International Journal of Academic Multidisciplinary Research (IJAMR)
ISSN: 2643-9670
Vol. 5 Issue 9, September - 2021, Pages: 197-206

Effects of Low and Medium Microwave Radiation on Germination of Bean and Maize Seedlings

Olajide Oyinloluwa Fisayomi[1], Adekanmi, Abideen Adeyinka[2], Ayoade, Julius Oluwatosin[3], Omole, Folasade Oyindamola[4], Adekanmi Adeniyi S.[5]

[1]Department of Science Laboratory Technology, Osun State College of Technology, Esa-Oke, Osun Nigeria
E mail: oyinloluwafisayomi@gmail.com
[2] Raw Materials Research and Development Council, Abuja, Nigeria
E mail: yinklab1234@gmail.com
[3] Department of Microbiology, University of Ibadan, Ibadan, Nigeria
E mail: ayoadejulius8@gmail.com
[4]Department of Science Laboratory Technology, Osun State College of Technology, Esa-Oke, Osun Nigeria
E mail: Omolefolasade83@gmail.com
[5]Osun State University Teaching Hospital, Osogbo
E mail: adekaniyi@yahoo.com
Corresponding Author: Name; Adekanmi, Abideen Adeyinka, Phone; +2348060214264, E-mail; yinklab1234@gmail.com

Abstract: *Microwave radiation effects depend on radiation frequency and exposure period. Generally, low microwave exposure has been successfully used as a positive effect on the accelerating seed germination, while a long exposure usually tends to reduce plant growth. Microwave irradiation could affect plant growth, development and seed germination. The objective of the study is to examine the effects of microwave radiation (low and medium) on seed germination of bean and maize. Various germination traits were estimated and monitored during the experiment at different time-points; 4, 7, and 10 days after sowing (DAS). Seeds of Maize and Bean were divided into two, each group containing three replicas of maize and bean seeds. The first group represents the untreated (unexposed) control and second group was irradiated with different exposure periods to microwave Panasonic® NN-N740 (Low and Medium for 1, 2, 3 and 4 minutes for both maize and beans). The length of maize and bean seeds increased during the trials germination days (5,7 and 10) compare to length recorded for control for exposed low and medium microwave radiation at time interval of 1, 2, 3 and 4 minutes respectively. The microwave radiation used in the present study promoted grains germination, accelerated seedling development and growth. The results obtained from this experiment emphasized the necessity of exposing maize and bean seeds to lowest time of microwave before sowing in seed beds to promote a high germinate and to produce uniform seedlings. The effects of different treatments were found to be stimulating the germination and seedling vigour of plants especially in power and exposure time treatments.*

Keywords: Microwave Radiation, Low, Medium, Germination, Maize, Beans

1. INTRODUCTION

Corn is farmed throughout Latin America and is a key staple in Central America, along with beans. The FAO has identified a gap in production areas in this region, as well as a need that must be addressed: increasing maize production, which requires significant effort but is one of the few crops with commercial seed production (Laynez- Garsaball *et al*., 2007).
The growing demand for organic products, combined with an increase in plant materials for food production, has prompted scientists to look for systemic factors to boost output, taking into account not only traditional methods of crop development, such as the use of fertilizers and agrochemicals, which can cause environmental damage to some extent, but also physical methods, such as the use of lasers (Hernandez *et al*., 2009; Dominguez *et al*., 2010).
Physical treatment techniques are one of the safest popular methods for improving seed germination and plant growth, thanks to their low environmental impact. Physical elements have also been used to achieve a good biological change in plants without having an impact on the ecosystem (Govindaraj *et al*., 2017). Electromagnetic waves, including as ultraviolet and microwave radiation, ultrasound, laser, and ionizing radiation, are among the physical elements now used for seed treatments. Microwave and UV-radiation, in particular, are thought to be the most essential physical therapies for pre-sowing seed treatments (Araujo *et al*., 2016).
Microwaves (MWs) are a non-ionizing electromagnetic with a high-frequency range of 300 MHz to GHz and a wavelength range of 1m to 1mm (Wang *et al*., 2018). Microwaves are a type of electromagnetic radiation with frequencies ranging from 300 MHz to 300 GHz. They work through absorption on a molecular level, resulting in vibration energy or heat, as well as biological impacts (Pakhomov *et al*., 1998). Microwaves may have long-term health impacts, according to relevant study (Lin, 2004). Because there is no clear mechanism for the impact of microwave radio-frequencies on biological systems, the identification, evaluation, and assessment of microwave bio-effects has been difficult and contentious. In biophysical and engineering sciences, there has been a persistent belief that microwave fields are incapable of inducing bio-effects other than through heating (Banik *et al*., 2003).

The effects of microwave radiation are dependent on the frequency and duration of exposure. Low microwave exposure has been shown to have a good effect on seed germination; however a protracted exposure reduces plant growth. Several authors recently observed that microwave has a good effect on barley seed germination at short microwave exposure times, but that longer exposure times had a negative effect on seed germination (Abu-Elsaoud & Qari, 2017; Kretova et al., 2018). In addition, studies by Amirnia (2014), Abu-Elsaoud (2015), Jakubowski (2015), and Mohsenkhah *et al*. (2018) found that MW can be utilized to promote seed germination in pepper, wheat, maize, bean, soybean, and lentil, respectively.

Abu-Elsaoud (2015) found that microwave irradiation has an effect on plant growth, development, and seed germination. Low-intensity microwave was shown to have no effect on plant growth and development, whereas higher microwave irradiation doses reduced and retarded seed germination (Oprica, 2008). Ponomarev *et al*. (1996) investigated the direct effects of microwave on cereal germination, using a wavelength of 1 cm and an irradiation exposure dose of up to 40 minutes on barley, oats, and wheat seeds, with the best results after 20 minutes of microwave exposure (Ponomarev et al., 1996). Radzeviius et al. (2013) found that irradiating vegetable seeds with high-power microwave radiation stimulated many germination and growth rate parameters.

