# Application of Microwave in Agriculture

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**Abstract—***Electromagnetic radiations have many agricultural applications like imaging, remote sensing, dielectric heating, pre-harvest and post harvest treatment. The thermal heating brought about by the microwave can be efficiently used to disinfect food as well as non-food materials, soil and importantly it can be used to kill pests and bacteria's. This paper focuses on the effects of microwave heating of seeds and even weed killing that is brought about by heating. Microwave heating in seeds can enhance the seedling mass, promote germination and even cause an increase in the length of stems and roots. As the microwave heating is completely related to the dielectric constant of a medium. The dielectric properties of the agricultural produce, weeds, insects, pests and even the human tissues is measured and then we need to select an appropriate spectrum of frequency which can control and kill the weeds, insects and pests. The idea behind pest control is that pest and insects are mainly composed of water and the water content in their body is higher than any other materials that are present in the cropping environment. The heating method completely relies on the dielectric properties of the weed plants and the surrounding. The aim is to warm the weed plants without affecting the surrounding. This can be done if we precisely measure the difference in dielectric properties of materials at a specific frequency. We need to search for a particular frequency at which the pests and the agricultural materials have the highest difference in dielectric constant. At this particular frequency the pests and weeds readily absorb the electromagnetic energy but the product plants don't. The application of electromagnetic waves in agriculture have proved to be an environmental friendly method to control pests, weeds and insects without compromising the texture and taste of the agricultural produce*

## 1. . INTRODUCTION

The frequency region from 300MHz to 300 GHz of the electromagnetic spectrum corresponds to the microwave region. These waves propagate through the space as time varying electric and magnetic fields [1]. The entire microwave spectrum is further sub-divided into many smaller bands. Microwaves are unique as they can travel through lossy mediums, resulting in an increase in temperature of the medium. This uniqueness has led to the application of microwaves in agricultural and food industries. The heat generation in microwaves is due to the interaction between the medium and the microwave. The dissipation of energy depends on the frequency of the wave and the characteristics of the medium. The microwave energy is usually dissipated in form of heat throughout the medium. This volumetric heat generation [2] causes rapid heating and is a highly energy efficient method. The microwave heating has many industrial applications like the pest control [3], metal casting[4] , oil extraction from tar, increasing crop production, drying and enhancing the quality of crop, and controlling weeds n cropping system[5,6]. The microwave radiations are being readily used in agriculture as these radiations enable fast, continuous and non-destructive monitoring without contaminating the material. These radiations are much safer as compared to the ionizing radiations and are relatively insensitive to dust, wind, water vapor and other degrading environmental conditions. Microwaves can be used for drying of products. It is advantageous as it causes internal vapor pressure which brings the moisture out resulting in an improved quality of food products. The conventional methods for controlling weeds in a cropping system include the chemical and mechanical processes. The use of insecticides, herbicides, and pesticides can cause various health related issues as well as can hamper the soil quality. These environmental concerns have led to an increasing interest for the non-chemical weed control mechanisms. The efficient interaction between microwave and agriculture can result in higher and better agricultural produce. Efforts are being made to understand the underlying physics to employ microwaves efficiently in agriculture.

## 2. THE GENERAL PRINCIPLES OF MICROWAVE HEATING

The permittivity ε and permeability μ of a material determines its interaction with the electromagnetic fields. Dielectric constant is a parameter which is specific for a material and it describes its ability to store electric energy. Loss factor is again another such parameter which represents the loss of electric energy. Permittivity can be represented in terms of both loss factor and the dielectric constant as:

$$\varepsilon = \varepsilon' x - \mathrm{j}\varepsilon''$$

where $\varepsilon'$ is the dielectric constant and $\varepsilon''$ is the loss factor. Now the relative permittivity can be obtained by normalizing the material permittivity to that of the permittivity of vacuum:

$$\varepsilon_r = \frac{\varepsilon}{\varepsilon_0} - \mathrm{j}\,\frac{\varepsilon''}{\varepsilon_0}$$

where $\varepsilon_0$ = 8.854 X $10^{-12}$ F/m.

