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(Organizadores)

Ciência em Foco

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Apresentação

O avanço da Ciência tem promovido o desenvolvimento de inúmeras tecnologias que tende a proporcionar o incremento da produção de alimentos, a melhoria da qualidade de vida da população, a preservação e sustentabilidade do planeta. Todavia, além da geração de novos conhecimentos é necessário a dispersão para o público alvo. Algo que geralmente é negligenciado por muitos autores, pois, se limitam apenas em publicar um artigo científico.

Nesse aspecto, a "Pantanal Editora" surgiu com a missão de "publicação de trabalhos de pós-doutorado, teses, dissertações, monografias, trabalhos de conclusão de curso, ensaios e artigos científicos" com o lema "Ciência com consciência". Nossos valores são construídos sob esse alicerce. Qualidade, ética, relevância acadêmica e impacto social, norteiam nossos trabalhos. Diferentemente de outras editoras, nós procuramos pesquisadores que estejam dispostos a fazerem capítulos que passaram por revisões criteriosas e não somente aplicar o binômio pagou-publicou.

Além disso, tem como visão "A ciência é vital para o desenvolvimento humano, e seu progresso somente é possível quando apoiado sobre o conhecimento científico passado. Por isso a divulgação dos trabalhos científicos é essencial para que a ciência possa alcançar a todos, transformando nossa sociedade."

Com base nesses pilares, a "Pantanal Editora" orgulhosamente apresenta em seu primeiro livro "Ciência em Foco", em seus 22 capítulos, avanços nas áreas de Ciências Agrárias e da Engenharia. Conhecimento estes, que irá agregar muito aos seus leitores, entre os assuntos, adubação nitrogenada na soja, diversidade genética de cultivares de mandioca, produção de mudas, magnetismo na agricultura, técnicas de avaliação do sistema radicular das plantas, percepção ambiental de alunos, análise de gestão de resíduo sólidos, conservação de estradas, sustentabilidade e responsabilidade social. Portanto, fica evidente que essas pesquisas procuram promover melhorias quantitativas e qualitativas na produção de alimentos e, ou melhorar a qualidade de vida da sociedade. Sempre em busca da sustentabilidade do planeta.

Aos autores dos diversos capítulos, pela dedicação e esforços sem limites, que viabilizaram esta obra que retrata os recentes avanços científicos e tecnológicos, os agradecimentos dos Organizadores e da Pantanal Editora.

Por fim, esperamos que este livro possa colaborar e instigar mais estudantes e pesquisadores na constante busca de novas tecnologias. Assim, garantir uma difusão de conhecimento fácil, rápido para a sociedade.

Alan Mario Zuffo
Jorge González Aguilera
Bruno Rodrigues de Oliveira

SUMÁRIO

Ciências Agrárias

Engenharias

Capítulo 12

Use of GREMAG® technology to improve seed germination and seedling survival

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Elizabeth Isaac Alemán[1]
Alan Mario Zuffo[2]

INTRODUCTION

Producers and researchers have always been interested in increasing the economic value of horticultural crops (Casanova et al., 2007; Consonni et al., 2019). Vegetables make a major nutritional contribution to the human diet, hence their widespread consumption worldwide, thus stimulating their production. Within these vegetables, the great acceptance and importance of tomato (*Solanum lycopersicum L.*), bean (*Vicia faba L.*), pumpkin (*Cucurbita maxima*) and cucumber (*Cucumis sativus L.*), places them in a prominent place (FAOSTAT, 2018).

One of the objectives of agriculture is the constant supply of vegetables, and for the achievement of this purpose in the houses of postures or nurseries is of vital importance to achieve a high germination and survival of the seedlings.

For the growth of a seedling it is necessary that the germination of the seeds occurs initially. This process includes a set of stages by which the embryo, which is in a state of latent life within the seed, resumes its growth and develops. For the germination of a seed three conditions must be fulfilled, that the embryo is viable, that the external factors are favorable and that the germination of internal form is not prevented (Courtis, 2013).