Aladjadjiyan (2002) investigated the influence of microwave irradiation with varying powers on various seed germination consequences of four different ornamental crop species, finding a rise in various germination consequences. Abu-Elsaoud (2015) supported a dose-dependent putative stimulating impact of microwave on growth and germination by comparing the effect of microwave radiations on germination and growth of six distinct Egyptian genotypes using varied exposure times. Crețescu *et al*. (2013) investigated the effect of microwave radiations of 2.45 GHz on the chlorophyll contents of four barley genotypes after exposure to 0, 10, and 20 seconds. The results revealed a dose-dependent change in chlorophyll contents, ranging from lower chlorophyll in sensitive genotypes to higher chlorophyll in tolerant genotypes (Crețescu *et al.*, 2013). Microwave irradiation causes resonance events in biological systems and stimulates living organisms (Aladjadjiyan, 2002).

The majority of studies on the biological impacts of phone masts and microwave radiofrequencies on animal and human health were centered on possible biological effects from phone masts and microwave radiofrequencies (Balmori, 2009). The biochemical mechanism by which microwave radiations affect living organisms' biological systems is not entirely understood, and it may vary depending on the amplitude, frequency, and irradiation duty cycle (Aladjadjiyan, 2010; Abu-Elsaoud, 2015; Williams, 2016).

Microwaves (300 MHz to 300 GHz) have been shown to cause changes in cell membrane permeability and cell growth rate, as well as interference with ions and organic compounds such as proteins (Eugen Ungureanu *et al*., 2009). Plants are crucial components of a healthy ecosystem and play an important part in the living world as primary providers of food and oxygen; consequently, it would be helpful to research their interaction with today's enhanced radio and microwave frequency fields.

Light, moisture, temperature, and other environmental factors that influence plant growth have been well documented, and research papers based on these investigations are widely available. Plants are acceptable environmental signals, and studies on plants are less emotionally distressing than human or animal studies (Verdus *et al*., 1997; Vian *et al*., 1999). Microwave bioeffects research is a new and exciting field of science that involves both biotechnology and microwave engineering.

Microwave bio-effects can be divided into two types: thermal and non-thermal. Microwave fields have been shown to cause harmful biological effects at high power levels. Bio-effects at low power levels, on the other hand, are yet to be thoroughly understood. Radiation is known to cause physiological and genetic changes, such as the development of numerous epidermal meristems in the hypocotyl, changes in the proteome, and so on (Tafforeau *et al*., 2004; Tafforeau *et al*., 2006).

Seed germination, shoot development, plant length, fresh weight, fruit yield, and mean fruit weight are all known to be positively influenced by the application of extremely low frequency magnetic fields today (Cakmak *et al*., 2010). Protein biosynthesis, cell production, photochemical activity, respiration rate, enzyme activity, and nucleic acid content have all been demonstrated to benefit from magnetic fields (Stange *et al*., 2002).

Natural aging has been seen in maize and beans, resulting in a reduction in the physiological potential of seeds, which reduces germination capacity, early seedling growth rate, and tolerance to adverse environments (Gutierrez-Hernandez *et al*., 2007). However, because the action of electromagnetic fields on seeds can affect the course of several physiological processes and drive plant development (Podleny *et al*., 2005), it can greatly reverse this phenomenon.

Few, if any, empirical investigations have been conducted in Nigeria to indicate that microwave radiation has a good influence on seed germination (Hu *et al*., 1996 and Chen *et al*., 2005). Regardless of the data on the effect of microwaves on plants that has been gathered, little is known about whether microwave pretreatment of seeds causes a change in the inner energy of seeds, stimulating enzyme activities, improving metabolism, and increasing the intensity of biophoton emission, which is used as a measure of cell metabolism. As a result, we attempted to evaluate the influence of a microwave on maize and bean seed germination in the current study.

2. METHODOLOGY

2.1 Materials

Seed samples, Sample container, Petri plates, Beaker, Microwave, Frequency meter, Microwave power meter, Microwave absorber; Microwave, Microwave power meter, Microwave absorber; Microwave, Microwave power meter, Microwave absorber; Microwave, Microwave power meter, Microwave absorber Electronic balance, stop watch, thread, scale, seed germination chamber, permanent marker, zip-lock plastic baggies, water dropper, and petri plates were among the other items used in the experiment.

2.2 Collection of Seeds sample

The maize and bean seeds were purchased at the Esa-Oke market and transported to the Osun State College of Technology's Environmental Biology Laboratory in Esa Oke in plastic bags..

2.3 Exposure of seeds to microwave radiation

Maize and bean seeds were divided into two groups, with three replicas of maize and bean seeds in each group. The untreated (unexposed) control group was irradiated with varied microwave Panasonic® NN-N740 exposure times, whereas the second group was irradiated with varying microwave Panasonic® NN-N740 exposure periods (Low and Medium for 1, 2, 3 and 4 minutes for both maize and beans).

2.4 Experimental Design for Sowing of Maize and Beans

The soil used for sowing seeds was collected from an experimental plot at the Department and was employed in a pot experiment. Test crop seeds were individually planted in pots containing 300 g soil after being exposed to microwave radiation for 1, 2, 3, and 4 minutes. All pots were put on a screen house bench with a fully randomized design (three replicates per treatment) and were watered on a regular basis to ensure enough moisture.

2.5 Effect of microwave radiations on germination

During the experiment, distinct germination features were assessed and observed at three time points: 4, 7, and 10 days after sowing

2.5 Statistical Analysis

Data was subjected to software program of SPSS version 17 for statistical analysis.

