicting its quality characteristics and functionality [Dowell et al., 2006]. Mid-infrared spectroscopy was used by Amir et al. [2013] to identify wheat varieties, by Morales-Ortega et al. [2013] to characterize water-extractable arabinoxylans from spring wheat flour, and by Guo et al. [2015] to detect fluorescent brighteners in wheat flour. On the other hand, the influence of a magnetic field on the infrared spectrum of a material was not addressed as often. She et al. [2009] studied the effect of an ultra-strong static magnetic field on the 1,600–1,700 cm^{-1} range of FTIR spectrum of protein in bacteria, and Kolotovska et al. [2006] investigated the influence of a strong magnetic field on molecular alignment in thin vanadyl phthalocyanine films grown by organic molecular beam deposition.

Our objective was to examine if static magnetic fields that caused enhanced wheat germination also changed the mid-infrared spectrum of the exposed wheat. The importance of this hypothesis lies in its truthful outcome, which may enable possible application of infrared spectroscopy in detecting and studying structural changes in seeds caused by static magnetic fields and in analyzing possible mechanisms of action between these fields and organic materials.

The magnetic fields in our study were chosen to be strong, that is of the order of hundreds of mT, since such fields had been observed to cause increased germination of various plants [Vashisth and Nagarajan, 2008; Grewal and Maheshwari, 2011; Shine et al., 2011] as well as to affect other species [László et al., 2012; Vergallo et al., 2014; Elferchichi et al., 2016; Milovanovich et al., 2016]. The experiences of other researchers were also used to determine the exposure time schedule. The exposure times were taken to be of the order of 1 h/day [Vashisth and Nagarajan, 2008;

Todorović et al., 2015; Elferchichi et al., 2016; Milovanovich et al., 2016] for several consecutive days [Jan et al., 2015; Elferchichi et al., 2016; Milovanovich et al., 2016]. In the referenced studies, the effects of the magnetic field were shown to be exposure-dependent; however, a firm correlation between the effect intensity and applied exposure characteristics was not reported. With the aim to reduce the number of variable parameters of the exposure, we opted for two exposure schedules with equal cumulative exposure times, that is equal exposure doses [Pietruszewski and Kania, 2010]. Consequently, in our study the seeds were exposed to a 340 mT static magnetic field, 2 and 4 h/day for 8 and 4 days, respectively.

MATERIALS AND METHODS

Wheat

A wheat seed (*Triticum aestivum* L.) used in the experiment was of a certified variety (Pobeda, Institute of Field and Vegetable Crops, Novi Sad, Serbia), which is characterized by a very good winter-hardiness, good resistance to lodging, and powdery mildew. Its test weight is 80–87 kg/hl, protein content 12–15%, and wet gluten content around 32%. The seeds selected for the experiment were similar in size, color, and shape.

Wheat Germination

The experiment was conducted in two subsequent parts, each of which involved exposed and control groups of seeds. The two exposed groups were subject to two different magnetic field influences whereas the control groups were sham-exposed. Each of the four groups had 100 seeds that were planted 25 per pot. Plastic pots of 16 cm in diameter were filled with 2,300 ml of 3:1 mixture of sterilized soil and sand. The seeds were sown in laboratory conditions. Two groups of seeds, each contained in four pots, were housed in a growth chamber, and were monitored for 3 weeks. One of the groups was the control group, that was sham exposed, and the other group was exposed to the magnetic field; however, the researcher handling the germination was not aware of which one was which. In both parts of the experiment, the exposed and control groups were subject to the same growing conditions; however, the settings were different for the two parts. During the first part of the experiment the day/night cycle conditions in the growth chamber were programmed to temperatures of 16/12 °C, relative humidity of 70%/70%, and time interval cycles of 12/12 h. In the second part of the experiment, the second set of eight pots, four of which contained non-exposed and four with exposed seeds, were subject to a temperature of 22 °C and relative humidity of 70% that were kept constant for the entire course of the experiment. During each part of the experiment the germination rate was observed for 3 weeks after sowing.