Now the relative loss factor $\varepsilon_r'' = \frac{\varepsilon''}{\varepsilon_0} = \frac{\sigma}{2\pi f_0 \varepsilon_0}$

is a function of both conductivity (σ) and the operating frequency $f_0$ .Hence the dielectric properties of the agricultural produce are found to depend on the temperature, operating frequencies, composition, physical state and density. The composition here in particular represents the composition of water and salt content in a material. The heat generated due to microwave in any material is given by the relation:

$$H= 5.5.6 \text{ X } 10^{-14} \text{ X } f_0 \, \varepsilon'' \, E^2$$

where H represents the converted thermal energy in W/cm$^3$, $\varepsilon''$ represents the relative loss factor,$f_0$ is the microwave frequency in GHz and the electric field intensity in V/cm is represented by E.

The interaction between microwave and the medium results in heat generation. The generated heat is dependent on both the moisture content and the dielectric constant of the medium. Microwave heating is because of the simultaneous moisture and heat diffusion in the material. A rapid moisture and heat diffusion through biological material yields faster heating as compared to the conventional heating system.

The geometry of microwave applicators can be employed to provide non-uniform heating. Applicators with larger cross section can provide faster microwave heating. This microwave heating is used for killing weeds and controlling insects in agriculture. It is one of the fastest methods which do not keep any chemical residue. Microwave heating is beneficial as it produces highest heating in the core of the stem, which then results in permanent rupture of the plant. The conventional heating indeed produces the least temperature at the core of the stem and highest at the surface. The microwave applications are dominated by the fastest diffusing waves whereas the conventional heating techniques are characterized by the slower waves. The effect of heating the seeds using microwave frequencies was first studied by Davis et al. [7, 8]. The applications of transmitted microwave to the seeds are listed below.

### 2.1 Promoting germination

Microwaves can be used to simulate growth and seed germination. This dry method is being used for unfolding the seed coating has far beneficial results as compared to the conventional boiling water mechanism. Plants like Accacia have a waterproof coating which impedes germination. After being micro waved the resulting seeds can be stored for a longer period of time and even remain more viable.

### 2.2 Increasing length of stems and roots

An increase in the length of stems and root in some plant species can be obtained by employing microwave techniques. Microwaving of seeds have shown a dramatic increase in both the stem and root length. The agricultural University of Bulgaria has researched that microwaving the lentil seeds at 450W for a time period of 30secs resulted in about 10 percent longer stems and about 7 percent longer roots. When the application time was increased to about 60 seconds, it resulted in seeds having 9 percent longer stems and about 6.5 percent longer roots. A further increase in the heating time for about 90 seconds showed severely negative results.

### 2.3 Enhancing seedling mass

Microwave treatment can be used to enhance the total mass of the seedling. The Bulgarian University revealed that when the seedling was exposed to 450 W of microwave treatment for about 30 seconds and was measured at the 14$^{th}$ day, the total mass was found to be 16 percent higher than the usual mass. An exposure time of 60 seconds boosted the seedling mass by 36 percent. Considering the later stages of growth, it was found that treating the seed for about 30 seconds with 450 Watt of microwave energy gives the best result.

## 3. DIELECTRIC PROPERTIES OF PLANTS

The dielectric constant of material increases with an increase in moisture content. The materials with higher dielectric constant interact more readily with microwave radiations and therefore are more susceptible to microwave damage. The loss of moisture is linearly associated with microwave heating. Thermal runaway is a phenomenon in which there is a sudden rise in temperature in a very short period of time. As the plants are heated up, the moisture content gets lower and eventually the dielectric constant becomes less. A lower dielectric constant allows an increased transmission across the surface of the material, as a result of which more and more energy is transferred to the material leading to the phenomena of thermal runaway. This thermal runaway can cause undesirable destruction during microwave heating [9], but it can have beneficial applications when it is used efficiently. Thermal runaway can induce internal stem pressure which will lead to stem rupture in several weed plants like paddy melon and fleabean. If the dielectric properties of the weed plants and the crop plants are significantly distinguishable, measures can be taken to bring about thermal runaway for weed plants during microwave heating. Thermal runaway can kill weed plants in a cropping environment when these specific heating conditions are maintained appropriately.