3.0 RESULTS AND DISCUSSION

3.1 Germination of Mize Seeds Exposed to Low Frequency of Microwave Radiation

Effects of low microwave radiation on germination of maize seedlings at days interval was shown in figure 1 below. Control was not expose to microwave radiation while other maize seeds were exposed to microwave at low frequency with time interval of 1, 2, 3 and 4 minutes respectively (Figure 1).

At Day 4, all maize seeds exposed to low microwave radiation had increased length of germination (7 and 6 cm) compare to value recorded in control (5cm) except maize exposed to low microwave radiation for period of a minute and 4 minutes respectively (Figure 1). The maize exposed to radiation for a minute had equal length of germination with the control while the length recorded after 4 minutes of low radiation exposure had growth length lower (4cm) than control (5 cm).

Maize seed exposed to low frequency of microwave radiation for a minute had highest length of germination (14.5cm) at day 7 of growth. This was preceded by growth length of 14 cm and 13.5 cm observed for Maize seeds exposed to microwave radiation at time interval of 3 and 2 minutes respectively (Figure 1). Only maize seed exposed to low frequency of radiation for 4 minutes had low germination length (11 cm) compare to 12cm recorded in the control at day 7 (Figure 1).

At day 10, maize seeds exposed to low radiation at 1, 2, 3 had increase length of germination (28, 27 and 27 cm) compare to length of 25 cm observed in control. The highest germination length (28 cm) was obtained at exposure period of a minute (Figure 41). The maize seed exposed at period of 4 minutes of low frequency of microwave radiation had similar germination length equal with length recorded for control (Figure 4.1).

The effect of microwave radiation in boosting rapid germination and development rate is revealed in this study by exposing or treating maize seedlings with microwave radiation. Throughout the investigated germination days of growth, low frequency microwave radiation was beneficial in promoting quick germination of maize seeds, particularly at exposure times of 4 minutes. Rajagopal (2009) demonstrated that microwave frequency aided the germination rate and growth indices in wheat, barley, and rye in a similar study. This could be related to microwave frequency's beneficial impact on water absorption and other metabolic processes (Nelson, 1987).

Gaurilcikiene *et al*. (2013) also found that exposing wheat seeds to a strong microwave electric field at 2.6 GHz for 20 minutes enhanced grain production. Low microwave frequency also promoted plant growth, however high microwave frequencies had little or no influence on plant growth (Murakarmi *et al*., 2001).

Furthermore, low-power microwave radiation (1 KHz) was found to have a stimulating effect on seed germination and seedling vigour in wheat, Bengal gram, green gram, and moth bean (Ragha *et al*., 2011). This can also be linked to the submissions of Baskin and Baskin (2001) and Basra (2006), who said that the germination stage in plants generally demands a higher amount of warmth than the other growth phases. This could be another good reason to boost the germination rate of maize that has been planted.

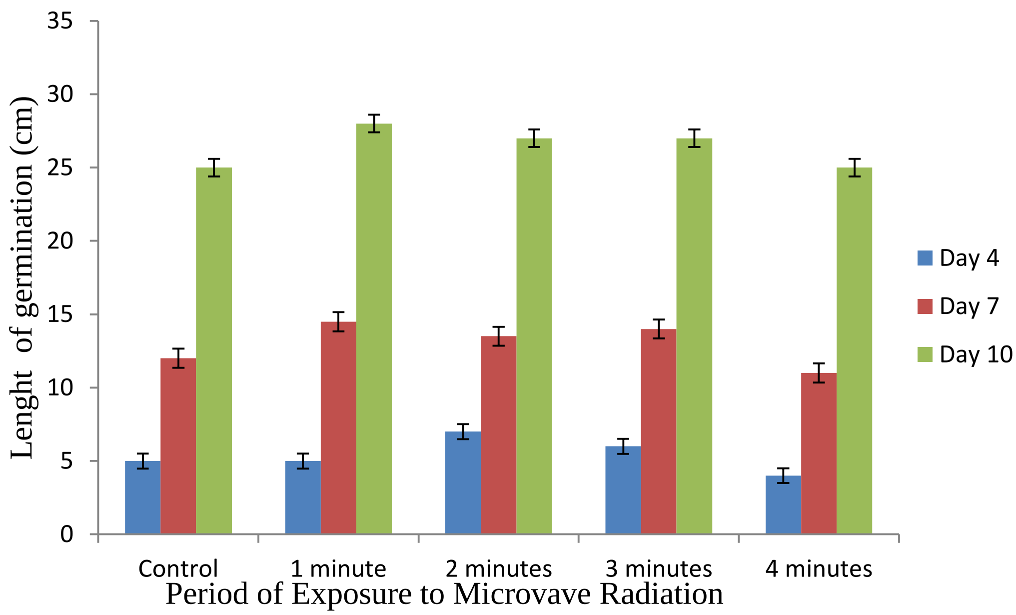

Figure 1: Shows the germination length of maize seeds within period of 10 days after exposure to low frequency of microwave radiation at time interval of 1, 2, 3 and 4 minutes.

3.2 Germination of Mize Seeds Exposed to Medium Frequency of Microwave Radiation

Germination length of maize seeds within period of 10 days after exposure to medium frequency of microwave radiation at time interval of 1, 2, 3 and 4 minutes was shown in figure 2 below. Control was not exposed to microwave while other maize seeds were exposed to microwave at medium frequency at time interval of 1, 2, 3 and 4 minutes respectively.

The effects of microwave was observed in all seeds planted (7, 6, 11 and 7 cm) at microwave exposure of 1, 2, 3 and 4 minutes respectively (Figure 2). Maize exposed to medium microwave for 3 minutes had highest length of growth (11 cm) compare to values of 5 observed in control after day 4 of germination. This reveals that microwave exposure aids growth of maize (Figure 2).