Data and Statistics

The germination percentage was calculated as

$$G = 100 \cdot \frac{n_{\mathrm{g}}}{N_{\mathrm{s}}},$$

where n_{g} is number of germinated seeds and N_{s} is number of sown seeds that were in our experiment equal to 25 per pot. Note that in our case the total number of seeds was 100 for all seed groups, which makes the germination percentage equal to the total number of germinated seeds. The values of the mean and standard error of the mean were calculated as

$$\overline{G} = \frac{\sum_{i=1}^{N_{\mathrm{p}}} G_i}{N_{\mathrm{p}}},$$

$$\mathrm{SEM_G} = \frac{s_{\mathrm{G}}}{\sqrt{N_{\mathrm{p}}}} = \sqrt{\frac{\sum_{i=1}^{N_{\mathrm{p}}} \left(G_i - \overline{G}\right)^2}{(N_{\mathrm{p}} - 1)N_{\mathrm{p}}}},$$

where G_i is germination percentage in the ith pot, $N_{\mathrm{p}} = 4$ is the number of pots, and s_G is standard deviation of the germination percentage.

The germination time was calculated as

$$t_{\mathrm{g}} = \frac{\sum n_t \cdot t}{\sum n_t},$$

where n_{t} is number of seeds that germinated at day t after sowing, and the standard error of the mean was obtained as

$$\mathrm{SEM_t} = \frac{s_{\mathrm{t}}}{\sqrt{N_{\mathrm{g}}}} = \sqrt{\frac{\sum_{i=1}^{N_{\mathrm{g}}} \left(t_{\mathrm{i}} - t_{\mathrm{g}}\right)^2}{(N_{\mathrm{g}} - 1)N_{\mathrm{g}}}},$$

where s_{t} is the standard deviation of germination time and N_{g} is the total number of germinated seeds.

Data statistics were calculated in Matlab. The groups were compared using the germination time and built-in function ttest2 for Student's t-test method that uses Satterthwaite's approximation for effective degrees of freedom. The function performs an unpaired two sample t-test with pooled or unpooled variance estimate. The test checks the hypothesis that two independent samples come from distributions with equal means. Data are assumed to come from normal distributions with unknown but equal variances. The null hypothesis is "the means are equal" and positive result of the test indicates that the null hypothesis can be rejected. The P-value is the probability of observing the given result, or one more extreme, by chance if the null hypothesis is true, that is small values of P cast doubt on the validity of the null hypothesis.

A change of peak intensity caused by an exposure to the magnetic field was calculated as well. If the intensity of a peak, I, between the wavenumbers ν_1 and ν_2 is taken to be the surface under the absorbance curve, namely

$$I(\nu_1,\nu_2)=\int_{\nu_1}^{\nu_2}\mathrm{A}d\nu,$$

where A is absorbance, then the relative peak intensity increase caused by exposure becomes

$$\Delta I(\nu_1,\nu_2)=\frac{I_{\mathrm{exposed}}(\nu_1,\nu_2)-I_{\mathrm{control}}(\nu_1,\nu_2)}{I_{\mathrm{control}}(\nu_1,\nu_2)}.$$

Magnetic Field

The samples were exposed to the static magnetic field produced with a custom-made electromagnet depicted in Figure 1. The operating parameters were set to produce 340 mT in the center of the 2-cm gap between the poles, as measured with a digital teslameter (DTM-151, Group3 Technology, Auckland, New Zealand) with a resolution of 0.002 mT. Four plastic vials containing 25 seeds each were held within the magnet gap by a wooden holder. Exposed seeds were placed in the experimental volume of $1\times1\times6\,\mathrm{cm}^3$ around the center of the gap, as indicated in Figure 1. Outer surfaces of the electromagnet's coils were water cooled. Temperature measurements away from the magnet and in the magnet's gap during the 4 h of magnet operation showed that coil heating did not produce a temperature increase in the experimental volume.

