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Prospects for the use of microwave energy in grain crop seeding

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Abstract

This study looks at determining the main trends in the application of microwaves on plants in agricultural production in the processing of grain material, it provides examples of their effectiveness and an overview of the use of microwaves on plants available on the Russian market. Additionally, the research studied the experience and developments of leading scientists in the field of microwave radiation. Analysis of the available sources provided information on the positive effect of microwave radiation in the processing of crops. The use of microwaves on plants during drying destroys pathogens and bacteria, in particular, microwave processing of red lentils reduces grey mould damage by up to 30%. Positive results are also noted in the microwave processing of other crops, providing an increase in germination capacity of up to 7% and yield growth of up to 6%. The microwave plant market in Russia is represented mainly by dryers, and the use of microwaves on plants combining several functions of drying, disinfection, and pre-sowing stimulation.

Key words: *disinfection, microwave drying, microwave energy, microwave use on plants, pre-sowing treatment*

INTRODUCTION

Exposing seeds to fresh air and the sun is the primary means of drying. This technique is widely employed around the world, particularly in tropical climates, as the energy used is free and abundant. It does not require any additional expertise. However, there are many drawbacks as it is highly dependent on weather and drying times are very long and require large areas. In addition, it is not possible to have full control over the drying process, and the effect could be non-uniform drying. The seeds are also subjected to climatic changes, thus reducing their viability and efficiency. They are also vulnerable to threats such as pollution from the atmosphere, pests, diseases and soil and dust contamination. Since agricultural operation and conservation of biodiversity are priorities, it would be of great interest to explore new technologies to improve the drying process [MORENO *et al.* 2016; 2017; NAIR *et al.* 2011; NELSON 1987].

Seed treatment using an ultra-high frequency electromagnetic field is becoming increasingly popular. The range of microwave application in grain farming [SURYOPUTRO *et al.* 2018] includes drying, disinfection and disinfestation, and pre-sowing. Tests have shown in most cases that microwave drying improves the rate of drying without impairing the final product's consistency. Nonetheless, in order to prevent damage to the samples, the technique and the power level need to be carefully selected (e.g., the germination rate and the consistency of the final product decrease at higher power levels or under over-exposure to microwave radiation). It should also be noted that not only the power or temperature used but also the initial moisture content depends on the time needed for drying the seeds [BUDNIKOV, VASILIEV 2018; VADIVAMBAL *et al.* 2010; WARCHALEWSKI *et al.* 2011].

The study of the current situation and prospects for the use of microwave energy in the processing of grain material

[DAS *et al.* 2009; SRIKANT *et al.* 2013] is one of the main stages in the study of this problem, which allows us to assess the degree of elaboration of the topic, indicating the main trends of further work. It should be noted that the problem of using microwave energy is widely and thoroughly covered in the works of scientists around the world. The results presented in scientific articles generally note the positive effect of microwave frequency electromagnetic fields (EMFs) processing.

MATERIALS AND METHODS

Electromagnetic waves with a frequency of 3.1 to 311 GHz. These waves penetrate into plant tissue and react with polar molecules such as water to generate heat. In fact, polar molecules like water absorb these waves, causing high internal heat in plant matter and thus destroying cells. Microwaves are used for industrial, scientific, medical and communication purposes. These waves, due to their low frequency, are not able to break chemical bonds and damage food molecules, unlike X-rays and Gamma rays. In this way, the microwave penetrates deep into the food, so the size of the food is not a limiting factor. The microwave method is used to store food (drying, balancing, pasteurization, etc.). The microwave is produced by magnetic apparatus, magnetron and klystron. The waves generated by the magnetron create an alternating magnetic field, and food molecules, especially polar molecules such as water, proteins, and fats, align themselves with rapid changes in the alternating electric field.

The magnetron is an empty cylinder shaped like a horseshoe in a magnetic field. In the centre of the cylinder there is a cathode rod and the wall of the cylinder acts as an anode. When the cylinder heats up, the cathode emits electrons the negatively charged particles flow towards the anode which in this case is the cylinder wall itself. The force from the magnetic field causes the electrons to rotate in a circular direction. This movement of charged particles produces a suitable cooking frequency. A wave conductor directs microwaves to the cooking chamber. And the blades of a fan cause the microwave to spread to all parts of the oven. The microwave cooking operation is due to the interaction of the electric field component of the radiation with the polar molecules (mainly water) present in the food. All molecules rotate at room temperature. If the frequency of the radiation and the frequency of the molecular rotation are equal, energy can be transferred from the microwave to the polar molecule, so that the molecule can spin faster. The friction caused by the rapid rotation of water molecules eventually causes the food molecules surrounding the molecules to heat up.

The study of the practical application of microwave EMF in processing grain material started first with the work of foreign scientists involved in both pre-sowing seed treatment and drying, and in protecting grain material from pathogenic microorganisms [KELMENDI *et al.* 2018]. As a source of information, mainly open access scientific articles published in leading scientometric databases were used. Commercial microwave plants on the Russian market were evaluated according to the technical characteristics available via the Internet from manufacturers and retailers of this type of product.