## 4. MICROWAVE DRYING

The drying mechanism in process industries consumes an intensive amount of energy. The conventional hot-air drying methods demands a prolonged drying time, because of which the final product is degraded in quality. Volumetric heating at about 2.45 GHz facilitates microwave drying. The microwave drying process should not be used individually and is used to assist other drying processes.

A combination of hot-air drying with microwave heating is widely accepted [10]. Microwave exposure can result in highly porous and dried products if it employed individually during the initial stages of drying. Therefore these are used during the final stages of drying to reduce shrinkage [11] and shorten the total drying time. Microwave drying brings about 25-90 percent [12, 13] reduction in drying time and the drying rate is increases by a factor of four [14, 15] as compared to the conventional drying techniques. The products dried using microwaves are found to have higher porosity [16], better rehydration[17, 18], better aroma retention[19] and better color retention [20]. This process is being adopted in a slower pace by the industries due to the complexities in designing of microwave drying chambers.[21].

## 5. MICROWAVE TREATMENT OF WEEDS, INSECTS AND PESTS

Microwave heating of seeds is already discussed in the previous section. This section emphasizes the use of microwave heating for pests and weed killing purposes. The agricultural industries invest a heavy amount in weed management strategies. The conventional chemical fumigation methods have various disadvantages. Besides their simplicity, the continuous use of chemical fumigants like Methyl Bromide can reduce the thickness of Ozone layer.

The interactive relation among several branches of science and technology has brought about improvements in interdisciplinary fields like agriculture. The use of electromagnetic radiations does not keep any residues and hence is considered to be one of the fastest developing environmental friendly methods for weed and pest control. The microwave radiations have larger application periods as these are not affected by winds. It even facilitates selective heating through which only the desired plants can be targeted without hampering the adjacent ones. This principle is extensively used in activities relating to spot-weed control.

The cost constraint both in form of the equipment cost as well as the energy requirement cost, limits the use of microwave heating. The presence of lossy unwanted targets in open environment leads to energy losses. The microwave applications can be made cost effective by improving the polarization field of microwave such that it functions only for some particular targets. When the non-polarized microwave radiations are induced in the weeds, they may not induce current in sensitive parts of the weed plant in order to kill them. Hence polarization of microwave radiation is important to carry out the desired operation. The standing wave patterns will have deep minima’s if we use a single microwave source to feed a single antenna or a small number of antennas. The weed located in the field minima’s will survive these radiations as the heating effect in these minima is too low for rupturing the weed plants.

A moving microwave source can solve the problem of deep minima’s and the standing waves generated due to this moving source will remain unaffected in the perpendicular direction. A moving microwave source indeed should produce efficient spatial incoherent fields in at least one direction. Many microwave sources like magnetrons can be operated independently and in an unsynchronized manner to develop spatially incoherent fields. The magnetrons feed energy to the horn antennas as the horns have large radiating apertures. The horns are usually wide open in the H plane and are stacked in the E plane. The larger phase error in the H plane is used to diminish the coupling between the adjacent apertures.

The following Fig. corresponds to a prototype of a stacked horn antenna which can be employed for weed killing. Here the standard magnetron is operating at 2.45 GHz and the waveguide dimensions are chosen to be 80X 85 cm. The length of the wider section was taken to be 52 cm for achieving minimum crosstalk.

