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The Effect of Audible Sound on the Germination and Root Elongation of Selected Seedlings

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THE EFFECT OF AUDIBLE SOUND ON THE GERMINATION AND ROOT ELONGATION OF SELECTED SEEDLINGS

by

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Introduction

Sound is energy which travels in the form of sound waves. It is present throughout the environment so that all living organisms are exposed to it. Man can detect sounds ranging in intensity from 10^{-12} watts/m^2 to 1 watt/m^2. The lower intensity is barely audible while the higher intensity is pain producing. The range of frequencies which man can detect is referred to as the audible sound range. Those sounds of frequencies above the audible range are called ultrasounds.

The frequency of sound is measured in Hertz or cycles per second and the intensity of sound is expressed in decibels (db). The decibel is defined according to a logarthmic scale. The intensity level in decibels = 10 log I/I_o where I_o is the intensity of the faintest audible sound which is 10^{-12} watts/m^2. This being the case, the intensity level of the least audible sound is 10 log $(10^{-12}/10^{-12})$ which is zero.

Most experiments reported in the literature involve the use of ultrasound (sound of higher frequency then audible sound). Ultrasound has very destructive effects on living cells. Yeast and bacterial cells present in milk have been destroyed upon exposure to ultrasonic waves (Beckwith and Weaver, 1936). The destructive effects of ultrasound are largely due to cavitation. Cavitation involves the formation

of partial vacuums within the cell due to the separation of intra-cellular structures (Clark and Hill, 1969). Ultrasonic waves are frequently used in the destruction of microbial cells and the separation of intra-cellular particles (El'Piner, 1964).

Experiments with audible sound reported in the literature generally involved animals. Disruption of animal cells by audible sound may be produced by the explosion of the organism as a result of the internal release of dissolved gases, or by actual tearing apart of tissues as a result of rapid alterations of tension and compression produced in the surrounding medium by the vibrations (Chambers and Gaines, 1932). Plant experimentation with audible sound generally concerns effects on germination and inhibition or stimulation of plant growth.

This work was initiated to examine the effects of audible sound on the germination and growth of cucumbers, oats, and wheat.

LITERATURE REVIEW

The effects of audible sound on animals and animal cells has been investigated in several ways. Chambers and Gaines (1932) found that the water flea, Daphnia pulex, when exposed to sonic irradiation in a shell vial filled with water, was killed within one second. The exoskeleton was shattered, the soft body parts were churned into an amorphous pulp, and clouds of colloidal material were released into the surrounding water. Bryshenskii and Meskhaeleva (1969) found that animals subjected to the prolonged action of sound exhibited a lower coagulation activity of the blood. The sound weakens the defense reactions which develope after the injection of thrombin. The death rate amoung the experimental animals was 72.5% while the death rate for the control animals was 40.9%. Aleksandrovskaya and Chezhenkova (1970) found that a weak sound (200 c.p.s.) in the rabbit cerebral cortex enhanced the slow waves and spindles, particularly in the motor area. In the deep layers of the motor area, the weak sound brought about an increase in astrocytes. In the deep layers of the projection area (auditory cortex) the astrocytes decreased in number.

Koitchev (1969) found that there was an increase of sodium in the organ of Corti after exposure to sound. This was attributed to changes in the permeability of excited membranes. Chambers and Harvey (1931) found that tadpoles of Bufo punctata when held in shell vials filled with water, above the vibrator, were killed within one minute. After one minute of sound treatment, bubbles of gas could be seen in

the abdominal cavity, and after two minutes the tadpoles actually exploded. Small fish were killed in three to four minutes and immature frogs were killed in about ten minutes.

Most of the work on the effects of audible sound on plants and plant cells concerns growth and germination. Northen and MacVicar (1939) showed that sound lowered the elasticity of the cytoplasm of Spirogyra by 20 per cent to 88 per cent. This could be seen by the displacement of chloroplasts in sound treated Spirogyra filaments. Singh (1959) reported that the water plant Hydrilla verticillata had an increased rate of photosynthesis after exposure to sound waves from an electric bell. Both the rate and the total volume of oxygen evolved from sound-excited Hydrilla plants were 60 per cent to 100 per cent higher then the control plants. Gnanam (1959) observed an increase in the photosynthetic rate of Spirogyra when exposed to sound. The volume of oxygen evolved in excited plants was much higher then the control, showing thereby, that in sound excited plants synthesis and production of food was higher.