In agriculture, the effects of the application of magnetic fields (MF) on plants have been evident. The MF by direct exposure and through magnetic treatment to the water used for irrigation. (Carrejo, 2015). In several horticultural crops this methodology has been applied to

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accelerate the germination and growth of plants, due to the favorable morphological and physiological changes it produces (Maffei, 2014; Maffei, 2018).

The use of magnetic inductions between 125 and 250 mT has favoured seed germination, vigour, growth, morphological characteristics, yield and the production of secondary metabolites (Dubois et al., 2007; Torres et al., 2008; Martínez et al., 2009; Dubois et al., 2012; Dubois et al., 2016; Yusuf et al., 2016; Ferrer-Dubois et al., 2018; Boix et al., 2019; Hozayn et al., 2019; Yusuf et al., 2019). According to studies of Pang (2014a), water under magnetic treatment is considered to be easy to apply and to have less impact on the environment.

The objective of this research was to determine the effect of the application of GREMAG® technology on seed germination and the survival of seedlings of bean, tomato, pumpkin and cucumber.

MATERIAL AND METHODS

The experiments were carried out in the Basic Unit of Cooperative Production "Luis Manuel Pozo Nápoles", Santiago of Cuba, Cuba. Bean (*Vicia faba* L. var. Lina), tomato (*Solanum lycopersicum* L. var. HA-3105), pumpkin (*Cucurbita maxima*) and cucumber (*Cucumis sativus* L. var. SS-5) were used. The seeds used had a good phytosanitary status and were supplied by the Provincial Seed Laboratory of the Ministry of Agriculture (MINAG), in Santiago of Cuba. The standards established by the Manual of Procedures for the Official Certification of Seeds were considered (FAO, 2016).

For the experimentation we used the methodology of treatment with static magnetic field (SMF) between 20 and 200 mT to the irrigation water, GREMAG®, which has been used in other plant species with excellent results. The techniques to follow for the conventional reproduction were carried out according to the recommendations of conventional methods of specialists of the Ministry of Agriculture of Cuba (Casanova et al., 2007).

The seeds (60) of each plant species were sown in polyfoam trays and one seed per alveolus was deposited. The physical-chemical characteristics of the substrate were determined at the Center for the Study of Biotechnology (CEBI), of the University of Oriente, in Santiago of Cuba. The determination of pathogenic agents was determined at the Provincial Plant Health Laboratory in Santiago of Cuba. During the experimentation, temperature and relative humidity measurements were made, obtaining average values of 32.1 ^{0}C and 72.2%, respectively, during the whole experimental period.

The seeds were divided into two experimental groups. One of them was irrigated with water treated with SMF between 20 and 200 mT with GREMAG® technology and the other group they were irrigated without water treated with static magnetic field (WMF, control), that is to say with running water. An external permanent magnet or SMF magnetizer was used for the magnetic treatment. This equipment was built in the CNEA and has a length of 20 cm and a magnetic induction between 20 and 200 mT. Magnetic characterization was performed by three different methods. The measurements were made with a Soviet Microweberimeter 192041, with a relative error of less than 5%, with a Nuclear Magnetic Resonance equipment and with a 410 Gaussmeter Teslameter from Lakeshore. There was a high reproducibility between the three methods used.

Irrigation was carried out twice a day for 20 minutes. An aerial microjet system was implemented, consisting of accessories such as an ITUR pump and a distributor system, controlled by valves that ensured that the irrigation was performed by sections. The flow of the pump was between 2.54 and 2.91 $m^3.h^{-1}$. The water speed was between 1.4 and 1.6 ms^{-1}. A chemical analysis was performed on the irrigation water.

A completely randomized experimental design was used with three replicates and the sample size was 30 for each of the replicates.