At Day 7, the length of growth obtained for control was 12 cm. All maize seeds exposed to microwave treatment recorded improve length of germination (13, 17, and 14 cm at 1, 3 and 4 minutes of exposure) except maize seed (12 cm) exposed to microwave for period of 2 minutes. The length obtained is equal to the germination length for control (Figure 2). The maize exposed to medium microwave for period of 3 minutes had highest germination length (17 cm) and this is preceded by germination length (14 cm) obtained for maize exposed to medium frequency of microwave at period of 4 minutes (Figure 2).

The highest germination length of 27 cm was obtained for maize seed exposed to medium frequency of microwave at period of 4 minutes after 10 day of germination. This was followed by maize (26 cm) exposed at period of 2 minutes (Figure 2). However, maize exposed to medium frequency of microwave at period of a minute had similar germination length (25 cm) with that of control while maize treated at period of 3 minutes had slight length of germination (25.5 cm) compare to control (Figure 2).

In this study, the medium frequency microwave radiation also showed an increase in maize length during germination. In comparison to the control, maize seeds exposed to above radiation for 3 and 4 minutes exhibit a quick development rate. This demonstrates the ability of microwave radiation to improve maize seed germination. The impact of microwave frequency in enhancing seed germination and shoot and root growth was demonstrated by this finding.

The findings of Nelson (1987), Tran (1979), and Vadivambal *et al*., (2007), who found that microwave frequency radiation aided the GR and growth indices of C. annuum, were consistent. This could be related to microwave frequency's beneficial impact on water absorption and other metabolic processes (Nelson, 1987).

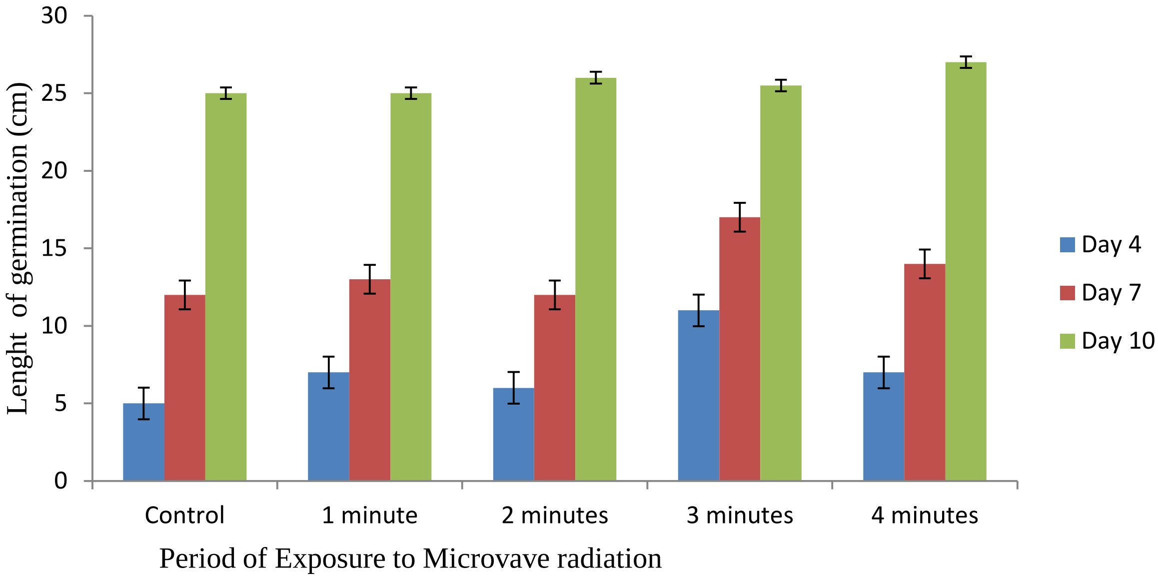

Figure 2: Shows the germination length of maize seeds within period of 10 days after exposure to medium frequency of microwave radiation at time interval of 1, 2, 3 and 4 minutes.

3.3 Germination of Bean Seeds Exposed to Low Frequency of Microwave Radiation

Effects of low microwave radiation on germination of bean seedlings at days interval was shown in figure 3 below. Other bean seeds were exposed to microwave at low frequency with time interval of 1, 2, 3 and 4 minutes but control was left unexposed to radiation (Figure 3).

Control had 13 cm length of germination after 4 days while all bean seeds exposed to microwave radiations had low and poor length of germination (3, 0, 3 and 8 cm at 1, 2, 3 and 4 minutes) after 4 days of germination (Figure 3). This implies that the low frequency of microwave radiation had no effect on bean seeds at all exposed time intervals after 4 days (Figure 3).

All bean seeds exposed to low frequency of microwave had low length of germination (13, 6, 8 and 17 cm) after day 7 of germination which is contrary to 18cm obtained as length of germination for control (Figure 3). Only bean seed exposed to low frequency of microwave at period of 4 minutes had increased length of germination (26 cm) compare to 23 cm recorded for control at day 10 of germination. Other bean seeds exposed to radiation at period of 1, 2 and 3 minutes had low germination length (19, 19 and 15 cm) (Figure 3).

At days 4 and 7, the germination rate of bean seeds exposed to low microwave radiation was stunted. When compared to the control, the values reported after one minute, two minutes, three minutes, and four minutes of exposure time are extremely low. After 10 days of germination, a similar instance was seen, with the exception of the exposure duration of 4 minutes, which had grown in length after day 10 when compared to the control length. This suggests that low microwave radiation is insufficient to promote quick germination of bean seeds, and that environmental factors may be involved.