The numerical simulation of the magnet confirmed that the magnetic field variation within the experimental volume was between 339.5 and 340 mT, which is less than 0.15%. The seeds in the first part of the experiment were exposed 2 h per day for 8 consecutive days, and exposure corresponding to the second part of the experiment was 4 h per day for 4 consecutive days. Control groups were sham-exposed. All exposures were performed in duplicate in order to provide seeds for sowing as well as for infrared spectrum measurements.

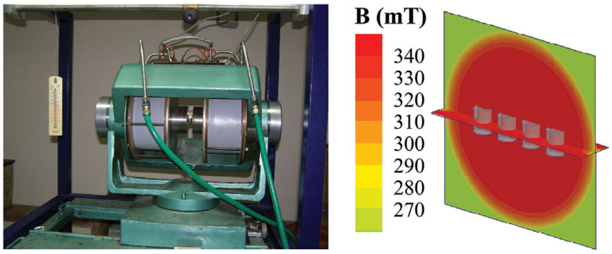

Fig. 1. Electromagnet and magnetic field within its gap. Pole diameter was 10 cm and gap between poles was adjusted to 2 cm. Magnetic field in the center was chosen to be 340 mT, which is about one half of 675 mT being the maximal magnetic induction that corresponds to chosen gap size. Tap water running through green hoses was used to cool outer surfaces of coils in order to eliminate possible temperature increase in experimental volume. Numerically simulated magnetic field is given in the $2\times10\,\mathrm{cm}^2$ and $10\times10\,\mathrm{cm}^2$ regions in horizontal and vertical planes through the gap center, respectively, along with placement of seeds during exposure in four plastic vials. Field within the experimental volume can be considered to be homogeneous.

Infrared Spectroscopy

Infrared reflectivity measurements were performed at room temperature with a Fourier-transform IR spectrometer (DA-8, ABB Bomem, Québec City, Canada). KBr beamsplitter and liquid-nitrogen-cooled Hg-Cd-Te (MCT) detector were used to cover the wavenumber range between 600 and 4,000 cm^{-1}. The spectra were recorded with a resolution of 2 cm^{-1} and with a very large number (500) of interferometer scans added for each spectrum in order to obtain high quality spectra. The spectra were measured in vacuum (0.2 mbar) in order to eliminate the presence of rotational-vibrational modes of CO_2 and water vapor present in air. The samples were prepared for IR spectrum measurements by grounding the wheat seeds, mixing the obtained flour with KBr powder, and by pressing the mixture into tablets always using the same pressure of 2 $\mathrm{t/cm}^2$. Preprocessing of the spectra was performed in three steps. The spectra were smoothed using a Savitzky-Golay polynomial smoothing filter, which was followed by baseline subtraction and SNV normalization.

Exposures of seeds within the electromagnet, germination, and infrared spectra measurements were handled in two different institutions by three different researchers who were not aware of the conditions the seed groups had previously been under; therefore, the study was double-blind.

RESULTS

Wheat germination results are given in Figures 2 and 3. Average germination times of the control and exposed groups in the first part of the experiment were t_g (control I) = 10.20 days and t_g (exposed I) = 9.02 days. In the second part of the experiment, we obtained values t_g (control II) = 7.02 days and t_g (exposed II) = 6.31 days. Consequently, in the first part of the experiment exposure to the magnetic field caused 11.5% decrease in the average germination time, whereas in the second part of the experiment, the magnetic field caused germination time to drop by 10.1%. Different growing conditions produced faster germination of the control group in the second part than in the first part of the experiment by 31.1%.

