Effectiveness of Microwave Energy as a Tool for Red Spider (*Tetranychus urticae*) Control and Their Side Effects on Some Vegetable Plants

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ABSTRACT--- ***In many agricultural productions, especially which being performed at outdoors, the pests create many negative effects. Pests cause losses even after harvest and sales as well as during production. This study was aimed to reveal how the plant and Tetranychus urticae that has economic harm against bean, cucumber and eggplant plants at greenhouses will be affected when microwave energy is applied on. For this purpose, first a testing apparatus was prepared, the power of microwave energy by which the plants and pest are being affected, the exposure period to this power and distance of the system from the target was determined. Finally, The study of how damaged plants under study were recorded. An increasing of the rate of pest death, the rate of color change and plants weight had been shown as a result of an increase of the power of microwave energy and application period, while inverse relationship was observed with the application distance. Regularity of measured values was deteriorated and irregular data was obtained especially at pedicle sections. When the power of 700W was applied on Tetranychus urticae at 15 cm distance for 20 seconds under laboratory conditions, 65±5.8% death rate was obtained. By the end of this study, the optimum point of microwave energy power, distance and period of exposure -where the plants were least affected and the pest remained ineffective were revealed.***

Keywords -- Pest, Colour, Bean, Eggplant, Cucumber, Tetranychus urticae

1. INTRODUCTION

Challenge in agriculture is to protect plants from the negative effects of diseases, pests and weeds within economic criteria, and increase the quantity and quality of production, this with no influence or less effects on human health and the environment. As it is known, agricultural fight cover many different methods, and the most effective and widespread one is pesticides

In the modern world where humans and the environment has attention, the risks of creating resistance on harmful organisms as the result of unconscious and uncontrolled use of pesticides and the negative effects of pesticides on human health and environment should not be ignored. In recent years, researchers are carrying out various studies in order to eliminate the use of chemicals. For this purpose, various thermal tests are being performed. Besides these, various methods by benefiting from radio frequency and microwave energy had started to be developed especially at greenhouses. Some applications had been made on weeds (Velázquez-Martí *et al.,* 2008) and pests that damaged the plants (Ernieenor *et al.,* 2012; Rahi & Rich 2011; Vadivambal *et al.,* 2010: Velázquez-Martí & Gracia-López 2004; Wang *et al.,* 2003 and Wang *et al.,* 2001) especially which are being observed at croplands. In practice, cultivated plants are not being observed. Any study that had been put to practice had not been seen even if the design of some systems had been tried in the light of the obtained findings.One of the reasons of being unable to perform studies on this trend is being considered as the negative effect of microwave energy on human health. Microwave ray is included in the group of ones that can't be ionized. It doesn't change the structure of substance and living cells, and it doesn't cause radioactive damage. According to the performed studies by the World Health Organization (WHO), no direct relation could be revealed in between the magnetic field formed by the RF transmitters and cancer against the widespread belief in public opinion. World Health Organization had published a report through the tests made on animals specifying that being present at magnetic field formed by RF transmitters doesn't increase the risk of cancer (WHO 2006). This had played a significant role in entrance of microwave into food sector.

In controlling of weeds, the use microwave energy especially after growing enables less energy consumption compared to other thermal methods (Sartorato *et al.,* 2006). Moreover, it is also being encountered by some limitations such as the risk of fire in fight by the use of flame and heavy loads in hot water methods.

The aim of this work is to reveal how eggplant (*Solanum melongena L.*), cucumber (*Cucumis sativus*) and bean (*Phaseolus vulgaris L.*) plants and two pointed red spider (*Tetranychus urticae Koch* (Acarina: Tetranychidae)) causes economic damage would be affected by the application of microwave energy. In the light of the obtained data, the proper microwave energy power –that can be used for the plants and pest-, its application period and distance parameters were revealed.

