EFFECT OF DIFFERENT WAVEGUIDE GEOMETRIES ON MICROWAVE WEED CONTROL TECHNIQUE

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Abstract. It is a known fact that the use of pesticides should be reduced due to their pollution of soil and water and their carcinogenic effects on human health. Microwave weed control method, which is one of the candidate techniques to be an alternative (non-chemical) weed control method. In this study, the effect of waveguides on the scattering of microwaves and their target arrival speed was investigated by using waveguides with three different geometries. Experimental results using three different waveguides were compared with applications without using a guide. In addition, wild mustard (*Sinapis arvensis*), cress (*Lepidium sativum*) and arugula (*Eruca sativa*) plants were germinated under laboratory conditions to be used in the study. Germinating 1-week-old weed samples were exposed to microwaves at 1 kW power and 2.45 GHz constant frequency for 60 seconds. The experiment was repeated three times for each waveguide geometry. NDVI (Normalized Difference Vegetation Index) values of plants were measured before microwave exposure. In the experiments, approximately 58%, 34% and 36% mortality rates were observed in arugula (Eruca sativa) with waveguides number 1, 2 and 3, respectively. Ansys HFSS (High Frequency Structural Simulator) 3D electromagnetic (EM) simulations of waveguides have also revealed the importance of waveguide geometry.
Keywords: *agriculture, environment, alternative weed management, herbicides, health*

Introduction

Basic physical control methods were used to control weeds that caused significant economic losses in agricultural production activities. Later, the use of herbicides in the fight against weeds became widespread and the most preferred method of control due to their easy application, effectiveness, and low cost. However, due to the possibility of herbicides used in weed control mixing with drinking water, polluting the soil and leaving residues in agricultural products, alternative (non-chemical) methods were tried to be developed.

Non-chemical methods such as electric current (Sahin, 2020, 2022), microwave (Sahin, 2014), laser and thermal hot steam (Muscalu et al., 2017; Marx et al., 2012; Bauer et al., 2020) are used in the literature as "alternative methods". In recent years, methods called "Alternative Methods" have begun to come to the fore as more environmentally friendly methods.

It is also known that long-term use of herbicides in agricultural fields causes weeds to become resistant to these herbicides (Hussain et al., 2018). This situation further increases the interest in alternative control methods. In parallel with these methods, field-specific weed control management (SSWM; site-specific weed management) in large-scale agricultural areas also offers new solutions with robotics and artificial intelligence applications (Gée and Denimal, 2020).

Chemicals used in weed control are widely used in both agricultural and non-agricultural areas. However, research has revealed that these chemicals also mix with drinking water, reducing water quality and threatening human health (Dede and Sezer, 2017). It has been stated in scientific research that some herbicide types detected in

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drinking water can only be separated using special purification methods. It has been determined that residues of herbicides such as norflurazon and oxadiazon can be detected in plants and soil even after a month, and this poses a danger to human health (Kahlau et al., 2020).

In addition to the effects of agricultural chemicals on human health, their effects on animals such as bees, birds, and fish, microorganisms, and invertebrates are also very serious. Known side effects of herbicides include long-term effects such as the death of nontarget organisms and changes in ecosystem structure and species numbers (Asad et al., 2017; Fallah et al., 2020).

In studies on weed control with microwave energy, it is stated that it also neutralizes plant roots and seeds buried a few centimetres deep in the soil (Sahin, 2014). Most of the studies conducted under experimental conditions aimed to determine the best microwave treatment based on power, time, and soil moisture to prevent the germination of invasive species, and the importance of seed burial depth was also emphasized (Hess et al., 2018). The study, which was conducted to determine the amount of energy required for the control of weeds, was carried out with rye and rapeseeds that were germinated and exposed to microwaves.

The study emphasized that to accurately measure a weed's exposure to microwave radiation, the time between the time electricity is applied to the magnetron and the emission of microwave radiation must be known. Incomplete and incorrect evaluations may negatively affect the perception of alternative control methods. Possible incorrect energy consumption calculations will cause the perception that these methods consume excessive amounts of energy (Rana and Derr, 2017).

It is also concluded that high-energy microwaves seem to be a good alternative, as they effectively neutralize weeds and do not produce chemical residues (Rana and Derr, 2017). Furthermore, in studies, it has been determined that the yields of agricultural products increase in soils exposed to microwave energy, which can also be expressed as a side effect of microwave exposure (Khan et al., 2018). In a similar study, the possibilities of application in the seed industry were also discussed using parameters such as frequency, electric field, seed moisture content, and temperature that lead to increased germination in alfalfa seeds exposed to microwaves. In another study, it was reported that high germination rates were obtained after the application of Hordeum vulgare (barley) seeds with 400 W microwave output power. Mortality rates varying between 4.5% and 89% were obtained in Sinapis arvensis (wild mustard), Avena fatua (wild oat) and Lepidium sativum (cress) plants in the study, which was carried out applying a 2.45 GHz microwave and 4 different power levels.

Although there is concern that microwaves may cause genetic changes in food products or plants in microwave drying, heating, cooking, and other applications, more research is needed to get a concrete answer to mutagenic/carcinogenic activity (Mekki and Badr, 2013).