Some rather non-scientific literature has been concerned with the effect of music on plants. Retallack (1973) found that acid rock, after being played to plants for five days, had very devastating effects on plant growth. She observed a bending of the plants away from the speaker and a decrease in root developement. Music played by Ravi Shankar had no effect on root developement and the plants were found to be bending toward the speaker. Some

reference to the effects of music on plants has been recorded in scientific literature. Ponniah (1958) played a single note to Mimosa pudica, Impatiens balsamina, Tagetes erecta, and Hydrilla verticillata. She found an increase in root developement, total number of leaves, and length of branches. Singh and Ponniah (1955) found that the musical sound of the Veena stimulated the growth of balsam plants in all parameters measured.

Lisenkov (1966) found that seeds of Siberian larch exposed to sound treated water had an increase in ground germination, increased frost resistance, and better growth. The enzyme activity of the germinated seeds was also increased under certain conditions. Amylase activity increased when the seeds were soaked in sound treated water for periods between 0.5 and 1.0 hours.

Weinberger and Measures (1968) exposed spring and winter wheats (Triticum aestivum) to a single audible frequency of sound at a given time. They found better germination and an increase in growth in winter wheat (var. Rideau) and in some cases this was temperature or frequency dependent. Spring wheat (var. Marquis) showed an increase in germination at 2 degrees C and 10 degrees C, but not at 25 degrees C. The growth of spring wheat was found to vary with different treatments. It was suggested that the increase in germination at 2 degrees C and 10 degrees C may involve the production of ethylene.

The same workers in another experiment using spring wheat found a significant increase in some of the parameters measured

when 300 Hz and 5,000 Hz were used. However, plant growth was not significantly stimulated by treatment with either 1,250 Hz or 12,000 Hz sound frequencies (Measures and Weinberger, 1970).

Some negative effects of sound on growth have also been reported in scientific literature. Weinberger and Das (1972) found that continuous exposure of Scenedesmus obtusiusculus to 4,000 Hz resulted in a decrease in the rate of cell division. A decline of 15 per cent was obtained in 48 hours. The normal rate of cell division did not return until two life cycles had elapsed. The Scenedesmus cells were most sensitive to sonic shock in the early part of their life cycle. Woodlief et al., (1969) also found some negative effects of sound on plants. Tobacco plants subjected to random noise showed a decline in growth rate of over 40 per cent.

METHODS AND MATERIALS

Plant Material

The three types of certified seeds used in these experiments, wheat (Triticum aestivum), oats (Avena sativa var. AuSable), and cucumber (Cucumis sativis var. marketer) were obtained from Farm Bureau Services Inc., Kalamazoo, Michigan. When not being used for experimentation all seeds were stored in a refrigerator at approximately 8 degrees C.

Sound Source

Sound at a frequency of 600 Hz was generated by an audio-oscillator[1] connected to an amplifier[2]. Sound intensity was measured by using a sound level meter[3] using the 'C' weight. The audio-oscillator was adjusted to give sound of the intensity of 102 plus or minus 3 decibels in each of the two growth chambers. In all experiments a nine inch speaker was used. The speaker was suspended by heavy strings near the center of the growth chamber.

Growth Conditions

Both control series and experimental series consisted of

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[1]Audio-oscillator made by Hewlett Packard Co., Pala Alto, California (Model 200 CD).

[2]Amplifier made by the David Bogen Co., New York, New York (Model E14).

[3]Sound level meter made by the General Radio Co., West Concord, Massachusetts.