2. MATERIALS AND METHODS

2.1.Plants of the Application

Goynuk 98 bean (*Phaseolus vulgaris L.*) type was used as plant material. This type was obtained from Anatolia Agricultural Research Institute Directorate. The bean is scrub, growing vertically, has a height of 45-50 cm, non-hirudo, its flower color is white, its bean form is flat with curved end, and it has a grain number of 3-5 on each bean (Taskin, 2012).

Cucumber (*Cucumis sativus*) is a specie of Cucurbitaceae family. This species was obtained from West Mediterranean Research Institute. Under proper conditions, it grows at a depth of 20-25 cm. As it likes the moist of soil, its roots grow superficially. The trunk of cucumber is herbaceous, and it is angled and hairy with climbing character. Trunk is not of a strength that will be able to bear the weight of side branches, leaves and fruits, and that will be able to stand upright. The leaves grow from the internodes on the trunk. They are connected to the trunk by a long pedicle. Depending on the property of the species and cultivation environment, the size of leaves vary. Leaves with a width of 25-30 cm arise at humid and warm environments (BBTU, 2013).

Eggplant (*Solanum melongena L.*) belongs to the Solanaceae family. Along with the germination of seed, a taproot arises. 7 weeks after planting the seedling, the eggplants have taproots reaching a depth of 0.90 m despite their part on the soil is 0.15-0.25 m. As from the seedling period with 4-5 leaves, the trunk starts to become lignified. The trunk is very strong in the growing plant. The length of the plant varies in between 0.60-1.0 m in average. Its leaves are small, thin, narrow, long, or large and wide. The edges of leaves can either be flat or fragmented and slightly slitted (MEGEP, 2008).

The seeds required in order to be used in for tests to be performed under the project were planted at the area formed in the laboratory of a number more than the requirement, and it was continued with production along the test for unexpected requirements. By providing the suitable environment, the growing of the seeds was enabled.

2.2.Pest of the Application

Red spider *Tetranychus urticae Koch* (Acarina: Tetranychidae) is a harmful polyphagia icarus specie feeding with the parenchyma cells of the host plant (Van Den Boom *et al.,* 2004). Due to finding suitable living environment along the year under greenhouse conditions, it reaches a high population and causes significant economic losses (Tsagkarakou *et al.,* 1999). While the red spiders cause direct harm as yellowing, drying and fall of leaves by sucking the juice of the plant, they also give rise to indirect damages by the decrease of photosynthesis and transfer of virus diseases (Van Leeuwen *et al.,* 2005). Chemical fight is being preferred as it is easy to apply in fight with *T. urticae*, shows effect in a short time and generally doesn't require the determination of species. But the structure of *T. Urticae*, its high reproduction potential and short life cycle facilitates is to develop resistance to acaricides after few applications (Van Leeuwen *et al.,* 2006).

2.3.Materials used for Plants and Production of Samples of Pest

The seeds required in order to be used in the tests is to be performed under the project were planted at the area formed in the laboratory of a number more than the requirement, and it was continued with production along the test for unexpected requirements. By providing the suitable environment, the growing of the seeds was enabled. The plants were grown for two different purposes. First was raising red spider by enabling hosting and feeding of it. For this purpose, the plants were grown until a size of being able to produce fruits, and they were carried to the environment where red spider were present. Another purpose was to raise them in order to make measurement in the microwave test unit. Plants were grown until five leaves period for this purpose, and they were removed from soil for these measurements.

Laboratory conditions, were being controlled, for raising the red spider and for increasing its population. At this laboratory, the plants prepared for the first purpose. Red spiders were spread on the plants and their reproduction was enabled.

2.4.Microwave Test Unit

The test apparatus comprised of magnetron system spreading microwave energy, electrical equipments and roof that was bearing the system and enabling to adjust the distance to target surface (Figure 1).