On the other hand, thermal leaks that occur during microwave applications are known to also cause a significant loss of energy, which reduces the efficiency of the application and creates a false perception of microwave heat treatments. It has also been stated that knowing the dielectric properties of agricultural products in heat treatments using microwave and radiofrequency will increase the efficiency of the application (Taheri et al., 2018). One of the important problems encountered in heat treatment studies with microwaves is the non-uniform heat distribution. In a study with a 1 kW 2.45 GHz microwave applicator with a vertically slit-loaded array waveguide to improve heating

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uniformity, an improvement of up to 77.4% was achieved at 2.45 GHz compared to a conventional microwave applicator (Ahn and Lee, 2020).

Today, there are many new approaches to weed control, including artificial neural networks and robotic technologies (Monteiro et al., 2021). It is important to reduce the losses due to weed control, which cause significant losses in many agricultural products such as sesame, by using nonchemical environmental methods (Lins et al., 2019). Studies have been carried out showing that the use of high technology in agricultural areas also reduces the abundance of weeds (Werle et al., 2021). Furthermore, widely used herbicides in the control of agricultural weeds have caused undesirable plants to develop resistance to all kinds of herbicides. This has increased the orientation towards electrical/mechanical weed control methods in an electrical/mechanical weed management strategy (Kahn et al., 2021). It is also important to know which method is more suitable for which weed control by comparing mechanical, physical, and chemical weed control methods (Faleiro et al., 2022).

In experimental studies on electrical/mechanical weed control methods, it is important to accurately determine the mortality rates of plants. As far as is known, the NDVI technique is used for the first time in this study to calculate the mortality rate of weeds. The normalized difference vegetation index (NDVI) is a widely used method to determine plant growth and mortality rates (Rodrigues et al., 2021).

As the harms of herbicides are revealed and the environmental awareness of humans increases, interest in nonchemical weed control methods (Banaras et al., 2020) (especially electric current and microwave) will increase. Furthermore, it is a known fact that long-term use of some herbicides creates resistance in weeds, making control even more difficult (Bonow et al., 2018).

The aim of this study is to investigate the effect of different waveguide geometries used in microwave weed control technique on the efficiency of the application. Therefore, non-chemical weed control methods need to be developed to maintain ecological balance and support sustainable agricultural activities. The microwave weed control method, which is one of the candidate techniques to be an alternative (non-chemical) weed control method, is the method on which the most scientific studies have been conducted, even though it is a technology under development. In this study, the effect of waveguides on the scattering and target arrival rates of microwaves was investigated by using waveguides with three different geometries. Experimental results using three different waveguides were compared with the applications made without using a guide. Additionally, wild mustard (Sinapis arvensis), cress (Lepidium sativum), and arugula (Eruca sativa) plants were germinated under laboratory conditions to be used in the study. Germinated 1-week-old weed samples were exposed to microwaves at 1 kW power and 2.45 GHz constant frequency for 60 seconds. The experiment was repeated three times for each waveguide geometry. The NDVI (Normalized Difference Vegetation Index) values of the plants were measured before microwave exposure. The NDVI values of samples exposed to microwaves, kept at an appropriate temperature and humidity in the air-conditioning cabinet, were measured after 1 week.

Materials and Methods

Air conditioning cabinet: To germinate the plant seeds at a temperature of 20-22 °C and 60-70% humidity, a Laborteknik IK-300 air conditioning cabinet was used with temperature, humidity and light controlled.

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Microwave application cabinet: The microwave application cabinet with dimensions of 60 cm x 40 cm x 30 cm is made of sheet metal with a wall thickness of 2 mm. The magnetron output, which is mounted on the upper surface of the cabinet and emits a microwave frequency of 2.45 GHz with a power of 1 kW, made by *Hangzhou Gangchun Electric Appliance Co., Ltd.*, opens into the waveguide cabinet (*Figure 1*). During microwave applications, microwave leaks were tried to minimize by closing the cabinet with a suitable metal cover

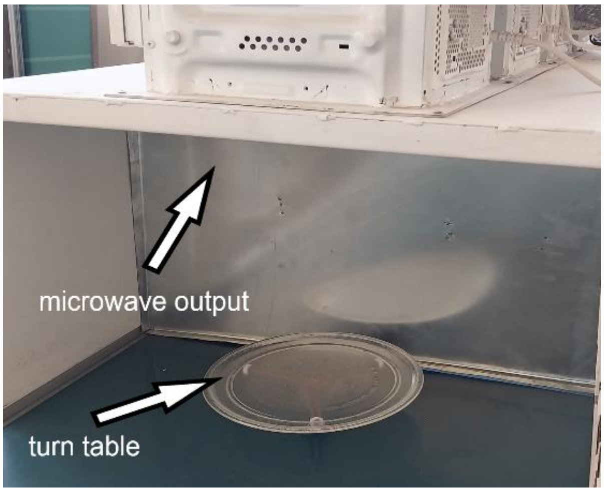

Figure 1. *Microwave application unit*

NDVI (normalized difference vegetation index) Meter: NVDI values before the exposure of the plants to electric current and 1 week after application were measured with the TRIMBLE Green Seeker handheld device (*Figure 2)*. The emission wavelengths of the device are red 660 nm, 25 nm FWHM, near-infrared 780 nm, and 25 nm FWHM, and the field of view of the device is 25 cm at 60 cm or 50 cm at 122 cm.

Figure 2. *Trimble GreenSeeker handheld NDVI meter device (Trimble, 2023)*

Microwave leakage detector: The Trotec BR15 model microwave leak detectors were used to measure possible microwave leaks and minimize risks during microwave applications (*Figure 3*). The detectors have a safety limit sensitivity of 5 mW/cm². Microwave leak detection device with frequency calibration of 2.450 MHz and measuring in the range of 0-9.99 mW/cm^2, its sensitivity; ± 1 dB and the warning limit value is 5 mW/cm².