RESULTS AND DISCUSSION

One of the advantages of using microwave energy to dry seeds is the destruction of pathogens, moulds, and bacteria. The drying of red lentils seeds [TAHERI *et al.* 2020a, b, c] provides a 30% decrease in damage by mould, with a slight decrease in seed viability, which makes it possible to use this drying method in the processing of seed material. Moreover, other studies note that a decrease in the amount of background acid pathogen [TAHERI *et al.* 2019] can be one of the elements of a comprehensive treatment of diseases. However, with the positive effect, which manifests itself in maintaining a high percentage of germination, the results of some studies obtained during the processing of soybeans indicate a seed coat softening and cracking during microwave processing [ANAND *et al.* 2019]. This can be eliminated by identifying the optimal heat exposure regime, such as during rice drying, where the results showed that maximum energy efficiency, maximum thermal efficiency, maximum drying efficiency, minimum specific energy consumption, and the minimum percentage of seed destruction was observed at a microwave power of 90 W and thickness drying of 18 mm [JAFARI *et al.* 2018].

The use of microwave treated plants for seed drying is attractive to consumers due to the lack of fuel. At the same time, the technical parameters of such plants, such as AST-3, allow drying of the product with an initial humidity of 25%, with a productivity of 1.5 to 4.5 $t \cdot h^{-1}$, removing 4 to 6.2% of moisture in a single pass when drying grain [GANEEV *et al.* 2020; HEMIS *et al.* 2016]. A comparative assessment of the economic efficiency of the AST-3 [BOSHKOVA *et al.* 2019] revealed a decrease in production costs and the cost of processing a ton of grain by more than 20% compared to a Vesta 5 dryer operating on diesel fuel.

The positive effect of microwave processing during seed disinfection is quite widely noted since exposure with a heating power of 1400 W, and a frequency of 2450 MHz for 120 s destroys fungal and bacterial pathogens in cassava seeds [LOZANO *et al.* 1986]. A positive effect of microwave disinfection is also achieved for one of the most common grain crops in Russia – wheat and barley. So, while maintaining germination capacity of more than 85%, the infection of wheat seeds with *Fusarium graminearum* can be reduced to 4–7%, while, as the authors of the study note, expanding the range of operating conditions will increase the efficiency of the process [REDDY *et al.* 1998]. The heating rate of $0.4°C \cdot s^{-1}$ and the treatment exposure time of 30 s showed the strongest decontamination effect while maintaining the viability of barley grain and reducing the microbial load to 80% [ARABIAN *et al.* 2020; KRETOVA *et al.* 2018].

As a number of foreign studies show, it seems promising to use microwave energy in pre-sown seed treatment as an environmentally friendly method that increases the germination and productivity of crops [KAKATI *et al.* 2019; RIFNA *et al.* 2019]. The effectiveness of microwave treatment on pre-sown wheat seeds and its positive effect on sowing and yield qualities are noted [Vendin *et al.* 2020]. The authors also indicate that the greatest effect is achieved when treating seeds that initially have low germination ability, recommending a specific microwave power output in the range of 0.83–0.89 kW·kg^{-1}, with a heating temperature varying from 38 to 60°C.

The research results also show that pre-sown seed stimulation with microwave EMF provides 7% increase in germination, up to 6% increase in germination energy and up to 20–25% increase in yield [Filatova *et al.* 2010; Jakubowski 2015; Pietruszewski *et al.* 2007]. The use of a seed dresser and growth stimulator can further increase the efficiency of microwave seed treatment.

The modern market of grain processing microwave plants offers plants of various design solutions aimed at solving either a single task, such as drying, or a set of tasks, for example, disinfection and pre-sowing.

Analysing the spectrum of microwave plants on the market and their concepts, two main areas should be distinguished: volumetric processing and seed layer treatment. Volumetric microwave plants are usually used for drying seeds.

An example of such a plant is the AST-3 direct-flow shaft dryer, noted earlier, which is a hopper with a product weight in the chamber of up to 600 kg. The unit is used for drying the seeds of oilseed and grain crops to the required degree of humidity.

This plant is designed to remove moisture from the surface of bulk materials (grains) by microwave drying, disinfection and disinfestation of the material to remove microorganisms such as bacteria, fungi, and mould [Madera *et al*. 2017].

An example of grain drying plants operating on the principle of processing a layer is the plant proposed by Miccio *et al.* [2020], which dries seeds with microwave energy to the required moisture content. In addition, the proposed plant, operating in the microwave processing mode, allows for pre-sowing stimulation of seeds.

Representatives of plants in the first group process seeds by movement using gravity under the influence of gravitational forces are Tsiklon-7 [Avdeeva *et al.* 2016], and Potok plants. Plants such as these are the most widely available on the market.