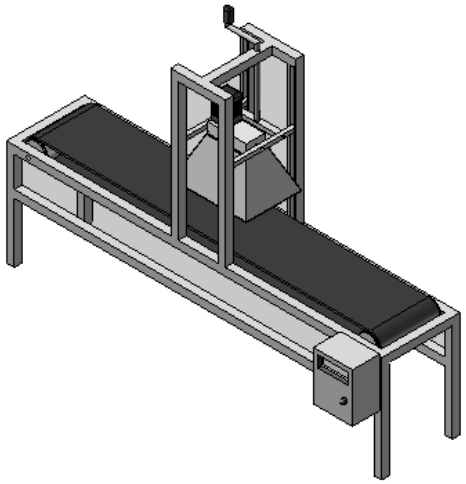

Figure 1: Microwave Test Unit

The system was able to be adjusted as maximum 700W, minimum 90W and approximately 350W power values. Moreover, the distance of the magnetron's mouth to the target surface was able to be adjusted as required.

In order to operate the magnetron with a line voltage of 220V AC, a power electronic circuit was formed that comprised of 1 transformer, noise filter that would decrease the noise from the line-, 2 adjusting buttons enabling the adjustment of period and power- and a lamp indicating the operation of the system. Magnetron was forming a microwave having a frequency of 2450 MHz by the energy it receives from the electric circuit.

Pre-tests were made on the prepared test unit in order to determine the impairment thresholds of the plant. With this purpose, different heights, application period and limits to be used in the tests in respect of provided energy amount were determined. As the result of these tests, the distance between the mouth of magnetron and the target surface was determined as 15cm, 25cm and 35cm, and the application period was determined as 5s, 10s, 15s and 20s. The values of maximum 700W, minimum 90W and approximately 350W power values were determined as the microwave powers by which the plants were being affected in these periods and distances. By using these determined values, all tests were carried out at test unit by three repetitions.

As it was observed by these pre-tests that the plants were being affected more from the microwave in the 3-5 leaf period, the studies were carried out on the plants while they were in the 3-5 leaf period. The bean, eggplant and cucumber plants were removed from the pots in the 3-5 leaf period, and the measurements were made by cleaning their soil.

During the measurements, the weights and color values (L,a,b) of plants were individually measured before and after exposure to microwave energy. RADWAG AS 220 / C / 2 (RADWAG, Poland) brand precision balance was used for the weight measurements of the plants and pests. And in the color measurements of plants, HP200 (Sinodevices, China) model portable color measurement device was used.

2.5.Color Measurement in Plants

The color parameters of all the plants that were used in the tests were individually measured before and after exposure to microwave energy. The measured values were calculated in terms of L, a, b.

The well balanced structure of the L*a*b* color space specifies that a color can not be green and red and blue at the same time. Simple values may be used in order to define the characters of red/green and yellow/blue. In CIE L*a*b*; L* indicates luminosity, a* indicates red/green, b* indicates yellow/blue values (Kose & Sahinbaskan 2008).

The measurement values were specified as % relevant to the relation between the values prior to and after exposure to microwave. The results were assessed also statistically with the coincidence parcels test pattern method (SPSS).

2.6.Rate of Death of *Tetranychus urticae*

While calculating the rate of death of red spiders, they were exposed to microwave energy under the conditions determined in the method (different height, different powers and different periods). In each application, at least 100 pests

were placed in petri dishes, and the tests were carried out with three replications. The rates of death were revealed by counting under microscope before and after the application. The damaged ones were also deemed as dead.

3. RESULTS AND DISCUSSION

In the performed measurements, the results were assessed by addressing each plant individually. Due to use of different plants in all measurements and in each application, a regular increase couldn't be observed in the rates of change. The small differences in the physical structures of plants despite being in the same period had been effective on the results.