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Figure 3. *Microwave leakage detectors*

Waveguide Attachments

To determine the effect of waveguide geometry on thermal distribution and microwave density in microwave weed control applications, three guide attachments with different geometries were produced and used in the study (*Figure 4*).

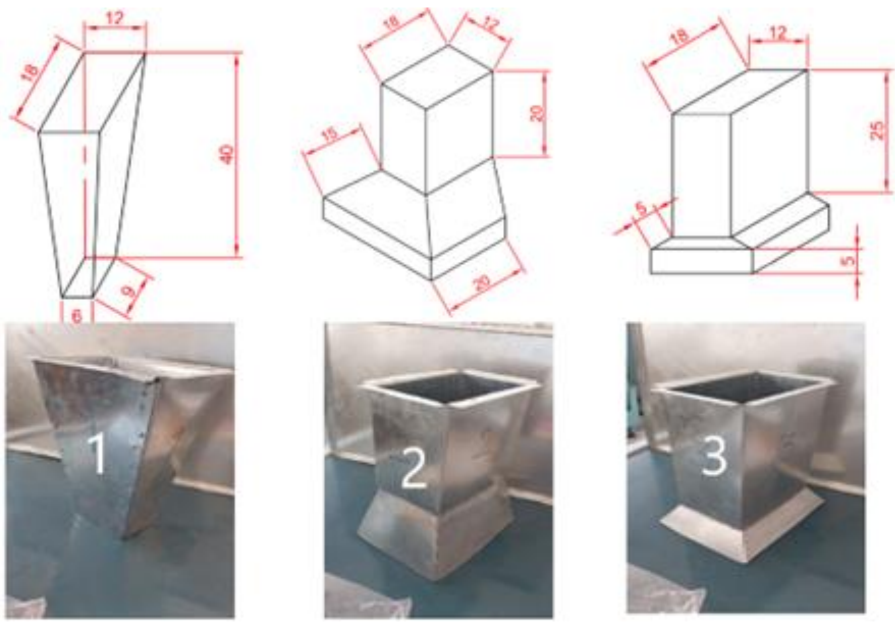

Figure 4. *Microwave guides number 1, 2 and 3 (lengths in cm)*

Biological Material

Wild mustard seeds *(sinapis arvensis)*, cress *(lepidium sativum)*, and arugula *(eruca sativa)*, which are easily available weeds, were preferred for use in the experiments. The weed seeds used in the experiments were obtained from the local market manufacturers.

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Experimental Method

To measure the heat dissipation and microwave intensities created by three microwave guide attachments with different geometries, prepared 400 g water masses were exposed to the microwave for 60 seconds. By measuring the pre-application and post-exposure temperatures, the amount of energy stored by the water bodies was calculated for all three waveguides. With these obtained temperature values, the temperatures of the same amount of water masses applied to the microwave were compared without using the guide attachment.

Wild mustard seeds *(sinapis arvensis)*, cress *(lepidium sativum)*, and arugula *(eruca sativa)* seeds were germinated in a total of 4 pieces of 30-mesh pots, one for the control group and three for the sample. The germinated weed seeds were then used in experiments with wave guides numbered 1, 2 and 3.

The plants were kept in an air conditioning cabinet at a temperature of 20-22 ° C, with an average light intensity of 950-1150 lux and a humidity of 45-55% during the pre-experiment and post-experiment observation period. Germinated weed samples were exposed to a microwave at a power of 1 kW and a frequency of 2.45 GHz for 60 s using three different types of microwave guide attachments for 1 week (*Figure 5*).

Figure 5. *Microwave applications using microwave guides number 1, 2, and 3*

The temperature and moisture values of the soil were recorded before and after microwave exposure. Before the application ($NDVI_1$) and 1 week after the application ($NDVI_2$), the values were measured and recorded. The mortality rates of plants exposed to microwaves were determined by calculating the difference between the $NDVI_2$ and $NDVI_1$ values.

Statistical Analysis

In the calculation of the sample size of this study, which was carried out for the "comparison of mortality rates in three different weed plants by using 3 waveguides with different geometries designed to detect the effect of different waveguides in microwave weed control", power (power of test) was used for each variable taking at least 80% and type 1 error 5%. The normality of the continuous variables in the study was determined by the Shapiro-Wilk (n<50) test, and nonparametric tests were applied since some of the measurements were not normally distributed. Descriptive statistics values for continuous variables in the study; expressed as mean, standard deviation, median, minimum, and maximum. The 'Kruskal-Wallis H test' was used to compare measurements according to groups (guidelines).

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After the Kruskal-Wallis test, the "Posthoc Test with Bonferroni correction" was used to determine the different groups. The statistical significance level (a) was taken as 5% in the calculations and the SPSS (IBM SPSS 26) statistical package program was used for the calculations.

Ansys HFSS (High-Frequency Structural Simulator) Analysis

The results obtained by 3D electromagnetic (EM) simulation of waveguides 1, 2 and 3 were compared with vegetative mortality rates to detect microwave propagation and thermal dissipation in waveguides with different geometries used in the experiments. 3D solid models of waveguides 1, 2 and 3 were designed and analysed with Ansys HFSS. The Ansys Electronic Desktop 2022 R2 version was used in the study.