The mid-infrared absorbance spectra of the exposed as well as of the unexposed, that is sham exposed, grounded seeds are shown in Figure 4. Both of the considered exposures to the magnetic field caused broadening of the peak at 3,369 cm^{-1} and increased intensity of the peaks at 1,662 and 1,740 cm^{-1}, as well as decrease of all other peaks. The peak at 3,369 cm^{-1} corresponds to the O—H stretch, whereas the peaks at 1,662 and 1,740 cm^{-1} are associated with C═O stretches [Coates, 2000; Morales-Ortega et al., 2013]. To enhance visibility of the effects, differences between the absorbances, ΔA, are given in Figure 5.

The absorbance increases between $\nu_1 = 1{,}610\ \text{cm}^{-1}$ and $\nu_2 = 1{,}770\ \text{cm}^{-1}$ (C═O stretches) were calculated to be $\Delta I_{2h8d} = 5.4\%$ and $\Delta I_{4h4d} = 8.2\%$, whereas in the wavenumber range between $\nu_1 = 3{,}040\ \text{cm}^{-1}$ and $\nu_2 = 3{,}945\ \text{cm}^{-1}$ (O—H stretch) they were $\Delta I_{2h8d} = 11.4\%$ and $\Delta I_{4h4d} = 14.7\%$.

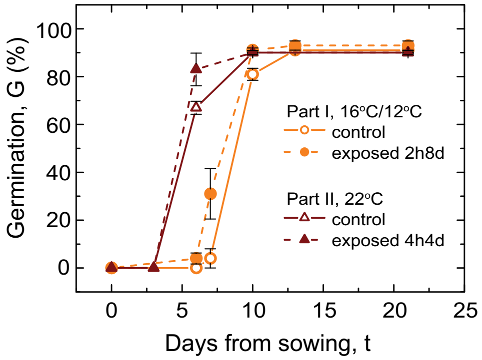

Fig. 2. Dynamics of germination. Exposures to magnetic field caused faster germination. Constant growth temperature of 22 °C caused faster germination than temperatures of 16/12 °C during 12 h-day/12 h-night cycle. Data points and error bars are presented as mean ± SEM of data corresponding to appropriate four pots.

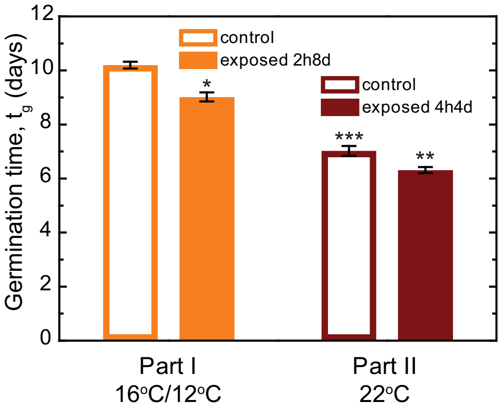

Fig. 3. Comparison of average germination times. Germination times are given as mean ± SEM. Exposed group differs compared to control group with $P < 0.001$ (*) and $P < 0.01$ (**) in the first and second part of the experiment, respectively. Difference between control groups in the first and second part of the experiment was obtained with $P < 0.001$ (***).

DISCUSSION

Results given in Figures 2 and 3 indicate that seed exposure to the magnetic field caused faster germination in both parts of the experiment, that is, regardless of the exposure schedule and of the conditions that were applied later in the growth chamber. However, due to germination dependence on the growing conditions as well as on the magnetic field exposure, the difference in growth conditions in the two parts of the experiment prevented the quantitative comparison of the achieved germination

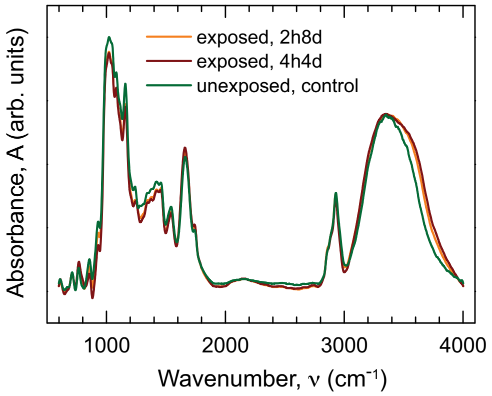

Fig. 4. Mid-infrared spectra. Exposures to magnetic field caused enhancement of oxygen peaks at 3,369 cm^{-1} (O—H stretch), 1,662 cm^{-1} (C═O stretch), and 1,740 cm^{-1} (C═O stretch), and decrease of all other peaks.