3.1.Eggplant (*Solanum melongena L.*)

When the eggplant was exposed to microwave energy, changes of weight were determined as the power of microwave energy was increased (Figure 3)???. But this change couldn't get above 5%. Microwave energy that was applied by different powers, different periods and from different distances had not showed a regular change. But as the application period was increased, the weight loss in plants had shown a continuous increase. When the conditions of application were examined individually, large differences were not seen on the distance as the power was increased. While the change was 2.11% in the application performed under 90W power value from a distance of 15 cm for 5 sec, it had been 2.09% and 2.59% under power values of 350W and 700W. But the effects on plants had not changed by the change of period. These values were measured as 4.87%, 4.5% and 4% respectively under the application with 20s.

The differences among the effects of power and distance factors on weight were deemed insignificant. It was revealed that the effect of different period on the change of weight by microwave was significant at the level of 1%. When LSD test was applied LSD was found as 5.158. And for the period factor, the F values of 19.063a, 11.185b and 3.333 c were calculated for the 20, 15 and 10s values.

When the change of L value (luminosity) under 700W power was examined in eggplant, it was observed that the change of L value decreases as the distance to the plant increases. Especially the applications from 15 cm distance had caused high difference even under different periods. In the application of 90W power, the change depending on period (5, 10, 15 and 20 s) in the application from 15 cm distance was determined as 1.72%, 8.9%, 8.6% and 9.59% respectively. The changes had generally shown a regular increase. The change of L value of eggplant had been at most 9.59%.

When the power-distance-period-repetitions were examined individually, and when their interaction was considered, the differences among the effects of the factors on the L value were observed as insignificant.

The values of the eggplant had been effective especially under 350W from 15 cm distance, it had showed a change of at most 9.71%. Generally in all the applications, the change of a value had varied as the application period increased. When the power distance period-repetitions were examined individually, it was found that, the differences among the effects of the factors on the value were observed as insignificant.

In the eggplant, the change of b value under 700W had decreased as the distance increased in another word it had an inverse relationship. While the change of b value depending on period had showed an irregular change. The highest change (9.52%) was observed in the application made under 90W power value for 20s from a distance of 15 cm. After this value, generally explosion had occurred in the pedicles of plants depending on temperature and the plant had lost its living character. Thus, the change of power value had showed high differences in a short while on the plant. When the power distance period-repetitions were examined individually, and when their interaction was considered, the differences among the effects of the factors on the b value were observed as insignificant.

3.2.Cucumber (Cucumis sativus)

The change in cucumber had showed an increase in all the applications when the period of exposure had increased as a Positive relationship. In the application under 350W power from a distance of 15 cm, the rate of change had increased as the period increased, and it had been 9.57% in the application made for 20s. Generally, explosions were observed on the pedicles of plant after that power value. When the power-distance-period-repetitions were examined individually, and when their interaction was considered, the differences among the effects of the factors on the weight value were observed as insignificant (Figure 2).