Results and Discussion

In the preliminary study conducted by heating water bodies (*Table 1*), it was observed that different waveguide geometries reduced thermal losses (Rana, 2017) as expected. The highest thermal absorption occurred in the experiment using waveguide number 1.

Table 1. *Detection of the thermal effect of microwave guide attachment*

Microwave (2.45 GHz)	MW Exposure Duration (s)	Temperature difference (T_s-T_i) (°C)	Water quantity (kg)	Specific heat of water (joule/kg°C)	The amount of stored heat Q (joule)
waveguide 1	60	33-15	0.400	4184	30124
waveguide 2	60	28-15	0.400	4184	21756
waveguide 3	60	26-15	0.400	4184	18409
no-waveguide	60	23-15	0.400	4184	13388

When waveguides number 2 and 3 were used, thermal absorption of 21756 joules and 18409 joules occurred, respectively. In trials conducted without using a waveguide, a relatively lower thermal absorption of was achieved (Rana and Derr, 2018).

In the second stage of the experiment, wild mustard *(sinapis arvensis)*, cress *(lepidium sativum)* and arugula *(eruca sativa)* seeds germinated under suitable conditions were exposed to microwaves using waveguides 1, 2 and 3 and mortality rates were observed (Sahin, 2014; Taheri et al., 2018). Comparative results of waveguides 1, 2 and 3 of the arugula plant measurements are shown in *Table 2*.

A statistically significant difference was observed in temperature measurement and microwave exposure values ($p = 0.047$). Cabinets that make a difference are shown in small letters. Here is the mortality rate of the arugula plant; It makes a difference that microwave exposure in cabin number 1 is higher compared to other test results (*Figure 6*). Similar mortality results were obtained in waveguides number 2 and number 3.

The mortality rates resulting from exposure of cress plants *(lepidium sativum)* to microwave in waveguide number 1 (*Figure 7*) are higher than in waveguides number 2 and 3 (*Table 3*).

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***Table 2.** Microwave exposure of arugula (Eruca sativa) plant with waveguide number 1, 2 and 3*

	Arugula	Mean	Std. Dev.	Median	Min.	Max.	*p.
Temperature (Ts-Ti) (°C)	cabin number 1	12.33a	0.58	1200	12.00	13.00	0.047
	cabin number 2	9.00b	1.00	9.00	800	10.00	
	cabin number 3	10.00b	1.00	10.00	9.00	11.00	
Soil moisture (%)	cabin number 1	50.00	2.65	51.00	4700	52.00	0.416
	cabin number 2	52.00	1.73	53.00	50.00	53.00	
	cabin number 3	50.67	1.15	50.00	50.00	52.00	
Plant density (pcs/cm^2)	cabin number 1	4.7	0.58	5.00	4.00	5.00	0.102
	cabin number 2	4.00	0.00	4.00	4.00	4.00	
	cabin number 3	4.00	0.00	4.00	4.00	4.00	
$NDVI_1$	cabin number 1	0.64	0.02	0.64	0.62	0.66	0.717
	cabin number 2	0.63	0.03	0.64	0.60	0.66	
	cabin number 3	0.65	0.01	0.65	0.64	0.66	
$NDVI_2$	cabin number 1	0.27	0.02	0.27	0.25	0.28	0.066
	cabin number 2	0.42	0.02	0.41	0.40	0.44	
	cabin number 3	0.42	0.03	0.42	0.39	0.44	
Mortality rate (%)	cabin number 1	58.26a	3.67	57.82	54.84	62.13	0.061
	cabin number 2	34.32b	3.18	33.34	31.75	37.88	
	cabin number 3	35.92b	3.40	36.37	32.31	39.07	

* Significance level between groups (cabins) according to Kruskal-Wallis H Test results. a,b,c: Shows the difference between the cabinets according to the Post-Hoc pairwise comparison test with Bonferroni correction