International Journal of Academic Multidisciplinary Research (IJAMR)
ISSN: 2643-9670
Vol. 5 Issue 9, September - 2021, Pages: 197-206

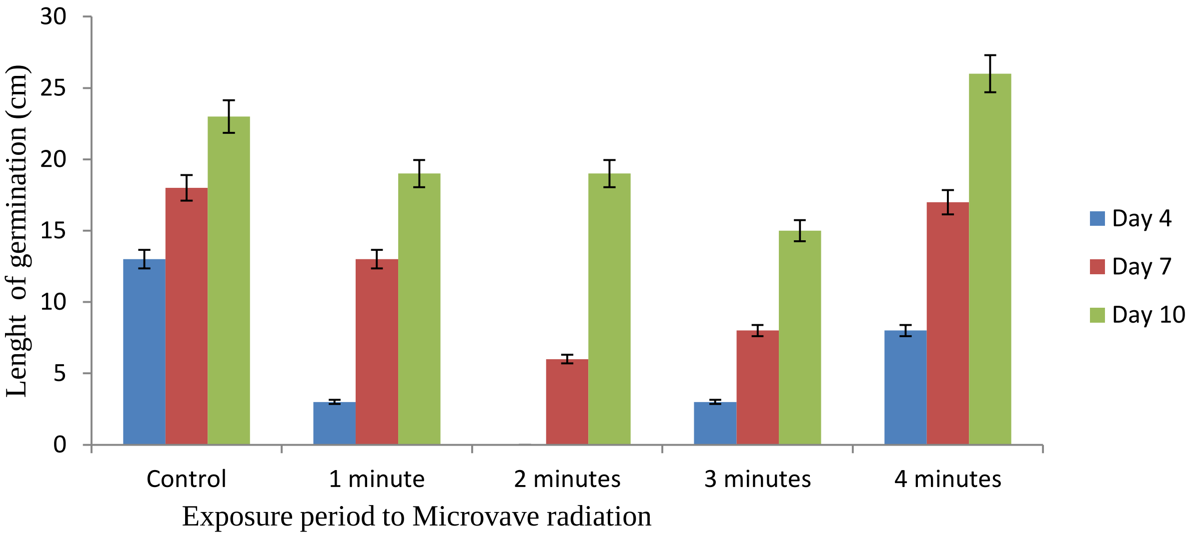

Figure 3: Shows the germination length of bean seeds within period of 10 days after exposure to low frequency of microwave radiation at time interval of 1, 2, 3 and 4 minutes

3.4 Germination of Bean Seeds Exposed to Medium Frequency of Microwave Radiation

Effects of medium microwave radiation on germination of bean seed seedlings at days interval was shown in figure 4. Apart from control other bean seeds were exposed to microwave at medium frequency with time interval of 1, 2, 3 and 4 minutes (Figure 4).

After day 4 of germination, control had length of 13 cm while the highest length of germination (18 cm) was observed in bean seeds exposed to radiation for 3 minutes and this was followed by values (15 cm) recorded for bean seeds exposed to microwave for 4 minutes (Figure 4). The values recorded for control is higher than those obtained (10 and 11 cm) after 1 and 2 minutes of exposure to medium microwave radiation (Figure 4).

Bean seeds exposed to radiation at period of 3 and 4 minutes had high lengths (24 and 20 cm) after day 7 of germinations compare to 18 cm recorded for control while bean seeds exposed to radiation for 2 minutes had similar length (18 cm) with control but length observed after a minute of microwave radiation is low after day 7 of germination (Figure 4).

All bean seeds exposed to radiation had high length of germination (23.5, 26, 30 and 25 cm) compare to values obtained for control (23 cm) after day 10 of germination (Figure 4). The highest length of germination (30cm) was recorded after bean seed was exposed to radiation after 3 minutes, next is 2 minutes exposure to microwave with length of 26 cm (Figure 4).

Throughout the trial days, the bean seedlings exposed to medium microwave radiation exhibited a higher germination rate. When evaluated at day 4, 7, and 10, those who were exposed for 3 and 4 minutes exhibited increased germination length. This suggests that exposing bean seeds to a microwave at a medium frequency will hasten germination. In a similar vein, Jakubowski (2010) found that microwave irradiating potato tuber variety Felka Bona for 10 seconds at a frequency of 2.45 GHz increased the weight and growth biomass in potato, whereas higher frequencies of 38, 46, and 54 GHz for 20 seconds had no effect on the weight of irradiated seed potato germs and potato tuber crop of variety Felka Bona

International Journal of Academic Multidisciplinary Research (IJAMR)
ISSN: 2643-9670
Vol. 5 Issue 9, September - 2021, Pages: 197-206

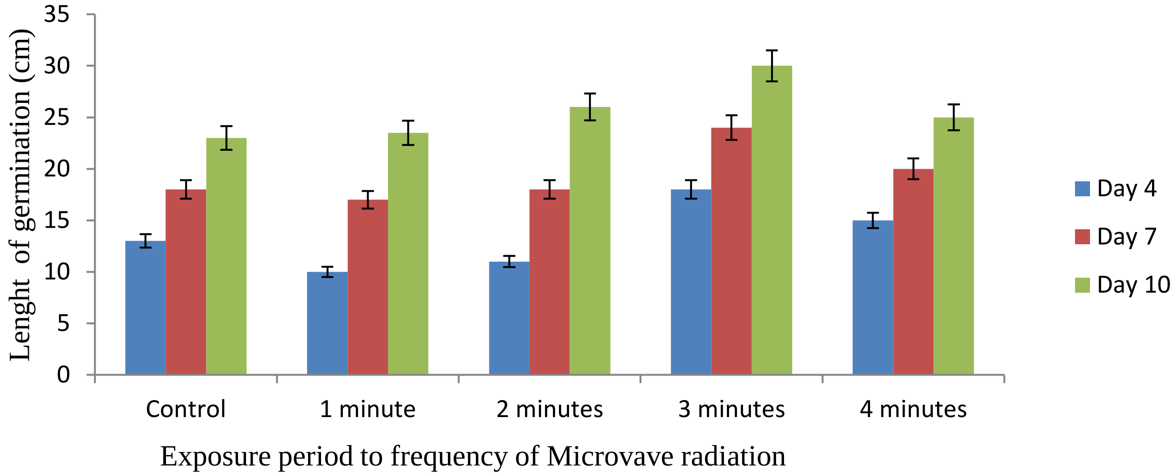

Figure 4: Shows the germination length of bean seeds within period of 10 days after exposure to medium frequency of microwave radiation at time interval of 1, 2, 3 and 4 minutes.