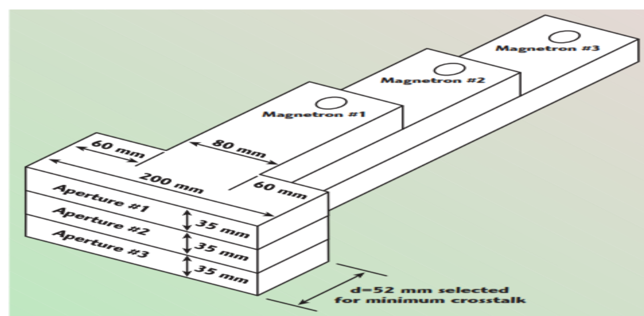


**Fig. 1: Design of Horn antenna Array**

This design can be implemented to develop a stacked horn antenna which uses microwave frequencies to kill weeds.

Species of weeds like Marsh mellow seedlings( Malva Parviflora), paddy melon and fleabean (conyza bonariensis) were observed under microwave treatment by Brodie et al.[10] and their probability of survival under microwave radiation was found to follow a simple logistic response function given as:

$$S_{survival} = \frac{1.0}{1+(\Psi/a)^n}$$

Where a and n are the response parameters and

$\Psi$ is the applied microwave energy in $Jcm^{-2}$.

$S_{survival}$ represents the probability of survival of species.

Considering the experimentally calculated response parameters of the following species as mentioned in the table below, simulations were carried out using the MATLAB.

| Species | Response Parameters | |
|---|---|---|
| | a(Jcm-2) | n |
| Fleabean | 201.5 | 10 |
| Marsh mellow | 162 | 20 |
| Paddy Melon | 145 | 20 |

The simulation results for computing the probability of survival using MATLAB are shown :

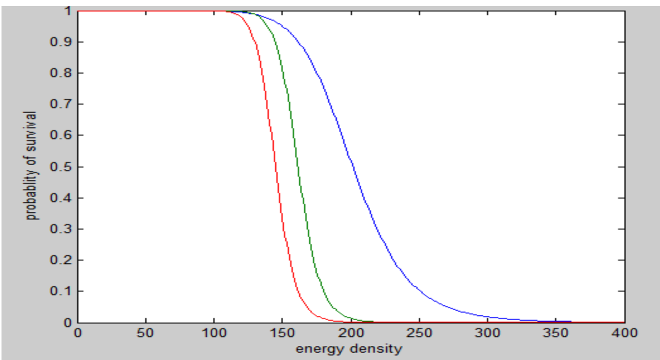


**Fig. 2: Simulation results for Probability of Survival of Paddy Melon, Fleabane and Marsh mellow.**

The red, green and blue curves represent Paddy Melon, Fleabane and Marsh mellow respectively. It can be seen that Fleabean is more susceptible to microwave damage as compared to the Marsh mellow weed species. Paddy melon indeed has the highest susceptibility among the three observed species. The simulated result makes it clear that an energy of about 350 $Jcm^{-2}$ is sufficient to kill all the three observed species. Hence the antenna is to be fed with such energy that it delivers a minimum energy of 350$Jcm^{-2}$ to destroy the weeds. As the weeds and pests have a higher concentration of water and moisture as compared to that of the crop, they cannot survive these high radiations. The crop and other agricultural produce with lesser moisture content as compared to pests and weeds can easily withstand such radiations.

## 6. CONCLUSION

There are many potential applications of microwave and RF frequencies in agriculture. The advancement in techniques for precise measurement of dielectric properties of various materials in a cropping environment can be exploited to facilitate microwave drying, microwave heating of seeds, pest and weed control, and even for many more applications which have not yet been developed and discussed.

## REFERENCES

[1] Hao Feng, Yun Yin, Juming Tang (2012) Microwave drying of Food and Agricultural Materials: Basic Heat and Mass Transfer Modelling .

[2] Zielonka P and Dolowy K (1998) Microwave Drying of Spruce: Moisture Content, Temperature and Heat Energy Distribution. Forest Products Journal. 48: 77-80.

[3] Graham Brodie, Carmel Ryan, Carmel Lancaster, " Microwave Technologies as part of an Integrated weed Management strategy: A review(2012). Hidwani Publishing Corporation.