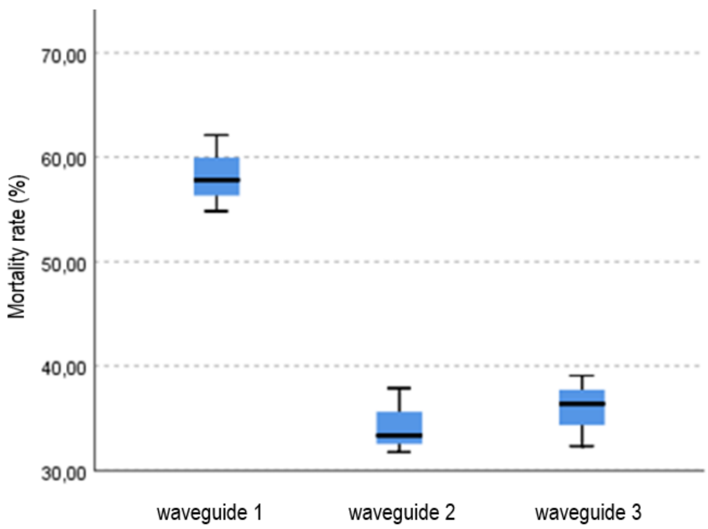

***Figure 6.** Distribution of mortality rates in different waveguide applications of arugula (Eruca sativa) plant*

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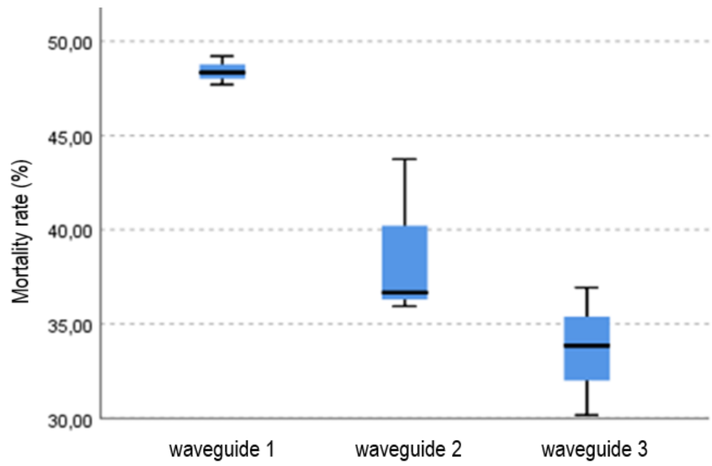

Figure 7. *Distribution of mortality rates in different waveguide applications of cress (Lepidium sativum) plant*

Table 3. *Microwave exposure of cress (Lepidium sativum) plant in the cabinet with waveguides numbered 1, 2 and 3*

	Cress	Mean	Std. Dev.	Median	Min.	Max.	*p.
Temperature (Ts-Ti) (°C)	cabin number 1	12.00 a	1.00	12.00	11.00	13.00	0.041
	cabin number 2	9.33 b	0.58	9.00	9.00	10.00	
	cabin number 3	10.33 b	0.58	10.00	10.00	11.00	
Soil moisture (%)	cabin number 1	49.00	2.65	48.00	47.00	52.00	0.188
	cabin number 2	52.67	1.15	52.00	52.00	54.00	
	cabin number 3	51.00	1.73	50.00	50.00	53.00	
Plant density (pcs/cm^2)	cabin number 1	4.33	0.58	4.00	4.00	5.00	1.00
	cabin number 2	4.33	0.58	4.00	4.00	5.00	
	cabin number 3	4.33	0.58	4.00	4.00	5.00	
$NDVI_1$	cabin number 1	0.63	0.03	0.63	0.60	0.65	0.159
	cabin number 2	0.64	0.02	0.65	0.62	0.65	
	cabin number 3	0.61	0.01	0.61	0.60	0.61	
$NDVI_2$	cabin number 1	0.30 b	0.02	0.30	0.28	0.31	0.050
	cabin number 2	0.43 a	0.02	0.43	0.42	0.45	
	cabin number 3	0.43 a	0.02	0.42	0.42	0.45	
Mortality rate (%)	cabin number 1	53.19 a	0.74	53.34	52.39	53.85	0.048
	cabin number 2	32.22 b	4.23	33.85	27.42	35.39	
	cabin number 3	29.13 b	2.57	30.00	26.23	31.15	

* Significance level between groups (cabins) according to Kruskal-Wallis H Test results. a,b,c: Shows the difference between the cabinets according to the Post-Hoc pairwise comparison test with Bonferroni correction

Additionally, a statistically significant difference was observed in $NDVI_2$ measurements (*Table 4*) compared to those made after microwave exposure using a waveguide (p=0.032). The highest $NDVI_2$ values of the wild mustard plant exposed to microwave using the guide are listed as guide number 3, 2 and 1, respectively.

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Table 4. *Microwave exposure of wild mustard (Sinapis arvensis) plant in the cabinet with waveguides numbered 1, 2 and 3*

	Wild mustard	Mean	Std. Dev.	Median	Min.	Max.	*p.
Temperature (Ts-Ti) (°C)	cabin number 1	13.33 a	0.58	13.00	13.00	1400	0.025
	cabin number 2	7.33 c	0,58	700	7.00	8.00	
	cabin number 3	10.67 b	0.58	11.00	10.00	1100	
Soil moisture (%)	cabin number 1	51.00	1.73	50.00	50.00	53.00	0.229
	cabin number 2	52.67	1.15	52.00	52.00	54.00	
	cabin number 3	50.33	1.53	50.00	49.00	52.00	
Plant density (pcs/cm^2)	cabin number 1	2.67	0.58	3.00	2.00	3.00	0.304
	cabin number 2	3.33	0.58	3.00	3.00	4.00	
	cabin number 3	2.67	0.58	3.00	2.00	3.00	
$NDVI_1$	cabin number 1	0.63	0.03	0.63	0.60	0.65	0.487
	cabin number 2	0.63	0.02	0.64	0.60	0.64	
	cabin number 3	0.64	0.01	0.65	0.63	0.65	
$NDVI_2$	cabin number 1	0.32 c	0.02	0.32	0.31	0.34	0.032
	cabin number 2	0.38 b	0.03	0.38	0.36	0.41	
	cabin number 3	0.43 a	0.02	0.43	0.41	0.44	
Mortality rate (%)	cabin number 1	48.42a	0.76	48.34	47.70	49.21	0.049
	cabin number 2	38.79 b	4.31	36.67	35.94	43.75	
	cabin number 3	33.65 b	3.39	33.85	30.16	36.93	

* Significance level between groups (cabins) according to Kruskal-Wallis H Test results. a,b,c: Shows the difference between the cabinets according to the Post-Hoc pairwise comparison test with Bonferroni correction

On the other hand, a statistically significant difference was observed in temperature measurement (*Table 4*), (Mekki and Badr, 2013), according to guided microwave exposure ($p = 0.025$). The highest $NDVI_2$ value of wild mustard plants exposed to guided microwave was obtained with guides 1, 2 and 3, respectively (*Figure 8*).