5 plastic dishes[1] (155 mm by 63 mm). Each dish was lined with Armstrong #6 filter paper[2] and was moistened with 15 ml of distilled water. A total of 20 seeds were randomly scattered in each dish giving 100 seeds for each run. The plastic containers were then placed in clear polyethylene bags[3] which were closed by using wire twists. After all dishes were moistened and planted, they were placed in Sherer Controlled Environment Chambers[4]. Experiments in which cucumbers were tested and those in which oats were tested were run simultaneously. The experiments with wheat were run separately since there was not enough room in the growth chamber to run 3 sets of dishes at the same time.

The dishes were placed near the center of the growth chamber in a circular pattern. The growth chambers (experimental and control) were kept in constant darkness at a temperature of 20-21 degrees C. The experimental series was continuously exposed to sound. The control series was run in a second growth chamber under exactly the same conditions and at the same time. The only sound in the control chamber was due to normal background noise. After 5 days all seeds were removed and measured. A total of 8 separate runs, 4 replications

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[1]Plastic containers were obtained from Bradley Industries, Inc., Franklin Park, Illinois.

[2]Paper manufactured by the Armstrong Cork Co., Lancaster, Pennsylvania.

[3]Bags made by Union Carbide Corp., Consumer Products Division, 270 Park Avenue, New York, New York, and sold under the trade name of 'Glad'.

[4]Sherer-Gillett Co., Marshall, Michigan.

of the experiment, were made for each of the 3 types of seeds. The growth chambers were interchanged for each succeeding run so that the 'experimental' chamber became the 'control' chamber on the next run.

Determination of Germination and Growth

Any seed was considered to have germinated if its root reached a length of 1 mm or longer. Growth was determined by using the method of Thompson et al., (1945) where the longest root of each germinated seed was measured in mm. A mean root length was determined for both control and experimental groups by using only root lengths of seeds that did germinate.

Statistical Analysis

Data on root elongation were analyzed by means of library program # 1.9.2. using Western Michigan Universities PDP-10 computer. This program is a two-way analysis of variance (unbalanced case) where factor 1 is the difference between control and experimental treatments and factor 2 is the difference between runs. Seeds that did not germinate were not included in the analysis. Data on germination were analyzed using library program # 1.9.1. (version 2). This program is also a two-way analysis of variance. It shows the significance of control/experimental, replication, and growth chamber differences. It does not consider within cell variability. In both programs used a probability level was calculated from the 'F' value.

RESULTS

Root Elongation

Tables 1, 2, and 3; pages 13, 14, and 15 show the average length of the longest root of germinated cucumber, oat, and wheat seeds under both control and experimental conditions. In the case of cucumbers and oats the grand mean (GM) of the control group is significantly greater then the grand mean of the experimental group. In the case of wheat the grand mean of the control group is not significantly greater then the grand mean of the experimental group. Tables 7-21 on pages 19-33 show the results of statistical analysis.

Cucumber seeds

With cucumbers (see Table 1, page 13), the grand mean of the control group is 56.61 mm while the grand mean of the experimental group is 47.09 mm. The difference observed is significant at the 0.1 per cent level (see Table 11, page 23). A significant difference (at the 3.5 per cent level) is found between the 8 runs of the experiment. Interaction (which determines if differences are due to experimental conditions or some other factors) is significant at above the 23 per cent level. Since interaction is not significant at below the 5 per cent level, no further analysis of root elongation data for cucumbers is needed.

Oat seeds

The data for oats (see Table 2, page 14) is similar to that for cucumber showing an inhibition of growth in the sound treated

group. The grand mean of the control group is 112.17 mm and the grand mean of the experimental group is 99.23 mm. The difference between the two is a significant difference at below the 0.1 per cent level (Table 16, page 28). There is a significant difference between the 8 runs (below the 0.1 per cent level). The interaction is not significant being above the 70 per cent level. Once again, since interaction is not significant no further analysis of root elongation data for oats is needed.

Wheat seeds

The data for wheat (see Table 3, page 15) are different than the data for cucumbers and oats showing no real inhibition of growth in the sound treated group. The grand mean of the control group is 105.03 mm and the grand mean of the experimental group is 104.61 mm. The difference between the two is not significant (Table 19, page 31). There is a significant difference between the 8 runs (below the 1.4 per cent level). The interaction is significant only above the 8.5 per cent level. Since the difference between the control and sound treated wheat seeds is not significant no further analysis of the data is required.