The germination process of the seeds was evaluated with the method proposed by Deaquiz-Oyola et al. (2013). Observations were made daily. The seeds were evaluated as germinated and not germinated, from the fourth day. As an indicator of germination, we selected the moment when the embryos swelled, broke the cover of the seed and sprouted, when the cotyledonal leaves were noticed. The percentage of germination (PG) was determined according to the following equation:

$$PG = \frac{Number\ of\ sprouted\ seeds}{Number\ of\ sprouted\ seeds} * 100 \qquad (Equation\ 1)$$

In order to determine the survival of the seedlings, daily observations were made for 15 days on all plant species. Survival was used to determine the percentage of live plants with respect to the number of plants initially established. The seedlings that could not be established and died were determined in each treatment. The percentage of survival (PS) was evaluated with the equation proposed by Linares (2005):

$$PS = \frac{Live\ plants}{Live\ plants + Dead\ plants} * 100 \quad (Equation\ 2)$$

Statistical Analysis

The obtained data were evaluated statistically to know their normality through the Kolmogorov - Smirnov Test. The results were expressed in the arithmetic mean, as a measure of the central tendency; and the standard error of the mean, as a measure of dispersion. The T-Student Test was used with a probability level of 95%.

RESULTS AND DISCUSSION

By analyzing the physical-chemical characteristics of the substrate it was determined that it was formed by a mixture of soil and organic matter in a ratio 3:1 (v.v), P_20_5 (49 mgL^{-1}), K_2O (55.2 mgL^{-1}) and MgO (12.09 mgL^{-1}). Electrical conductivity was at 3 $mS.m^{-1}$ and pH at 6.4. No pathogens (bacteria, nematodes, or fungi) were detected in the substrate used.

In the chemical analysis carried out on the irrigation water, a pH value of 7.87 was determined and the electrical conductivity was 0.25 $mScm^{-1}$. Table 1 shows the values of the chemical elements determined in the irrigation water of the seedlings.

Table 1: Chemical analysis of irrigation water.

Chemical compounds	Concentration (mgL^{-1})
Na^{++}	**12.42**
Ca^{++}	**25.60**
Mg^{++}	**6.72**
KI	**4.68**
HCO_3	**73.20**
Cl^-	**17.75**
SO_4^{++}	**9.61**
CO_3^-	**18**

The evaluation of the germination percentage showed an unequal response between the seeds of all plant species in the different experimental groups (Figure 1).