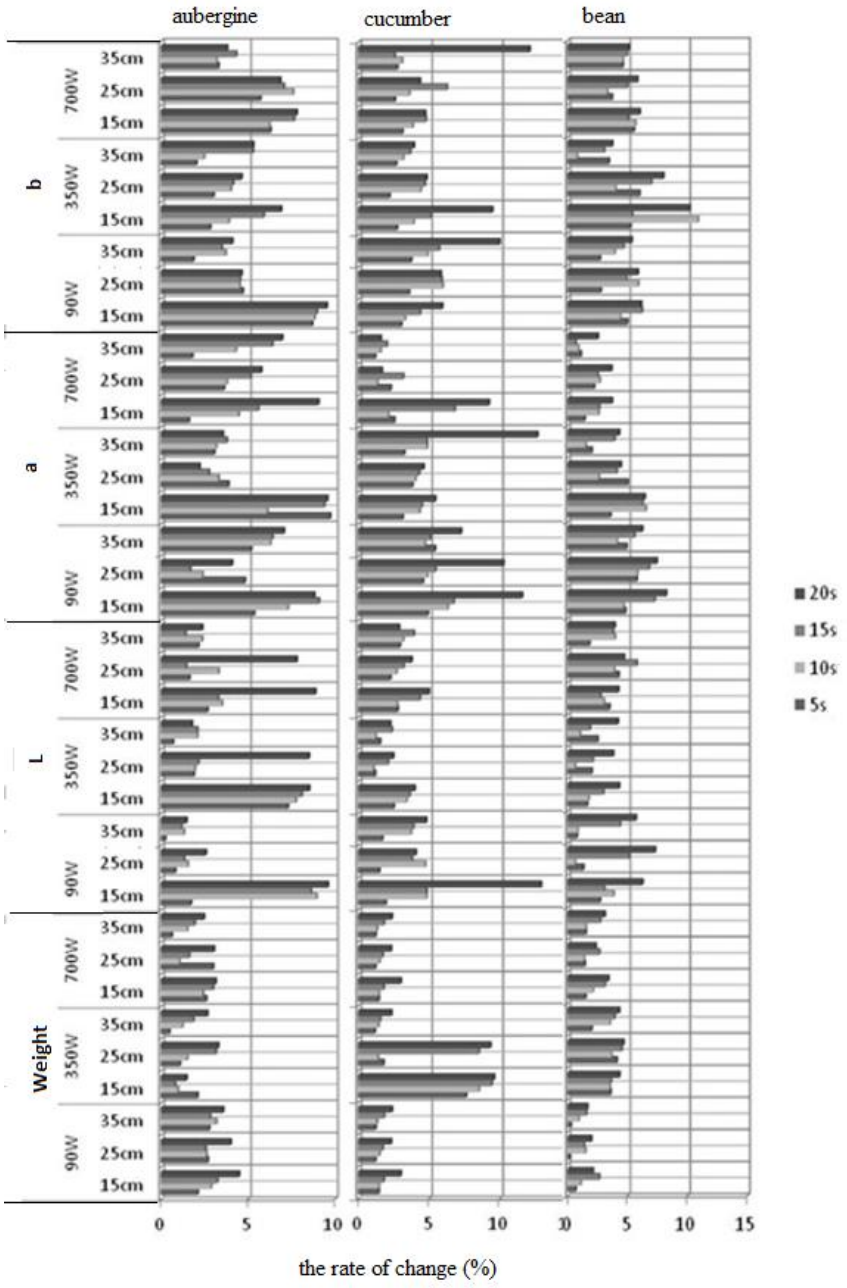

Figure 2: Microwave Effect on Cucumber Plants Eggplants, Beans, (L, a, b, Weight Change)

The change of L value of cucumber in applications from close distance and with long period had been the highest (12.8%). And when the microwave power (700W) was increased, a change of 2.91 was encountered at a distance of 35 cm. When the power-distance-period-repetitions were examined individually, and when their interaction was considered, the differences among the effects of the factors on the L value were observed as insignificant.

In the applications on cucumber from close distance and with long period, the change of a value had been the highest. In the application under 350W and from a distance of 35 cm, the change of rate was calculated as 12.6% when the period was kept as 20 sec. When the power (700W) was increased, a change of 5.4% was encountered in the application for 15 sec and from a distance of 15 cm. When the power-distance-period-repetitions were examined individually, and when their interaction was considered, the differences among the effects of the factors on the value were observed as insignificant.

As the result of application under 700W, from a distance of 35 cm and for 20s, a change at a rate of 12.08% was calculated in the b value of cucumber. The value had been 3.7% under 350W, for a period of 5s and from a distance of 35 cm. The value of cucumber which was exposed to 90W power from a distance of 25 cm for 10s had showed a change at a rate of 5.9%. When the power-distance-period-repetitions were examined individually, and when their interaction was considered, insignificant differences among the effects of the factors on the b value were observed.