Germination

Tables 4, 5, and 6; pages 16, 17, and 18 show the per cent germination for cucumbers, oats, and wheat. Tables 22, 23, and 24; pages 34, 35, and 36 show the level of significance for the differences. In cucumbers, oats, and wheat there is no significant difference in per cent germination for either growth chambers, replications,

or control/experimental differences.

Cucumber seeds

The data indicate that there is no significant difference in per cent germination between control and experimental plants (22.1 per cent level), between replications (36.5 per cent level), or between growth chambers A and B (22.1 per cent level).

Oat seeds

The data indicate that there is no significant difference in per cent germination between control and experimental plants (84.4 per cent level), between replications (8.0 per cent level), or between growth chambers A and B (55.5 per cent level).

Wheat seeds

As in cucumbers and oats, the data indicate that there is no significant difference in per cent germination between control and experimental plants (18.5 per cent level), between replications (18.5 per cent level), or between growth chambers A and B (42.5 per cent level).

Replications

	GM	1		2		3		4	
Control	56.61	47.95	63.74	54.09	57.45	56.24	51.36	59.08	62.96
Sound	47.09	41.53	52.11	38.31	45.95	52.53	40.91	51.85	53.81
		1	2	3	4	5	6	7	8

Runs

Table 1. Mean length in mm of longest root of germinated cucumbers for control and sound treated seeds. GM = Grand Mean. (Significant to 0.1 mm).

Replications

	GM	1		2		3		4	
Control	112.17	95.47	119.94	109.51	104.14	107.78	121.53	122.85	116.11
Sound	99.23	83.97	104.93	98.56	86.78	93.74	108.97	108.95	107.93
		1	2	3	4	5	6	7	8

Runs

Table 2. Mean length in mm of longest root of germinated oats for control and sound treated seeds. GM = Grand Mean. (Significant to 0.1 mm).

Replications

	GM	1		2		3		4	
Control	105.03	107.04	107.76	106.15	100.62	100.85	102.79	108.78	106.26
Sound	104.61	105.53	109.33	97.35	107.90	96.88	107.86	102.52	109.52
		1	2	3	4	5	6	7	8

Runs

Table 3. Mean length in mm of longest root of germinated wheat for control and sound treated seeds. GM = Grand Mean. (Significant to 0.1 mm)

Replications

	GM	1		2		3		4	
Control	95.10	99	93	97	94	98	96	96	98
Sound	95.80	97	97	96	97	100	98	98	94
		1	2	3	4	5	6	7	8

Runs

Table 4. Per cent germination of cucumber for control and sound treated seeds.

GM = Grand Mean.

Replications

	GM	1		2		3		4	
Control	89.00	87	89	88	90	94	87	92	85
Sound	89.50	85	92	88	89	92	87	93	90
		1	2	3	4	5	6	7	8

Runs

Table 5. Per cent germination of oats for control and sound treated seeds.

GM = Grand Mean.

Replications

	GM	1		2		3		4	
Control	97.00	97	97	95	97	97	98	100	95
Sound	97.60	95	98	99	98	100	94	97	100
		1	2	3	4	5	6	7	8

Runs

Table 6. Per cent germination of wheat for control and sound treated seeds.

GM = Grand Mean.

Grand mean for control	56.61 mm
Grand mean for experimental	47.09 mm

FACTOR	F VALUE	PROBABILITY
Weighted means analysis of variance		
Difference between control/experimental	20.74	0.000
Difference between runs	44.28	0.000
Interaction	1.73	0.190

Table 7. Two-way analysis of variance (unbalanced case) for root elongation data of cucumbers (library program # 1.9.2) for runs 1 and 2.

Grand mean for control	56.61 mm
Grand mean for experimental	47.09 mm

FACTOR	F VALUE	PROBABILITY
Weighted means analysis of variance		
Difference between control/experimental	48.52	0.000
Difference between runs	7.88	0.005
Interaction	1.20	0.275

Table 8. Two-way analysis of variance (unbalanced case) for root elongation data of cucumbers (library program # 1.9.2) for runs 3 and 4.