CONCLUSION

The microwave radiation utilized in this study increased seedling development and growth and enhanced grain germination. The findings of this experiment highlighted the need of exposing maize and bean seeds to the shortest amount of microwave time possible before sowing in seed beds to ensure a high percentage of seeds germinate and uniform seedlings. Different seed processing regimes were tested to see how they affected germination and growth rate. Plant germination and seedling vigour were found to be stimulated by the effects of various treatments, particularly in the power and exposure time treatments. Seed germination, seedling vigour, plant height, and bean seed samples using low microwave power and expo-sure time all show a decrease in trend as compared to control. When compared to control, medium frequency, on the other hand, stimulates seed germination in the majority of samples. In general, it was discovered that using a microwave has an influence on the revival of maize and bean seed germination at various doses. As a result, in addition to standard ways, it can be employed as a non-traditional mode of seed germination.

REFERENCES

Abu-Elsaoud, A. M. (2015). Effect of microwave electromagnetic radio frequency on germination and seedling growth consequences of six wheat *Triticum aestivum* L. cultivars. *Advances in Environmental Biology*, *9*, 270-280. https://www.researchgate.net/publication/286001801

Abu-Elsaoud, A. M., & Qari, S. H. (2017). Influence of microwave irradiations on germination, seedling growth and electrolyte leakage of Barley (*Hordeum vulgare* L.). *Catrina*, *16*, 11-24. https://cat.journals.ekb.eg/article_14255_56f69e03019247e811accc1f85ba70b5.pdf

Aladjadjiyan, A. (2010). Effect of microwave irradiation on seeds of lentils (Lens Culinaris, Med). *Romanian Journal of Biophysics*, *20*, 213–221. https://www.researchgate.net/publication/207703684

ALADJADJIYAN, A. 2002. Influence of microwave irradiation on some vitality indices and electro-conductivity of ornamental perennial crops. Journal of Central European Agriculture **3** (4).

Amirnia, R. (2014). Effect of Microwave Radiation on Germination and Seedling Growth of Soybean (Glycine max) Seeds. *Advances in Environmental Biology*, *8*, 311-314. https://www.researchgate.net/publication/316824478

Araujo, S. D., Paparella, S., Dondi, D., Bentivoglio, A., Carbonera, D., & Balestrazzi, A. (2016). Physical Methods for Seed Invigoration: Advantages and Challenges in Seed Technology. *Frontiers in Plant Science, 7*. doi:10.3389/fpls.2016.00646

Atmaca, S., Akdag, Z., Dasdag, S., & Celik, S. (1995). Effect of microwaves on survival of some bacterial strains. *Acta microbiologica et immunologica Hungarica*, *43*(4), 371-378

BALMORI, A. 2009. Electromagnetic pollution from phone masts. Effects on wildlife. Pathophysiology: the official journal of the International Society for Pathophysiology / ISP 16 (2–3): 191–199.

BANIK, S., S. BANDYOPADHYAY, AND S. GAN-GULY. 2003. Bioeffects of microwave a brief review. Bioresource technology 87 (2): 155–159

Bhattacharya, M., & Basak, T. (2017). A comprehensive analysis on the effect of shape on the microwave heating dynamics of food materials. Innovative Food Science & Emerging Technologies, 39, 247-266.

Brodie, G. (2011). Microwave heating in moist materials. In Advances in Induction and Microwave Heating of Mineral and Organic Materials: InTech.

Cavalcante, M. J. B., & Muchovej, J. J. (1993). MICROWAVE IRRADIATION OF SEEDS AND SELECTED FUNGAL SPORES. Seed Science and Technology, 21(1), 247-253.

CREȚESCU, I., R. CĂPRIȚĂ, G. VELICEVICI, S. ROPCIUC, AND G. BUZAMAT. 2013. Response of Barley Seedlings to Microwaves at 2.45 GHz. Scientific Papers Animal Science and Biotechn-ologies 46 (1): 185–191

Divekar, M. T., Karunakaran, C., Lahlali, R., Kumar, S., Chelladurai, V., Liu, X., . . . Jayas, D. S. (2017). Effect of microwave treatment on the cooking and macronutrient qualities of pulses. International Journal of Food Properties, 20(2), 409-422

Feng, H., & Tang, J. (1998). Microwave finish drying of diced apples in a spouted bed. Journal of Food Science, 63(4), 679-683.

Feng, H., Y. Yin and J. Tang. 2012. Microwave drying of food and agricultural materials: Basics heat and mass transfer modeling. Food Engin. Rev., 4(2): 89-106.

Friesen, A. P., Conner, R. L., Robinson, D. E., Barton, W. R., & Gillard, C. L. (2014b). Effect of microwave radiation on dry bean seed infected with Xanthomonas axonopodis pv. phaseoli with and without the use of chemical seed treatment. Crop Protection, 65, 77-85. doi:10.1016/j.cropro.2014.07.007

Gaurilcikiene, I., J. Ramanauskiene, M. Dagys, R. Simniskis, Z. Dabkevicius and S. Suproniene. 2013. The effect of strong microwave electric field radiation on wheat (Triticum aestivum L.) seed germination and sanitation. Zemdirbyste-Agriculture, 100(2): 185-190.