3.3.Bean (*Phaseolus vulgaris L.*)

In all the applications performed under 350W value, the highest change in weight was observed on bean, and explosions were observed on the pedicles when the values were increased. In the application made under 350W power value for 20 s period from a distance of 25 cm, weight change rate of 4.65% was calculated. The rate of change had also increased as the period increased. When the power-distance-period was examined individually, and when their interaction was considered, the differences among the effects of the factors on the weight value were observed as insignificant. Moreover, the difference among the repetitions was found to be significant at the level of 1%. When LSD test was applied LSD was found as a value of 1.891. During the repetitions, F values were calculated as 1.779a, 1.648a and 1.000 b, respectively (Figure 3).

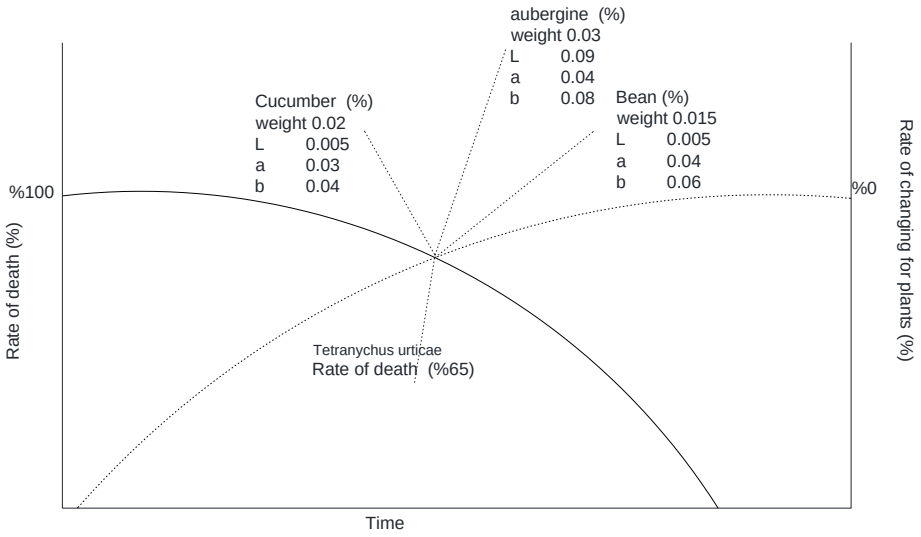

Figure 3. Schematic View of the Change of Subject Terms in 700 W- 15 cm -20 sn

In the bean, the highest L value change (7.3%) was observed in the application under 90W for 20s from a distance of 25 cm. Under the 700W power value, the rate of change (4.26%, 3.95% and 5.76%) had increased as the period increased (5, 10 and 15s). The rate of change had also increased as the period increased. When the power-distance-period was examined individually, and when their interaction was considered, the differences among the effects of the factors on the L value were observed as insignificant. Moreover, the difference among the repetitions was found to be significant at the level of 1%. When LSD test was applied LSD was found as 2.198. During the replications, F values were calculated as 5.779a, 5.648a and 1.000 b, respectively.

In the application made under 90W power value on the bean, the change of rate of a value had increased as the period increased. In the value of plant exposed to microwave from a distance of 15 cm for 20s, the highest rate of change of 8.23% was calculated. And the plants exposed to microwave under 350W power value for 10 s period from a distance of 15 cm had showed a change of a value of 6.52%. And under 700W power value, explosions were observed on the pedicles. When the power-distance-period was examined individually, and when their interaction was considered, insignificant differences among the effects of the factors on the b value was observed . Moreover, the difference among the repetitions was found to be significant at the level of 1%. When LSD test was applied LSD was found as 2.487. During the repetitions, F values were calculated as 7.654a, 6.464a and 1.000 b, respectively.