Grand mean for control	56.61 mm
Grand mean for experimental	47.09 mm

FACTOR	F VALUE	PROBABILITY
Weighted means analysis of variance		
Difference between control/experimental	11.92	0.001
Difference between runs	16.18	0.000
Interaction	2.70	0.101

Table 9. Two-way analysis of variance (unbalanced case) for root elongation data of cucumbers (library program # 1.9.2) for runs 5 and 6.

Grand mean for control	56.61 mm
Grand mean for experimental	47.09 mm

FACTOR	F VALUE	PROBABILITY
Weighted means analysis of variance		
Difference between control/experimental	13.51	0.000
Difference between runs	1.72	0.191
Interaction	0.18	0.668

Table 10. Two-way analysis of variance (unbalanced case) for root elongation data of cucumbers (library program # 1.9.2) for runs 7 and 8.

Grand mean for control	56.61 mm
Grand mean for experimental	47.09 mm

FACTOR	F VALUE	PROBABILITY
Weighted means analysis of variance		
Difference between control/experimental	36.66	0.000
Difference between runs	4.75	0.035
Interaction	1.47	0.232

Table 11. Two-way analysis of variance (unbalanced case) for root elongation data of cucumbers (library program # 1.9.2) all runs.

Grand mean for control	112.17 mm
Grand mean for experimental	99.23 mm

FACTOR	F VALUE	PROBABILITY
Weighted means analysis of variance		
Difference between control/experimental	15.41	0.000
Difference between runs	45.27	0.000
Interaction	0.27	0.604

Table 12. Two-way analysis of variance (unbalanced case) for root elongation data of oats (library program # 1.9.2) for runs 1 and 2.

Grand mean for control	112.17 mm
Grand mean for experimental	99.23 mm

FACTOR	F VALUE	PROBABILITY
Weighted means analysis of variance		
Difference between control/experimental	13.19	0.000
Difference between runs	4.83	0.029
Interaction	0.68	0.411

Table 13. Two-way analysis of variance (unbalanced case) for root elongation data of oats (library program # 1.9.2) for runs 3 and 4.

Grand mean for control	112.17 mm
Grand mean for experimental	99.23 mm

FACTOR	F VALUE	PROBABILITY
Weighted means analysis of variance		
Difference between control/experimental	17.91	0.000
Difference between runs	21.25	0.000
Interaction	0.05	0.815

Table 14. Two-way analysis of variance (unbalanced case) for root elongation data of oats (library program # 1.9.2) for runs 5 and 6.

Grand mean for control	112.17 mm
Grand mean for experimental	99.23 mm

FACTOR	F VALUE	PROBABILITY
Weighted means analysis of variance		
Difference between control/experimental	9.74	0.002
Difference between runs	1.20	0.274
Interaction	0.66	0.419

Table 15. Two-way analysis of variance (unbalanced case) for root elongation data of oats (library program # 1.9.2) for runs 7 and 8.

Grand mean for control	112.17 mm
Grand mean for experimental	99.23 mm

FACTOR	F VALUE	PROBABILITY
Weighted means analysis of variance		
Difference between control/experimental	32.05	0.000
Difference between runs	21.82	0.000
Interaction	0.15	0.702

Table 16. Two-way analysis of variance (unbalanced case) for root elongation data of oats (library program # 1.9.2) all runs.

Grand mean for control	105.03 mm
Grand mean for experimental	104.61 mm

FACTOR	F VALUE	PROBABILITY
Weighted means analysis of variance		
Difference between control/experimental	0.00	0.993
Difference between runs	0.60	0.440
Interaction	0.28	0.598

Table 17. Two-way analysis of variance (unbalanced case) for root elongation data of wheat (library program # 1.9.2) for runs 1 and 2.