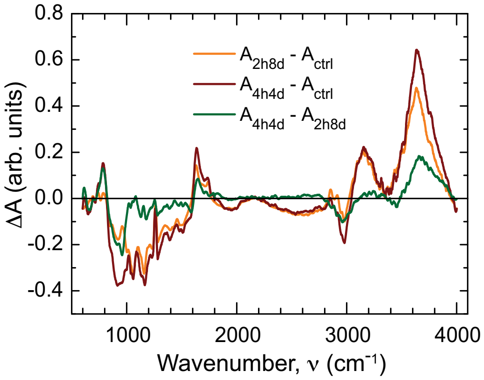

Fig. 5. Change in mid-infrared spectrum induced by magnetic field. Cumulative exposure time was equal to 16 h in both exposure time schedules; however, effects induced by 4 h/day exposure for 4 consecutive days were more pronounced.

potentials and applied exposure parameters. Growth chamber conditions applied in the second part of the experiment were favorable in terms of germination, as can be seen from comparison of the control groups. The germination enhancement of the exposed group in the second part of the experiment was the joint effect of exposure and growth conditions.

The mid-infrared absorbance spectra shown in Figure 4, in general, follow the shape of the wheat spectra given by other authors [Amir et al., 2013; Morales-Ortega et al., 2013; Guo et al., 2015]. The differences between the absorbances, ΔA, given in Figure 5 reveal that exposure to the magnetic field caused changes in the absorbance, and the effects were stronger for the 4 h/day exposure for 4 days than those corresponding to the 2 h/day exposure for 8 days. Since exposure doses were equal for both exposures, it seems that the dominant exposure parameter is the duration of the uninterrupted exposure rather than the cumulative exposure duration.

The wheat absorbance spectra were obtained from physiologically inactive seeds that were not subject to any other difference in treatment except for the magnetic field. Consequently, the magnetic field effect is not combined with growth conditions, as was the case with the germination potential, and quantitative comparisons were possible. Effects of the two magnetic field exposures on the wheat absorbance spectra were quantitatively compared using peak intensity increases, and exposure of 4 h/day during 4 days was more efficient than exposure of 2 h/day for 8 days by approximately 3%. Note that peak intensity was evaluated as the integral of the band instead of only its height because simple band height evaluation is more sensitive to noise, and integration provides better accuracy. In order to minimize the influence of all other factors except the magnetic field, the exposed and sham exposed samples used in the infrared spectral analysis were, except for exposure, otherwise treated in absolutely the same way. Namely, prior to exposure the physiologically inactive seeds for the control and exposed groups were taken from the same batch, whereas after exposure the tablets were prepared, and spectral analysis was conducted immediately following exposure.

Possible mechanisms of action between a magnetic field and biological materials were accessed by several authors [Brocklehurst, 1997; Eveson et al., 2000; Rosen, 2003; Shine et al., 2012; Lahbib et al., 2014]. Brocklehurst [1997] estimated the effects of isotopic substitution on the yield of chemical reactions involving radical pairs with the aim to explore the possible usefulness of magnetic isotope effects, especially to detect processes affected by magnetic fields. A review of the role of static magnetic fields in vitamins and glucose metabolism conducted by Lahbib et al. [2014] concluded that the primary cause of changes in cells after incubation in an external static magnetic field was the disruption of free radical metabolism and the elevation of their concentration leading to oxidative stress. Shine et al. [2012] found the influence of 150 and 200 mT on the production of reactive oxygen species in soybean, and Eveson et al. [2000] reported on the effects of weak magnetic fields on radical recombination reactions in micelles. The mechanism suggested by Rosen [2003] was based on diamagnetic anisotropic properties of membrane phospholipids. He proposed that reorientation of these molecules during moderate static magnetic field exposure would result in deformation of the imbedded ion channels, thereby altering their activation kinetics.