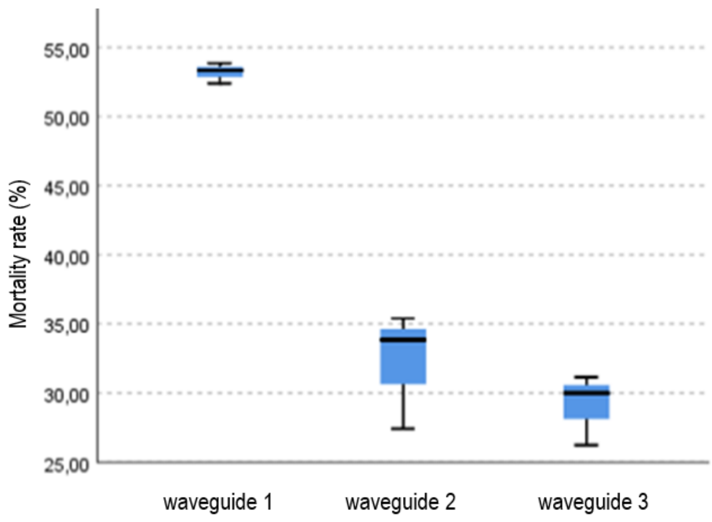

Figure 8. *Distribution of mortality rates in different waveguide applications of wild mustard (Sinapis arvensis) plant*

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In the graph obtained from the Ansys HFSS simulation of waveguide number 1, the regions where microwave and thermal condensation occur due to the guide geometry are the regions moving from yellow to red. The results show that in the microwave application using waveguide number 1, mortality rates of 58.26% in arugula plants, 53.19% in cress plants and 48.42% in wild mustard plants were achieved. There is a similarity between the HFSS simulation results, and the mortality rates obtained.

The graph obtained from the Ansys HFSS simulation of waveguide number 2 shows the regional distribution of microwave and thermal intensity due to the guide geometry (*Figure 9*).

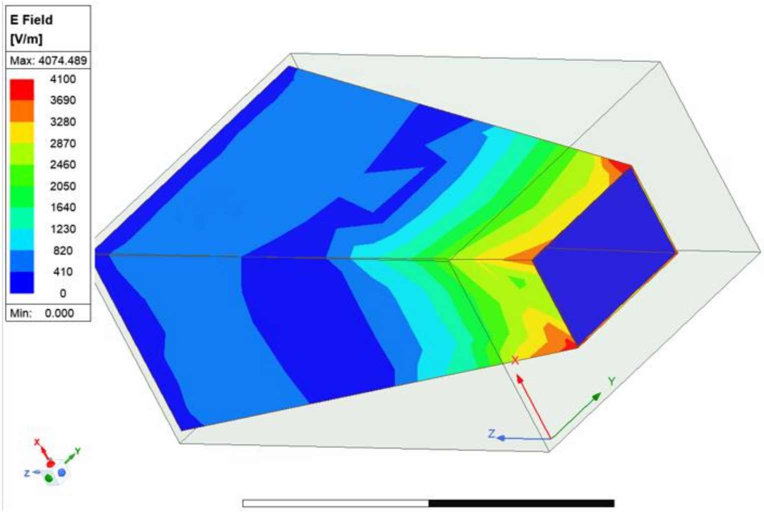

Figure 9. *HFSS simulation of microwave guide number 1*

Table 2, Table 3 and Table 4 show that in the microwave application using waveguide number 2, mortality rates of 34.32% in arugula, 32.22% in cress and 38.79% in wild mustard were obtained (*Figure 10*). According to these results, it can be said that microwave and thermal losses vary depending on the waveguide geometry.

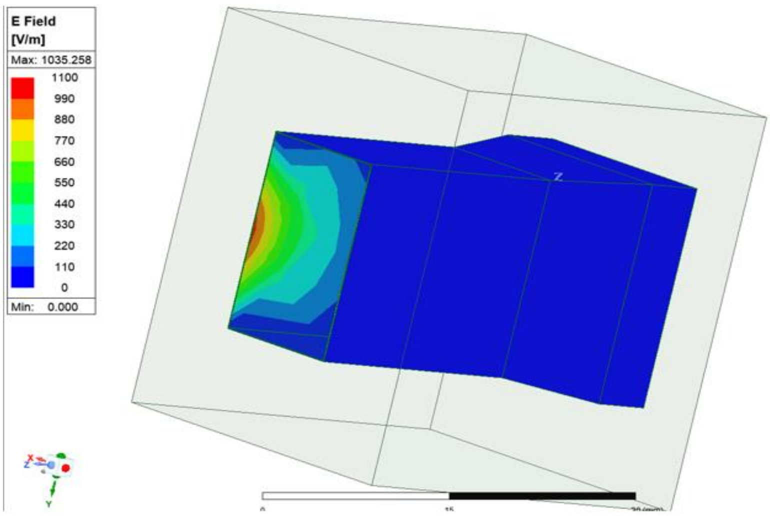

Figure 10. *HFSS simulation of microwave guide number 2*

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In the graph obtained from the Ansys HFSS simulation of waveguide number 3, microwave and thermal intensity are seen locally depending on the guide geometry. According to the result of microwave application using waveguide number 3, mortality rates of 35.92% in arugula plants, 29.13% in cress plants and 33.65% in wild mustard plants were obtained (*Figure 11*). We can easily say that microwave scattering, and thermal losses are reduced when the correct guide is used in the microwave weed control method.