Grand mean for control	105.03 mm
Grand mean for experimental	104.61 mm

FACTOR	F VALUE	PROBABILITY
Weighted means analysis of variance		
Difference between control/experimental	0.09	0.767
Difference between runs	0.97	0.326
Interaction	9.92	0.002

Table 18. Two-way analysis of variance (unbalanced case) for root elongation data of wheat (library program # 1.9.2) for runs 3 and 4.

Grand mean for control	105.03 mm
Grand mean for experimental	104.61 mm

FACTOR	F VALUE	PROBABILITY
Weighted means analysis of variance		
Difference between control/experimental	0.04	0.832
Difference between runs	6.07	0.014
Interaction	2.97	0.085

Table 19. Two-way analysis of variance (unbalanced case) for root elongation data of wheat (library program # 1.9.2) for runs 5 and 6.

Grand mean for control	105.03 mm
Grand mean for experimental	104.61 mm

FACTOR	F VALUE	PROBABILITY
Weighted means analysis of variance		
Difference between control/experimental	0.31	0.579
Difference between runs	0.69	0.408
Interaction	3.09	0.079

Table 20. Two-way analysis of variance (unbalanced case) for root elongation data of wheat (library program # 1.9.2) for runs 7 and 8.

Grand mean for control	105.03 mm
Grand mean for experimental	104.61 mm

FACTOR	F VALUE	PROBABILITY
Weighted means analysis of variance		
Difference between control/experimental	0.17	0.683
Difference between runs	0.38	0.541
Interaction	0.00	1.000

Table 21. Two-way analysis of variance (unbalanced case) for root elongation data of wheat (library program # 1.9.2) all runs.

FACTOR	F VALUE	PROBABILITY
Cucumber		
Difference between control/experimental	1.53	0.221
Difference between replications	1.18	0.365
Difference between chambers A and B	1.53	0.221

Table 22. Two-way analysis of variance of cucumber germination data (library program # 1.9.1 (version 2)).

FACTOR	F VALUE	PROBABILITY
Oats		
Difference between control/experimental	0.04	0.844
Difference between replications	3.17	0.080
Difference between chambers A and B	0.35	0.555

Table 23. Two-way analysis of variance of oat germination data (library program # 1.9.1 (version 2)).

FACTOR	F VALUE	PROBABILITY
Wheat		
Difference between control/experimental	1.79	0.185
Difference between replications	1.79	0.185
Differences between chambers A and B	0.65	0.425

Table 24. Two-way analysis of variance of wheat germination data (library program # 1.9.1 (version 2)).

DISCUSSION

Cucumbers and oats treated with 600 Hz audible sound showed a significant inhibition of root elongation. Wheat did not show any significant inhibition of root elongation. No significant change in per cent germination was observed for any of the experimental plants.

In all runs, considerable variation is observed in both control and experimental groups. In cucumbers, the control plants show a low mean of 47.95 mm and a high mean of 62.96 mm; experimental plants show a low mean of 38.31 mm and a high mean of 53.81 mm. In oats, the control plants show a low mean of 95.47 mm and a high mean of 122.85 mm. The experimental plants show a low mean of 83.97 mm and a high mean of 108.97 mm. Wheat control plants show a low mean of 100.62 mm and a high mean of 108.78 mm. Experimental wheat plants show a low mean of 96.88 mm and a high mean of 109.52 mm.

Since these variations cannot be attributed to growth chamber differences (see Tables 22, 23, and 24; pages 34, 35, and 36), some other factors must be involved. It seems logical that morphological variation in seeds may be a factor. Some selection in seeds was done during the course of the experiment. For example, all seeds that were obviously much larger or smaller then the 'average' seeds were not used in the experiment. Any broken or rotten seeds were discarded. However, considerable variation in runs still occurred. Perhaps the answer to this problem would be some type of screening apparatus. A series of two screens could be placed one below the other so that

very large seeds would not pass through the top screen. The seeds collected on the bottom screen (which would have smaller openings then the top screen) would be about the same size with the very small seeds falling through both the first and second screens. It also seems possible that size variations for runs would be smaller if the seeds were allowed to grow for a longer period of time. It was observed in other experimentation with Cyprus esculentus (nutsedge) that tubers which were heavier and larger in size were considerably larger then the lighter smaller tubers a few days after germination. However, after several weeks of growth it was observed that the differences in size were considerably less noticeable.