[4] Ayappa K G, Davis H T, Crapiste G, Davis E J and Gordon J (1991) Microwave heating: An evaluation of power formulations. Chemical Engineering Science. 46: 1005-1016.

[5] D. Batlla and R. L. Benech-Arnold, "Predicting changes in dormancy level in weed seed soil banks: implications for weedmanagement," *Crop Protection*, vol. 26, no. 3, pp. 189–197, 2007.

[6] E. F. Bebawi, A. P. Cooper, G. I. Brodie et al., "Effect of microwave radiation on seed mortality of rubber vine (*Cryptostegia grandiflora* R.Br.), parthenium (*Parthenium hysterophorous* L.) and bellyache bush (*Jatropha gossypiifolia* L.)," *Plant Protection Quarterly*, vol. 22, no. 4, pp. 136–142, 2007.

[7] F. S. Davis, J. R. Wayland, and M. G. Merkle, "Ultrahighfrequency electromagnetic fields for weed control: phytotoxicity and selectivity," *Science*, vol. 173, no. 3996, pp. 535–537, 1971

[8] F. S. Davis, J. R.Wayland, and M. G. Merkle, "Phytotoxicity of a UHF electromagnetic field," *Nature*, vol. 241, no. 5387, pp. 291–292, 1973.

[9] G. Brodie, S. Hamilton, and J. Woodworth, "An assessment of microwave soil pasteurization for killing seeds and weeds," *Plant Protection Quarterly*, vol. 22, no. 4, pp. 143–149, 2007.

[10] Andre´s A, Bilbao C, Fito P (2004) Drying kinetics of apple cylinders under combined hot air-microwave dehydration. J Food Eng 63:71–78

[11] Feng H, Tang J, Cavalieri RP, Plumb OA (2001) Heat and mass transport in microwave drying of porous materials in a spouted bed. AIChE J 47:1499–1512

[12] Feng H, Tang J, Mattinson DS, Fellman JK (1999) Microwave and spouted bed drying of blueberries: the effect of drying and pretreatment methods on physical properties and retention of flavor volatiles. J Food Process Preserv 23:463–479

[13] Feng H, Tang J, Cavalieri R (1999) Combined microwave and spouted bed drying of diced apples: effect of drying conditionson drying kinetics and product temperature. Invited contribution to the special Hall Issue. Dry Technol 17:1981 1998

[14] Brygidyr AM, Rzepecka MA, McConnell MB (1977) Characterization and drying of tomato paste foam by hot air and microwave energy. Can Inst Food Sci Technol J 10:313–319

[15] Maskan M (2001) Drying, shrinkage and rehydration characteristics of kiwifruits during hot air and microwave drying. J Food Eng 48:177–182

[16] Torringa HM, Dijk EJV, Bartels PV (1996) Microwave puffing of vegetables: Modeling and measurements. In: Proceedings of 31st microwave power symposium, pp 16–19

[17] Drouzas AE, Schubert H (1996) Microwave application in vacuum drying of fruits. J Food Eng 28:203–209

[18] Feng H, Tang J (1998) Microwave finish drying of diced apples in a spouted bed. J Food Sci 63:679–683

[19] Nury FS, Salunkhe DK (1968) Effects of microwave dehydration on components of apples. USDA, ARS

[20] Tulasidas TN, Raghavan GSV, Mujumdar AS (1995) Microwave drying of grapes in a single mode cavity at 2450 MHz–II:quality and energy aspects. Dry Technol 13:1973–1992

[21] Nijhuis HH, Torringa E, Luyten H, Rene´ F, Jones P, Funebo T,Ohlsson T (1996) Research needs and opportunities in the dry conservation of fruits and vegetables. Dry Technol 14:1429–1457

[22] P. Zielonka, E. Gierlik, M. Matejak, and K. Dolowy, "The comparison of experimental and theoretical temperature distribution during microwave wood heating," *Holz als Roh -und Werkstoff*, vol. 55, no. 6, pp. 395–398, 1997.