González, Z., & Pérez, E. (2002). Evaluation of lentil starches modified by microwave irradiation and extrusion cooking. Food Research International, 35(5), 415-420. doi:https://doi.org/10.1016/S0963-9969(01)00135-1

Govindaraj, M., Masilamani, P., Albert, V. A., & Bhaskaran, M. (2017). Effect of physical seed treatment on yield and quality of crops: A review. Agricultural Reviews, 38, 1-14. https://doi.org/10.18805/ag.v0iOF.7304

Grondeau, C., & Samson, R. (1994). A REVIEW OF THERMOTHERAPY TO FREE PLANT MATERIALS FROM PATHOGENS, ESPECIALLY SEEDS FROM BACTERIA. Critical Reviews in Plant Sciences, 13(1), 57-75. doi:10.1080/713608054

Gupta HS, Hossain F, Muthusamy V (2015a) Biofortifi cation of maize: an Indian perspective. Indian J Genet 75:1–22

Hansen, J., Johnson, J., & Winter, D. (2011). History and use of heat in pest control: a review. International journal of pest management, 57(4), 267-289

Hernandez-Infante, M., Sousa, V., Montalvo, I., & Tena, E. (1998). Impact of microwave heating on hemagglutinins, trypsin inhibitors and protein quality of selected legume seeds. Plant Foods for Human Nutrition (Formerly Qualitas Plantarum), 52(3), 199-208.

Irfan Afzal, H. U. R., Muhammad Naveed and Shahzad, Maqsood Ahmed Basra. (2016). Recent Advances in Seed Enhancements, New Challenges in Seed Biology doi: 10.5772/64791

Jakubowski, T. (2015). Evaluation of the impact of pre-sowing microwave stimulation of bean seeds of the germination process. Agricultural Engineering, 2, 45-56. http://dx.medra.org/10.14654/ir.2015.154.120

Jakubowski, T. 2010. The impact of microwave radiation at different frequencies on weight of seed potato germs and crop of potato tubers. Agricul Engin., 6(124): 57-64.

Jayas, D., & Ghosh, P. (2006). Preserving quality during grain drying and techniques for measuring grain quality. Paper presented at the 9 th International Working Conference on Stored Product Protection

Jones MS, Alexander CE, Smith B (2018). Economic consequences of post-harvest insect damage in Rwandan common bean markets. Crop Protection 104:92-100.

Keneni G, Bekele E, Getu E, Imtiaz M, Damte T, Mulatu B, Dagne K (2011). Breeding Food Legumes for Resistance to Storage Insect Pests: Potential and Limitations. Sustainability 3:1399-1415.

Kontar, A., Valevakhin, G., Buryak, Y. I., Bespalko, V., Ogurtsov, Y. Y., & Onischenko, O. (2015). Seed pre-treatment of grain and vegetable crops by microwave energy. Paper presented at the Antenna Theory and Techniques (ICATT), 2015 International Conference on.

Kretova, Y., Tsirulnichenko, L., Naumenko, N., Popova, N., & Kalinina, I. (2018). The application of micro-wave treatment to reduce barley contamination. Agronomy Research, 16, 2079- 2087.https://doi.org/10.15159/AR.18.198

Lee, D. S., Shin, D. H., & Yam, K. L. (2002). Improvement of temperature uniformity in microwave-reheated rice by optimizing heat/hold cycle. Food Service Technology, 2(2), 87-93.

LIN, J.C. 2004. Evaluating scientific literature on biological effects of microwave radiation. IEEE Microwave Magazine 5 (1): 34–37

López-Perea, P., Figueroa, J., Sevilla-Paniagua, E., Román-Gutiérrez, A., Reynoso, R., & Martínez-Peniche, R. (2008). Changes in Barley Kernel Hardness and Malting Quality Caused by Microwave Irradiation. J. Am. Soc. Brew. Chem, 66(4), 203-207.

Lorenson, C. P., Hewitt, B. C., Keefer, R., & Ball, M. D. (1991). Improved uniformity of microwave heating by control of the depth of a load in a container. In: Google Patents

M. C. Verdus, M. Thellier and C. Ripoll, “Storage of Environmental Signals in Flax: Their Morphogenetic Ef-fect as Enabled by a Transient Depletion of Calcium,” The Plant Journal, Vol. 12, No. 6, December 1997, pp. 1399-1410. doi:10.1046/j.1365-313x.1997.12061399.x

Mojica L, de Mejía EG (2015). Characterization and Comparison of Protein and Peptide Profiles and their Biological Activities of Improved Common Bean Cultivars (Phaseolus vulgaris L) from Mexico and Brazil. Plant Foods for Human Nutrition 70(2):105-112.

Nelson S. Potential agricultural applications for RF and microwave energy. Transactions of the ASAE. 1987;30(3):818–822.

Nelson, S. O. (1996). Review and assessment of radio-frequency and microwave energy for stored-grain insect control. Transactions-American Society of Agricultural Engineers, 39, 1475-1484

OPRICA, L. 2008. Effect of microwave on the dynamics of some oxidoreductase enzymes in Brassica napus germination seeds. Analele Stiinti-fice ale Universitatii "Alexandru Ioan Cuza" din Iasi Sec. II a. Genetica si Biologie Moleculara 9 (3).

PAKHOMOV, A.G., Y. AKYEL, O.N. PAKH-OMOVA, B.E. STUCK, AND M.R. MURPHY. 1998. Current state and implications of research on biological effects of millimeter waves: a review of the literature. Bioelectromagnetics 19 (7): 393–413

Pande, R., Mishra, H. N., & Singh, M. N. (2012). Microwave Drying for Safe Storage and Improved Nutritional Quality of Green Gram Seed (Vigna radiata). Journal of agricultural and food chemistry, 60(14), 3809-3816

Peyre, F., Datta, A., & Seyler, C. (1997). Influence of the dielectric property on microwave oven heating patterns: application to food materials. Journal of Microwave Power and Electromagnetic Energy, 32(1), 3-15.