Tsiklon is an auxiliary device in the form of an electromagnetic pipe attached to the unloading screw of the PS seed dresser. The seeds being processed, pass from the screw of the seed dresser through the plant by gravity, are processed by microwave currents. The advantage of this plant is the lack of a transportation mechanism for feeding seeds into the treatment zone with microwave currents. Manufacturers present the plant as an effective way to increase yield and germination of seeds, recommending processing seeds of reduced germination, bringing it to 92–95%. The main disadvantage of the proposed design is the limited adjustment of the speed of flow of seeds through the electromagnetic pipe, which depends on the parameters of the discharge screw and, accordingly, determining the exposure time of the electromagnetic field. The relative portioning of the material, characteristic of the screw conveyor makes the seed processing uneven.

Potok has a similar principle of operation, where the seeds also pass through the electromagnetic field using gravity. A distinctive feature is the presence of a feeding screw that feeds the seeds into the processing zone, which eliminates the disadvantages of the previous solution and regulates the seed supply. To eliminate the heterogeneity of the treatment, The Potok is fitted with a flow agitator, which ensures uniform heating of seeds (Photo 1).

Photo 1. Equipment for frying seeds, nuts, seeds (phot. *S. Belozerova*)

The Laminaria microwave plant by consists of a rotating drum which heats the seeds and applies microwave EMF to them. The declared processing performance is 500–600 kg·h^{-1}, in the presence of evaporated moisture, the performance is 20 kg·h^{-1}. The design of the installation provides for a change in the speed of rotation of the drum in order to control the duration of the drying process. Warm air for drying comes from the magnetron cooling system with the possibility of additional heating of the heater. Loading and unloading of material is carried out using screw conveyors.

The Barkhan microwave plant, used for drying various materials from food products, such as dry mixes and feed, to natural ones – sand, clay, and roasting nuts and seeds, the processing is carried out while moving on a conveyor. According to the process scheme, the processed material enters first the pre-drying zone, then moves to the microwave module. The technical characteristics of Barkhan-3 make it possible to adjust the heating temperature and moving speed, while providing a range of operating temperatures from +5 to +230°C with a performance range from 150 to 400 kg·h^{-1}, depending on the material being processed and the modification of the plant.

The Arabis microwave plant, designed for the heat treatment of various products, are tunnel plants and, due to the presence of their roll table design, can process various products. The most advisable is the use of the Arabis plants for defrosting various foodstuffs packed in radiolucent containers, such as frozen meat, fish, berries, etc. With defrosting from –18 to 0°C the plant performance reaches up to 500 kg·h^{-1}, and with microbiological disinfection – 350 kg·h^{-1}, the maximum power consumption is 16 kW.

The MUS-A microwave drying unit used for drying bulk products is a cyclic type of chamber microwave plant (about 2.45 GHz).

The Musson microwave vacuum plant is designed to process products and materials using microwave heating, vacuum and vacuum drying of the material. Drying products in a vacuum provides both the necessary reduction in humidity even at a temperature of 30°C, thereby specifying the use of this plant for drying biologically active and food additives, herbs, seafood, etc.

The UMOS-02 plants are designed both for drying and improving the microbiological composition and increasing germination and germination energy, with the performance of up to 300 kg·h^{-1}. The more powerful stationary drying module SM-5 allows for the reduction of humidity by 5–8% per pass, with relatively high productivity of 4 to 8 t·h^{-1}, depending on the cultivated crop.

The range of plants used exclusively for pre-sowing stimulation is less than that of the combination actions; this is primarily due to the lack of research into non-thermal effects of microwave EMF on the seed germ. But, at the same time, on the Russian market, this type of plant is represented by domestic and foreign scientists. Mikrostim-2M, presented by Ukrainian scientists as a farm microwave plant, is designed to stimulate the seed of agricultural crops and increase their germination [Bastron *et al.* 2020; Brodie *et al.* 2019; Khan, Brodie 2018; Moskovskiy 2013]. The laboratory of the Belarusian State University (Ukr. Bielaruski dziarzhaŭny ŭniviersitet) offers consumers several types of plants for the pre-sowing treatment of seed material of agricultural crops based on microwave EMF modules [Bastron *et al.* 2020], which allow optimizing plant operating modes depending on the crop being processed.

CONCLUSIONS

Despite the fact that the drying and disinfection of grain prevail in the range of grain drying and disinfection microwave plants, pre-sowing stimulation remains a pressing issue requiring in-depth study. In general, the prospects for the application of microwave energy in the processing of seed material are quite wide, and in the development of control technologies and process automation, in the near future, they will go beyond the areas described earlier, including in terms of design implementation and development of the plants. The obtained results are noted in the microwave processing of other crops, providing an increase in germination capacity of up to 7% and yield growth of up to 6%. The microwave plant market in Russia is represented mainly by dryers, and combination microwave plants combining several functions of drying, disinfection, and pre-sowing stimulation.

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