The change of b value in bean had showed the highest change in the application of 350W. When the microwave energy of 350W power was applied on bean from a distance of 15 cm for 20s, the b value had showed a change of 10.9%. And under 700W power value, explosions were observed on the pedicles. When the power-distance-period were examined individually, and when their interaction was considered, the differences among the effects of the factors on the value were observed as insignificant. Moreover, the difference among the repetitions was found to be significant at the level of 1%. When LSD test was applied LSD was found as 0.616. Among the 2nd, 1st and 3rd replications, F values were calculated as 1.656a, 1.633a and 1.000 b respectively.

3.4. Death Rates of Red Spider (*Tetranychus urticae*) under Microwave Energy

Applications were carried out on the red spider under determined height, period and power values. When the red spider population was examined after the application, it was observed that some red spiders had first lost their limbs and then died.

The average values of data obtained in the application made on red spiders are given Table 1 with ± standard deviation. In the tests, 100 red spiders were taken as sample in each application. After the application, the number of affected spiders was calculated.

Table 1: Mortality of Tetranychus urticae under Microwave Energy

Distance	15cm			25cm			35cm		
Time	10sn	15sn	20sn	10sn	15sn	20sn	10sn	15sn	20sn
90W	5±1.1	21±8.3	38±7.1	5±1.2	18±1.3	29±5.1	2±1.0	5±0.5	11±3.6
350W	12±2.9	29±3.7	39±3.6	10±2.2	25±3.6	36±4.1	9±1.1	13±1.9	15±2.7
700W	31±5.5	44±5.9	65±5.8	29±2.9	21±3.1	20±3.5	12±1.3	12±1.5	15±1.3

When the death rates were examined, the death rate under 700 W - 15 cm - 20 sec application conditions was determined as 65±5.8%, and it was determined as parameter in design as deeming it the highest death rate. Vadivambal *et al.,* 2005, had applied microwave for 28 sec under 400W on *Cryptolestes ferrugineus* pest, and they had determined a death rate of 69±8.7%. As long term applications could damage the plant, high power was preferred for a lower period in that study.

The measurements were assessed by the coincidence parcels test pattern method. The differences among the effect of power factor were seen as insignificant. It had been revealed that the effect on the death rate of red spiders of microwave applied by different distances and different periods was significant at a level of 1%. When LSD test was applied LSD was found as 7,138. Regarding the distance factor, the F values were calculated as 31.963a-21.926b-10.593c for 15-25-35 cm values. And for the period factor, the F values of 29.963a-21.185b-13.333 c were calculated for the 20-15-10 sec values.

4. CONCLUSIONS

In the applications on eggplant from a distance of 15 cm, the highest rates of change (weight, L, a, b) were calculated as 4.47%, 9.59%, 9.71% and 9.52%, respectively. The eggplant, exposed to microwave for 20s under all power values, had provided the highest rates of change. When the power value was used as 700W, explosions were observed on pedicles.

In the applications on cucumber for a period of 20s, the highest rates of change (weight, L, a, b) were calculated as 9.57%, 12.8%, 12.62% and 12.08%, respectively.

In the bean, while change (8.23%) starts under 90W power value for 20s from a distance of 15 cm, when the distance was taken as 25 cm a change of 7.3% was observed in the L value. And under 350W power value, in the application for 10s from a distance of 15 cm by changing the power value, while the change of b value changed the highest by 10.9%, a weight change of at most 4.65% was observed even under application for 20s from a distance of 25 cm.

An inverse relationship between change of rate and distance, while it was a positive relationship with the application period. And as the power value of microwave was increased, elevations were observed in rate of change. But as there had been tears at specific points, especially at pedicle sections, the regularity of the measured values was deteriorated and irregular data was obtained. Thus small power values were preferred.

When the death rates were examined, the death rate under 700 W - 15 cm - 20 sec application conditions was determined as 65±5.8%, and it was determined as parameter in design as deeming it the highest death rate.

The graph formed under the obtained findings in order to define the relation in between the plants and pests depending on the conditions of application is being seen in Figure 4. The results of this study will lead to the use of microwave energy in agriculture and especially to the design of suitable systems.

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