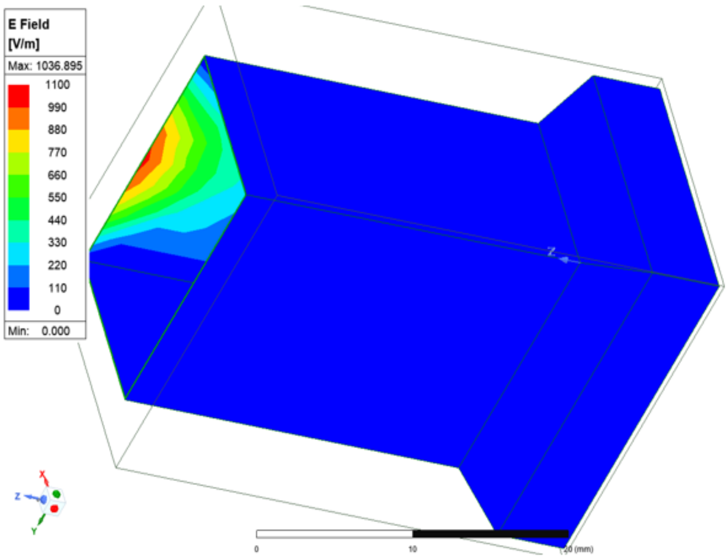

Figure 11. *HFSS simulation of microwave guide number 3*

As a result, it can be clearly said that weed control trials using microwave, electric current and similar technologies will soon be better understood by the relevant stakeholders and will come to the fore with their high efficiency and environmental friendliness compared to other methods.

In this study, 1 kW and 2.45 GHz magnetron was used. The effectiveness of the method can be increased by maintaining its frequency and increasing the application time and strength. However, the results show that the method has the potential to be used in the fight against all kinds of weeds when applied for the appropriate time and strength.

Since this study was carried out under laboratory conditions, a maximum power of 1 kW was obtained. As can be seen from the results, application time and power level will increase the success rate in weed control. Parameters such as the age of the weed, root and stem structure, type and soil moisture are other factors that may affect the effectiveness of the method.

According to the results obtained in the research, in order to achieve higher efficiency in weed control with microwave, it is necessary to know the physical, chemical, biological and dielectric properties of weeds.

The results obtained in the study show that the microwave weed control technique has the potential to be used as a "weed control method" if the correct frequency and power and sufficient application time are provided. It is thought that the data obtained in the study will help researchers who will study this subject. It is expected that the microwave weed control method in weed control will need more research and will be more on the agenda of relevant stakeholders.

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REFERENCES

[1] Ahn, S. H., Lee, W. S. (2020): Uniform microwave heating system design and evaluation with an orthogonally slot-loaded array waveguide. – Mic and Opt Tec Letters 62(11): 3419-3424. https://doi.org/10.1002/mop.32467.

[2] Asad, M. A. U., Lavoie, M., Song, H., Jin, Y., Fu, Z., Qian, H. (2017): Interaction of chiral herbicides with soil microorganisms, algae and vascular plants. – Sci of The Total Env. 580: 1287-1299. https://doi.org/10.1016/j.scitotenv.2016.12.092.

[3] Banaras, S., Javaid, A., Shoaib, A. (2020): Non-chemical control of charcoal rot of urdbean by *Sonchus oleraceous* application. – Advances in Weed Sci. (Planta Daninha) 38. https://doi.org/10.1590/S0100-83582020380100044.

[4] Bauer, M. V., Marx, C., Bauer, F. V., Flury, D. M., Ripken, T., Streit, B. (2020): Thermal weed control technologies for conservation agriculture-A review. – Weed Res. 60(4): 241-250. https://doi.org/10.1111/wre.12418.

[5] Bonow, J. F. L., Lamego, F. P., Andres, A., Avila, L. A., Teló, G. M., Egewarth, K. (2018): Resistance of *Echinochloa crusgalli* var. mitis to imazapyr+ imazapic herbicide and alternative control in irrigated rice. – Advances in Weed Sci. (Planta Daninha) 36. https://doi.org/10.1590/S0100-83582018360100028.

[6] Dede, Ö. T., Sezer, M. (2017): The application of Canadian water quality index (CWQI) model for the assessment of water quality of Aksu creek. – Journal of the Fac of Eng and Arc of Gazi Uni. 32(3): 909-917. http://dx.doi.org/10.17341/gazimmfd.337643.

[7] Faleiro, E. A., Lamego, F. P., Schaedler, C. E., Valle, T. A. D., Azevedo, E. B. D. (2022): Individual and integrated methods on tough lovegrass control. – Ciência Rural. 52. https://doi.org/10.1590/0103-8478cr20210490.

[8] Fallah Tafty, S., Mojaddam, M., Naderi, A., Abdollahian-Noghabi, M. (2020): The Effect of Different Doses of Tank-mixed Herbicides on Antioxidant Enzymes Activity of Soybean. – J of Nut and Food Sec. 5(3): 248-258. http://jnfs.ssu.ac.ir/article-1-288-en.html.

[9] Gée, C., Denimal, E. (2020): RGB image-derived indicators for spatial assessment of the impact of broadleaf weeds on wheat biomass. – Rem Sen. 12(18): 2982. https://doi.org/10.3390/rs12182982.