Podleśny, J., S. Pietruszewski, and A. Podleśna. 2005. Influence of magnetic stimulation of seeds on the formation of morphological features and yielding of the pea. Int. Agroph. 19, 61-68

PONOMAREV, L., V. DOLGODVOROV, V. POPOV, S. RODIN, AND O. ROMAN. 1996. The effect of low-intensivity electromagnetic microwave field on seed germination. (in Russian). In: Proceedings of Timiryazev Agricultural Academy-2 1996; 42– 46.

Poogungploy, P., Poomsa-ad, N., & Wiset, L. (2018). Control of microwave assisted macadamia drying. Journal of Microwave Power and Electromagnetic Energy, 52(1), 60-72.

Prasanna BM (2014) Maize research-for-development scenario: challenges and opportunities for Asia. In: Prasanna BM et al (eds) 12th Asian maize conference and expert consultation on maize for food, feed and nutritional security, book of extended summaries, 30 October–01 November, Bangkok, Thailand, pp 2–11

RADZEVIČIUS, A., S. SAKALAUSKIENĖ, M. DAGYS, R. SIMNIŠKIS, R. KARKLELIENĖ, Č. BOBINAS, AND P. DUCHOVSKIS. 2013. The effect of strong microwave electric field radiation on: (1) vegetable seed germination and seedling growth rate. Zemdirbyste-Agriculture 100 (2): 179–184.

Ragha, L., S. Mishra, V. Ramachandran and M.S. Bhatia. 2011. Effects of low-power microwave fields on seed germination and growth rate. J. Electro. Anal. & Applicat, 3(5): 1-7.

Roy, ., Boye, J. I., & Simpson, B. K. (2010). Bioactive proteins and peptides in pulse crops: Pea, chickpea and lentil. Food Research International, 43(2), 432-442. doi:http://dx.doi.org/10.1016/j.foodres.2009.09.002

Silva Fontes, L., Silva, P. R. R., Neves, J. A., Melo, A. F., & Esteves Filho, A. B. (2016). Microwave radiation to control Callosobruchus maculatus (Coleoptera: Chrysomelidae) larvae in cowpea cultivars. Austral Entomology, 56(1), 70-74.

Tafforeau, M. C. Verdus, V. Norris, C. Ripoll and M. Thellier, "Memory Processes in the Response of Plants to Environmental Signals," Plant Sign Behav., Vol. 1, 2006, pp. 9-14. doi:10.4161/psb.1.1.2164

Tafforeau, M. C. Verdus, V. Norris, G. J. White, M. Cole, M. Demarty, M. Thellier and C. Ripoll, "Plant Sen-sitivity to Low Intensity 105 GHz Electromagnetic Ra-diation," Bioelectromagnetics, Vol. 25, No. 6, September 2004, pp. 403-407. doi:10.1002/bem.10205

Taheri, S., Brodie, G. I., & Gupta, D. (2019c). Heat uniformity study and viability of red lentil at different moisture contents after low dose microwave treatment. Transactions of the ASABE, 62(2), 281-288. doi:https://doi.org/10.13031/trans.13002

Tang, J., Ikediala, J., Wang, S., Hansen, J. D., & Cavalieri, R. (2000). High-temperature-short-time thermal quarantine methods. Postharvest Biology and Technology, 21(1), 129-145.

Tran VN. Effects of microwave energy on the strophiole, seed coat and germination of Acacia seeds. Functional Plant Biology. 1979;6:277–287.

Vadivambal, R., & Jayas, D. (2010). Non-uniform temperature distribution during microwave heating of food materials—A review. Food and Bioprocess Technology, 3(2), 161-171.

Vadivambal, R., & Jayas, D. (2010). Non-uniform temperature distribution during microwave heating of food materials—A review. Food and Bioprocess Technology, 3(2), 161-171.

Vadivambal, R., Jayas, D., Chelladurai, V., & White, N. (2009). Preliminary study of surface temperature distribution during microwave heating of cereals and oilseed. Canadian Biosystems Engineering/Le Genie des biosystems au Canada, 51, 3.45-43.52

Velu, V., Nagender, A., Rao, P. P., & Rao, D. (2006b). Dry milling characteristics of microwave dried maize grains (Zea mays L.). Journal of Food Engineering, 74(1), 30-36.

Vian, C. Henry-Vian and E. Davies, "Rapid and Sys-temic Accumulation of Chloroplast mRNA Binding Pro-tein Transcripts after Flame Stimulus in Tomato," Plant Physiology, Vol. 121, No. 2, 1999, pp. 517-524. doi:10.1104/pp.121.2.517

Wang, S., Wang, J., & Guo, Y. (2018) Microwave irradiation enhances the germination rate of tartary buckwheat and content of some compounds in its sprouts. Polish Journal of Food and Nutrition Sciences, 68, 195-205. https://doi.org/10.1515/pjfns-2017-0025

Wang, S., Yue, J., Tang, J., & Chen, B. (2005). Mathematical modelling of heating uniformity for in-shell walnuts subjected to radio frequency treatments with intermittent stirrings. Postharvest Biology and Technology, 35(1), 97-107.

Yadav, D. N., Anand, T., Sharma, M., & Gupta, R. (2014). Microwave technology for disinfestation of cereals and pulses: An overview. Journal of food science and technology, 51(12), 3568-3576.

Zhang, H., Hayert-Bonneveau, L., Yout, W., Helstern, G. C., & Loizeau, G. (2004). Uniform microwave heating of food in a container. In: Google Patents.