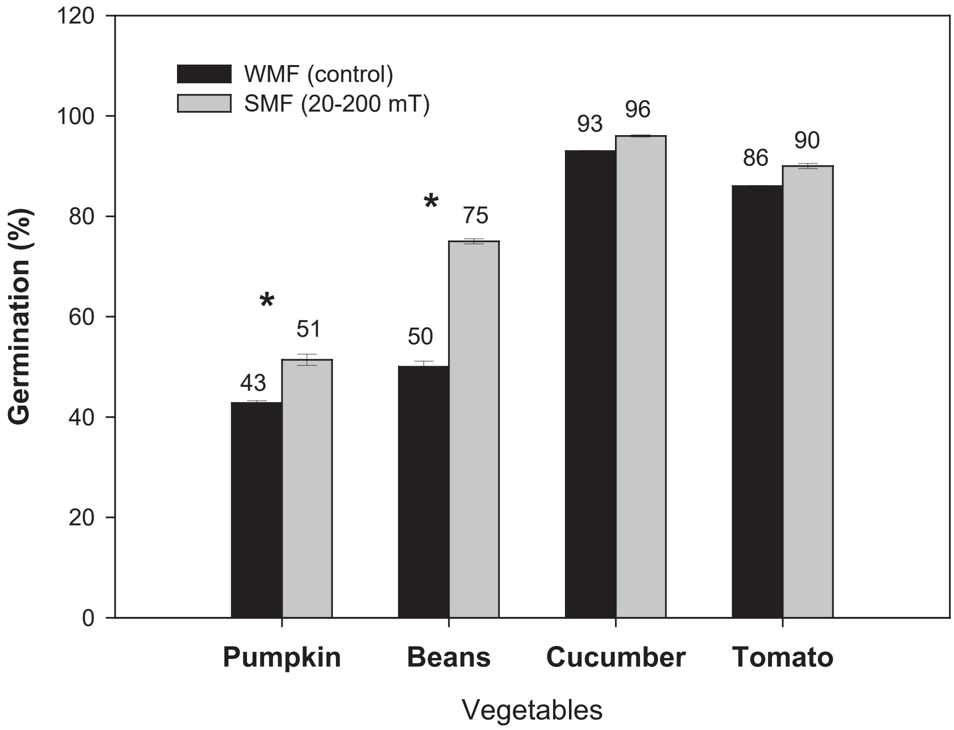

Figure 1. Percentage of germination of pumpkin, bean, cucumber and tomato with different treatments in the irrigation water. The bars show the mean values and the standard error of a representative experiment of three independent repetitions. Symbol * indicates statistically significant differences between the experimental groups, $p<0.05$ (T- Student).

It can be considered that in the results obtained an adequate survival was achieved in the plants of the experimented species. In all plant species a higher percentage of germination was obtained in the experimental group that received the magnetic treatment in the irrigation water, with respect to the seeds of the control group (WMF), irrigated with running water. Statistically significant differences were obtained ($p>0.05$) for pumpkin, beans and cucumber. Seeds irrigated with water treated with SMF had a higher percentage of germination (96 %), while 93 % was obtained in the seeds of the control group (WMF). It can be deduced that there was a stimulating effect of the SMF used in the seeds of the experimental group, which allowed a higher percentage of germination. The greatest difference between the two experimental groups tested occurred for beans, where the increase in germination was in the order of 25 % in favor of magnetic treatment to the irrigation water, with statistical differences ($p>0.05$) (Figure 1).

The germination stage is very important due to the direct impact on plant density. There is water imbibition; synthesis and activation of enzymatic systems; degradation of reserve substances and elongation of embryonic cells and emergence of radicle (Courtis, 2013). The ions in the soil or water can be considered to have acted as a stimulant for the seeds in the germination stage. (Goykovic et al., 2014). Apparently, the seeds that received the magnetic treatment of the water made a greater absorption of the water and the nutrients. The embryo is constituted by meristematic tissue, which presents within its characteristics an active mitosis, activated with the treatment and directly influencing the development of the seed and of the plant in general sense. Everything seems to indicate that the water treated with SMF contributed to accelerate this process of cell division and the subsequent stage of cell differentiation, where adult tissues were formed during the growth of the plant.

The results of this research are related to those obtained by several authors. It is suggested that SMF is probably responsible for better activation of respiration and energy metabolism in seeds, which correlated with increased germination percentages. Torres et al. (2008), determined increases in the germination percentage of the seeds of *Oryza sativa* L. (rice) and *Solanum lycopersicum* L. using 10 and 15 mT of MF.

On the other hand, De Souza et al., (2010), germinated seeds of *Solanum lycopersicum* L. (cv. Lignon) with MF of 160 and 200 mT per minute and obtained an increase in the germination percentage. In studies carried out by Grewal et al. (2011) in *Pisum sativum* L. (pea) and *Cicer arietinum* L. (chickpea), water treated with SMF produced an increase in the percentage of germination with an induction range between 3.5 and 136 mT.

The investigations of Feizi et al. (2012), confirmed that seeds of this species treated with 25 mT magnetic induction for 5 minutes experienced the effect of biostimulation in the early stages of germination and growth.

According to Najafi et al. (2013) in *Apium graveolens* (celery) and *Phaseolus vulgaris* (beans), there was a significant increase in seed germination rate, in the emergence rate and growth of roots and stems, with magnetic field of 1.8 mT. The reports exposed by Samani et al. (2013), describe that the exposure of seeds of *Cuminum cyminum* (cumin), to different intensities of MF significantly increased the germination percentage.