[10] Hess, M. C., De Wilde, M., Yavercovski, N., Willm, L., Mesléard, F., Buisson, E. (2018): Microwave soil heating reduces seedling emergence of a wide range of species including invasives. – Rest Eco. 26: S160-S169. https://doi.org/10.1111/rec.12668.

[11] Hussain, M., Farooq, S., Merfield, C., Jabran, K. (2018): Mechanical weed control. – In Non-chemical weed control. Academic Press., pp. 133-155. https://doi.org/10.1016/B978-0-12-809881-3.00008-5.

[12] Kahlau, S., Schröder, F., Freigang, J., Laber, B., Lange, G., Passon, D., Kleessen, S., Lohse, M., Schulz, A., von Koskull-Döring, P., Klie, S., Gille, S. (2020): Aclonifen targets solanesyl diphosphate synthase, representing a novel mode of action for herbicides. – Pest Man Sci. 76(10): 3377-3388. https://doi.org/10.1002/ps.5781.

[13] Khan, M. J., Brodie, G. I., Gupta, D., Foletta, S. (2018): Microwave soil treatment improves weed management in Australian dryland wheat. – Tran of the ASABE 61(2): 671-680. https://elibrary.asabe.org/abstract.asp?aid=48902.

[14] Khan, N., Ray, R. L., Sargani, G. R., Ihtisham, M., Khayyam, M., Ismail, S. (2021): Current progress and future prospects of agriculture technology: Gateway to sustainable agriculture. – Sustainability 13(9): 4883. https://doi.org/10.3390/su13094883.

[15] Lins, H. A., de Freitas Souza, M., de Albuquerque, J. R. T., dos Santos, M. G., Barros, A. P., Silva, D. V. (2019): Weed interference periods in sesame crop. – Ciência e Agr. 43. https://doi.org/10.1590/1413-7054201943000819.

[16] Marx, C., Pastrana Pérez, J. C., Hustedt, M., Barcikowski, S., Haferkamp, H., Rath, T. (2012): Investigations on the absorption and the application of laser radiation for weed control. – Landtechnik 67(2): 95-101. https://doi.org/10.15488/1375.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2206_55795592

[17] Mekki, L., Badr, A. (2013): Cytological and molecular consequences of wheat grain exposure to microwave radiation. – Acta Botanica Hungarica 55(1-2): 61-79. Available from: https://doi.org/10.1556/abot.55.2013.1-2.5.
[18] Monteiro, A. L., de Freitas Souza, M., Lins, H. A., da Silva Teófilo, T. M., Júnior, A. P. B., Silva, D. V., Mendonça, V. (2021): A new alternative to determine weed control in agricultural systems based on artificial neural networks (ANNs). – Field Cro Res. 263: 108075. https://doi.org/10.1016/j.fcr.2021.108075.
[19] Muscalu, A., Matache, M., Barsan, M., Dumitru, I., Tudora, C. (2017): Technology For Organic Weed Control. – Annals of the University of Craiova-Agriculture, Montanology, Cadastre Series 47(2): 377-380. https://anale.agro-craiova.ro/index.php/aamc/article/view/683.
[20] Rana, A., Derr, J. F. (2017): Determining the microwave radiations exposure level needed for weed control using a stationary and running belt microwave radiations applicator system. – J of Env Hort. 35: 58-65. https://doi.org/10.24266/0738-2898-35.2.58.
[21] Rana, A., Derr, J. F. (2018): Responses of ten weed species to microwave radiation exposure as affected by plant size. – J of Env Hort. 36(1): 14-20. https://doi.org/10.24266/0738-2898-36.1.14.
[22] Rodrigues, T. F., Cunha, F. F. D., Silva, G. H. D., Condé, S. B., Silva, F. C. D. S. (2021): Water use of different weed species using lysimeter and NDVI. – Advances in Weed Science 39: 1-10. https://doi.org/10.51694/AdvWeedSci/2021;39:00004.
[23] Sahin, H. (2014): Effects of Microwaves on the Germination of Weed Seeds. – Journal of Biosystems Engineering 39: 304-309. https://doi.org/10.5307/JBE.2014:39:4.304.
[24] Sahin, H. (2020): Investigating the effect of single and multiple electrodes on mortality ratio in electric current weed control method with NDVI technique. – J. of the Fac. of Eng. and Arc. of Gazi Univ. 35(4): 1973-1984. https://doi.org10.17341/gazimmfd.698307.
[25] Sahin, H. (2022): Investigation of the effectiveness of AC/DC electric current as a weed control method using NDVI technique. – Advances in Weed Science 40. https://doi.org/10.51694/AdvWeedSci/;40:00018.
[26] Taheri, S., Brodie, G., Jacob, M. V., Antunes, E. (2018): Dielectric properties of chickpea, red and green lentil in the microwave frequency range as a function of temperature and moisture content. – J of Mic P and Elec En. 52. https://doi.org/10.1080/08327823.2018.1452550.
[27] Werle, I. S., Zanon, A. J., Streck, N. A., Schaedler, C. E., Dalla Porta, F. S., Barbieri, G. F., da Rosa Ulguim, A., Tseng, T. M. (2021): Technology Levels in Cassava Cultivation Alter Phytosociology of Weeds. – HortScience 56(7): 787-794. https://doi.org/10.21273/HORTSCI15643-20.

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