Studies that use infrared spectroscopy in their analysis of materials focus on peaks in an infrared spectrum, because various peaks correspond to chemical bonds of different types. Consequently, any change in a peak indicates a change in the corresponding chemical bond. She et al. [2009] detected a magnetic field effect similar to the one we detected at 1,662 cm^{-1}. They studied the effect of an ultra-strong static magnetic field of 10 T on the secondary structures of protein in bacteria by analyzing the 1,600–1,700 cm^{-1} range of FTIR spectrum that corresponded to the amide I region. They found that magnetic field caused 3.46–9.92% of random coils in the secondary structure of protein in *E. coli* to turn into helices. The conversion of β-sheets from intermolecular into intramolecular indicated that cohesion among molecules decreased and intramolecular hydrogen bonds were enhanced. Kolotovska et al. [2006] used infrared spectroscopy to study the influence of a strong magnetic field on the molecular alignment in thin vanadyl phthalocyanine films grown by organic molecular beam deposition and reported that integral intensity of the peak of the layer grown in the magnetic field was 14% larger compared to that of the film grown without magnetic field. In our study, the integral peak intensity increase caused by the magnetic field is in the range of 5.4–14.7% and is in agreement with those reported by She et al. [2009] and Kolotovska et al. [2006]. A peak intensity increase is commonly interpreted as a stronger molecule polarity or a larger number of a particular bond. Given that wheat is a complex mixture of organic molecules, the peak intensity is a sum of contributions of all molecules containing the corresponding bond. Knowing a molecular composition of wheat [Koehler and Wieser, 2013], we may conclude that a hydroxyl (OH) group is a part of the chemical structure of octacosanol and proteins, whereas a carbonyl (C═O) group belongs to amino acids in proteins. The observed peak changes in the 340 mT static magnetic field could be a consequence of the nucleophilic interaction of free oxygen electrons, from both hydroxyl and carbonyl groups, with n-3 long unsaturated fatty acid double-bonds. Since our results indicate that a static magnetic field simultaneously caused enhanced germination and changes in the mid-infrared spectrum, it seems worthwhile to investigate if some of the enhanced O─H and C═O bonds are located within the phytohormones or participate in chemical reactions with them.

CONCLUSION

Exposure to a 340 mT static magnetic field for cumulatively 16 h simultaneously caused an increase in wheat seed germination and changes in the mid-infrared spectrum. Therefore, the hypothesis that a static magnetic field that causes enhanced germination can also induce changes in the infrared spectrum of wheat seeds was shown to be true. Since infrared spectra are records of chemical bonds in a material and its structural composition, it can further be concluded that static magnetic fields can cause weak changes in the distribution of chemical bonds in wheat seeds. The peaks at 3,369 cm^{-1} (O─H stretch), 1,662 cm^{-1} (CO stretch), and 1,740 cm^{-1} (C═O stretch) were enhanced, whereas the intensity of all other peaks decreased. Changes in the infrared spectrum were more pronounced when 16 h exposure was divided into 4 h–4 days than when the exposure schedule was 2 h–8 days. Due to the simultaneous effect of the field on wheat germination and infrared spectrum, it seems plausible that the affected bonds are within phytohormons or that they participate in chemical reactions with them. Further studies that use infrared spectroscopy to detect structural changes induced by a static magnetic field may lead to better understanding of the mechanism of action between a static magnetic field and wheat germination. Also, a quantitative correlation between germination enhancement and changes in infrared spectra may enable a faster search for optimal field intensity and exposure time, since it would eliminate the need for complete germination and growth of a large number of seed groups exposed to various exposure schemes.

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