On the other hand, Jedlička et al. (2014) in their study indicated a reduction of the germination period of *Solanum lycopersicum* L. seeds treated with SMF to a magnetic induction of 20, 40 and 60 mT. At the same time, the results obtained by Aguilera et al. (2016), demonstrated the positive effect of the application of magnetic treatment to water with an induction of 120 mT, during irrigation in the production phase of seedlings of the same plant species. Irrigation to *Cucumis sativus* L. seeds with 40 mT SMF for one hour carried out by Shahin et al. (2016), revealed a rapid germination.

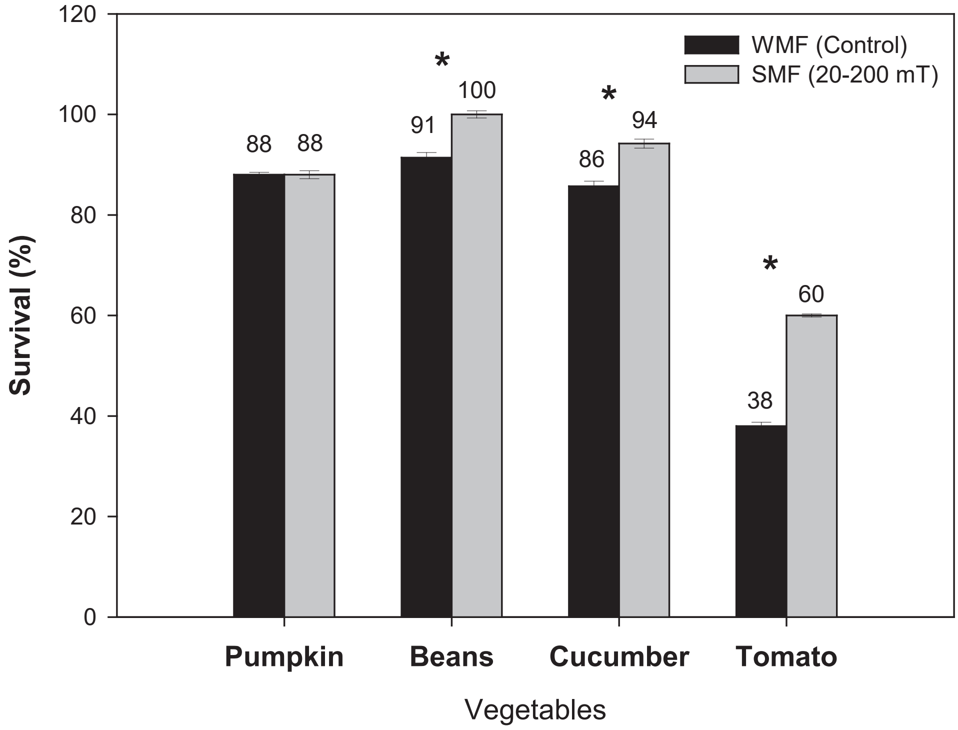

Figure 2. Survival percentage of pumpkin, bean, cucumber and tomato with different treatments in the irrigation water. The bars show the mean values and the standard error of a representative experiment of three independent repetitions. Symbol * indicates statistically significant differences between the experimental groups, $p<0.05$ (T- Student).

Figure 2 shows the results of the survival percentage of the four investigated plant species. It can be considered that in the results obtained an adequate survival was achieved in the plants of the experimented species. In the bean, cucumber and tomato seedlings, in which the magnetic treatment was used in the irrigation water, the survival percentage was higher with respect to the seedlings of the control group. There were statistically significant differences ($p<0.05$) between the experimental groups of each of the plant species. In beans, 100 % survival was achieved in the group to which water treated with SMF was applied, while 91.4 % was obtained in the plants of the control group. It can be assumed that seeds irrigated with SMF in irrigation water greatly enhanced their potential for adaptation and ability to survive by being in the presence of water excited by the application of SMF. Therefore, they developed better qualities in this first stage of their growth, and this increase in their adaptive power could favor the transplanting of these seedlings to field conditions.