At 600 Hz of sound, treated cucumber and oat seeds showed a significant inhibition of root elongation while wheat seeds did not. Work previously done in this lab (Ellis, 1973) at 300 Hz sound showed an inhibition of root elongation in wheat. However, it could not be stated conclusively that the inhibition was due to sound since interaction was significant. Experiments now in progress (Gyimah) indicate that there is no significant inhibition of root elongation in wheat, oats, or cucumber at 900 Hz or at 1,200 Hz. Weinberger and Measures (1970) found an increase in growth in Marquis spring wheat at 300 Hz of sound. They found no effect on growth at 1,250 Hz of sound treatment. The differences observed in the growth responses of different species of plants at different frequencies of sound treatment is not disturbing. There are several possible explanations for the occurrence of these varied responses.

In order for sound to effect growth, it seems logical that the

sound waves must penetrate the seeds. Possibly the make up of the seed coat varies with different species. A thick seed coat would make it more difficult for sound waves to enter the seed then a thin seed coat. It would be of interest to pursue this in further experimentation. It is also possible that there are different biochemical pathways in different species of plants. Some of these pathways may be disrupted by sound waves while others may be unaffected. It might be that an enzyme or an intermediate metabolic product could be broken down which would result in the destruction of a particular pathway necessary for normal growth to occur. Within the same plant species, it is quite possible that only a specific frequency of sound would have the ability to disrupt a particular metabolic pathway. It would be useful to carry on further experimentation in which the amino acid levels of sound treated and control seeds could be measured to see if there are any significant differences.

Another interesting question is how do sound waves inhibit growth in plants when this is seen to occur. Many investigators have attributed the destructive effects of sound waves on cells to cavitation (Chambers and Gaines, 1932). Cavitation involves the tearing apart of a column of fluid, and the production in it of regions of vapor or gases. The effects of cavitation are much more evident at very high frequencies of sound (ultrasound) then at audible frequencies.

Why sound waves do inhibit growth in some species, but may have no effect or may even stimulate growth in other species of plants is not really known. Weinberger and Measures (1970) found differences in growth in the same species of wheat when the frequency of sound

was varied. Below a certain frequency no inhibition of growth or germination could be seen. Above this frequency inhibition of growth and germination did occur. The frequency and amount of energy required to produce these effects appears to vary widely between species.

In this experiment there is no significant interaction (Tables 11, 16, and 21; pages 23, 28, and 33). This indicates very strongly that the observed effects, i.e. inhibition of root elongation in cucumbers and oats, is due to sound. No inhibition of root elongation is observed for wheat. The data for cucumbers and oats, however, point to a most dramatic inhibition of root elongation.

Germination in cucumbers, oats, and wheat treated by 600 Hz sound is not significantly effected (Tables 22, 23, and 24; pages 34, 35, and 36). In cucumbers the data is significant at the 22 per cent level, in oats at the 84 per cent level, and in wheat at the 18 per cent level.

In conclusion, I have rejected the null hypothesis --$U_c = U_e$ (no significant difference between control and experimental runs exists) for root elongation in cucumbers and oats. On the basis of a statistical analysis which includes all runs, I am able to state conclusively that the reduction in root elongation is due to sound treatment. However, the null hypothesis cannot be rejected for wheat since no significant inhibition of root elongation occurred. In future experiments it would be of value to be more selective in the choice of seeds. If only those seeds which were morphologically and genetically similar were used (such as screened seeds) there might be less variability between runs. Experiments should be designed which

consider the changes (if any) in amino acid concentration between control and sound treated seeds. A microscopic examination of seed coats to determine differences in thickness would be of value. Finally, it would be of interest to run either cucumbers and wheat or oats and wheat at the same time. In doing this, a species which did show root inhibition and one which did not show root inhibition could be run simultaneously. The null hypothesis for the effect of 600 Hz sound on germination --$U_c = U_e$-- is not rejected.

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