In *Cucurbita maxima*, the same survival value (88 %) was obtained for the two experimental groups. Therefore, the application of the SMF in the irrigation water did not stimulate the survival of the seedlings in this species.

Different researchers have verified that with the application of MF to the water, physical-chemical changes occur, in addition to alterations in the hydration of ions. Pang et al.

(2012), stated that devices for the magnetic treatment of water generate a rupture of the molecular structure of water. Together with the MF it produces, the gradient of magnetic induction and the polarity (Pang et al. 2013).

When water circulates through a MF, a Lorentz force is exerted in the opposite direction on each charged particle. The fact that protons or hydrogen ions are transferred along the bond chains of the hydrogen ring to form a current of protons under the action of this MF force is controversial. (Pang et al., 2012). At the same time, Wang et al. (2018), reported modifications to the water, stating that it is magnetized or disturbed, which affects various physiological processes in plants. This water is better assimilated by the cells, affecting the different potentials established in this process. The intensity of the flow of water towards the interior of the plant is favoured more quickly than in normal conditions, due to the activation of the cellular transport mechanism by osmosis. From these are derived the direct and indirect effects on the growth and productivity of crops, related to greater efficiency in irrigation and water use (Maffei, 2014).

It is suggested that this water be better assimilated or absorbed by the cells, and may affect the different potentials that are generated in that process. Therefore, it was possible to favor the intensity of the flow of water and minerals into the plant. All of which probably favored the transport routes of nutrients and soluble substances in seeds and seedlings irrigated with water treated with SMF.

In *vitroplants* of the orchid species *Spathoglottis plicata* the use of magnetically treated water favored the percentage of survival in more than 85% during the acclimatization stage, according to the reports of Aguilera et al. (2018).

MF has been shown to have positive effects on protein synthesis, cell proliferation, biochemical activity, respiration rate, enzyme activity, nucleic acids and growth rate. At the same time seed treatment with magnetic field increases seed germination and improves seed quality. Positive effects of SMF on the germination of seeds of several plant species have been reported. (Ulgen et al., 2017). It has been suggested that the seeds in the presence of a MF, swell and the activity of its auxins increases. In addition, the rate of respiration is stimulated and as a result germination is faster, generating seedlings more resistant to stress (Nyakane et al., 2019).

Experiences with water for irrigation treated with SMF indicate that the percentage of germination of the seeds is much higher, while the germination time decreases. The speed of development is accelerated, the vigour of crops is increased and production is increased. The quality of the products is improved and there is a reduction in the volume of water used for irrigation. These advantages raise the hypothesis of a better use of moisture by plants, greater effectiveness in absorbing nutrients and reduced evapotranspiration in crops.

Several hypotheses have been put forward which try to explain the biological action of the MF (Zhang et al., 2017). These influence the cellular functions, however, it is complicated to establish the mechanism of interaction with living cells by all the factors that can affect (Albuquerque et al., 2016; Maffei, 2018), although the Guide of the International Commission on Ionizing Radiation Protection on MF exposures should always be considered (INTERNATIONAL, 1998). In a general sense, there was a better adaptation to the environmental conditions and with it a greater survival in the seedlings irrigated with water treated with SMF.

CONCLUSIONS

The application of GREMAG® technology accelerated the process of germination of seeds in the houses of postures and a greater survival of the seedlings in three of the four species investigated. The potential of adaptation of the seedlings irrigated with water treated with SMF in the irrigation water was promoted, which developed better qualities for survival and were ready in less time to be transferred to the houses of protected cultivation or to the nurseries where they continued their growth. A greater number of plants was achieved in a shorter period of time. Production costs were reduced due to a reduction in the cultural, material and human resources needed at this stage of agricultural work. The use of GREMAG® technology does not contaminate water, air, soil or personnel. It is a solution that corresponds to the current requirements of environmental protection and agricultural development.

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CONFLICTS OF INTERESTS

The authors do not declare a conflict of interest.

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