南華大學科技學院自然生物科技學系自然療癒碩士班

碩士論文

Master's Program in Natural Healing Sciences

Department of Natural Biotechnology

College of Science and Technology

Nanhua University

Master Thesis

不同類型音樂對苜蓿和萵苣種子萌發和幼苗生長的影響

The Effects of Different Types of Music on the Germination and Seedling Growth of *Medicago sativa* and *Lactuca sativa* Plants

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中華民國 108 年 6 月

June 2019

南　華　大　學

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口試日期：中華民國 108 年 6 月 27 日

誌 謝

本論文能得以順利完成，首先要感謝我的指導教授 吳澔群博士。從計畫實驗到實驗完成並且完成論文，都要感謝老師的耐心指導與幫助。從一個分不清種子部位的指導生，直到能迅速的量測完根苗，努力的完成每一次的實驗，感謝老師在每一個困難的階段給予的叮嚀與指導，以及在論文寫作上不辭辛勞的指正與協助。

在撰寫論文期間，感謝陳嘉民博士在統計分析上的耐心指導，使得論文得以更加完整。感謝主任陳秋媛博士以及系所的師長們，在就學期間無私的教導，時時給予鼓勵。感謝羅俊智博士對於實驗設計所提出的看法與建議，能更周全的檢驗實驗條件所代表的意義。

實驗能順利完成要特別謝謝學弟們：朝宗，學融，致安，在實驗橫跨年假與連假期間因為你們的協助，實驗才得以順利完成。也要謝謝威仁學弟在統計上的幫助。

靖諭以及珮娟，感謝你們在 2 年讀研時光裡給予很多的幫助及

鼓勵，也謝謝班上的同學們，每周上課的療癒時光都是美好的記憶。

最後，要特別感謝外子的支持以及好友的鼓勵。每周的南下北上因為有你們的鼓勵，我完成了學業，感謝天父，一切的都是最好的安排。

Abstract

The aim of this study was to investigate the effects of different types of music on lettuce and alfalfa seed germination and seedling growth. In total, 9 music treatments were used, namely: 1) Control (no music); 2) Gregorian Chant; 3) Baroque; 4) Classical; 5) Jazz; 6) Rock; 7) Nature sound; 8) New-age; 9) Waltz. In addition, each music was played for either 12 h or 24 h daily. The germination percentage was recorded on the 3rd, 5th, and 7th day. Measurements for the radicle length and hypocotyl length were made on the 7th day.

Results showed no significant differences between the different types of music on the germination percentage of lettuce seeds on day 3, 5, and 7, irrespective of the playback duration. Significant differences (P=0.027) were observed, however, between alfalfa seeds exposed to different 12 h music treatments, with the lowest germination percentage being rock music (91.7%). The highest percentage (100%) of seeds germinated in treatments with music being played was those in the classical, nature sound, and waltz treatments.

In lettuces, compared to control (no music), continuous playback (24 h) of any type of music, with the exception of jazz music, resulted in an overall increase in radicle length. A similar trend was evident in alfalfa seedlings where in comparison to germinating with no music (control), except for jazz and nature sound (12 h), and new-age and waltz music (24 h), a general increase in alfalfa radicle lengths was observed in all music treatments. These findings indicate that there is a tendency for an increase in radicle growth of lettuce and alfalfa seedlings when music is present during germination.

In terms of hypocotyl growth, when lettuce seedlings were exposed to music, regardless of the music type or playback duration, there seemed to be a stimulatory effect on its growth. On the contrary, the overall hypocotyl growth of alfalfa seedlings tend to be suppressed. The exceptions being classical and waltz music, and jazz and waltz music in the 12 h and 24 h treatments, respectively.

Keywords: Alfalfa, lettuce, hypocotyl, music treatment, radicle, seed germination

摘 要

本研究的目的是研究不同類型的音樂對萵苣和苜蓿種子萌發和幼苗生長的影響。總共使用了 9 種音樂處理，即：1）對照組（沒有音樂）；2）葛麗果聖歌；3）巴洛克音樂；4）古典音樂；5）爵士樂；6）搖滾樂；7）自然音樂；8）新世紀音樂；9）華爾滋音樂。此外，每首音樂每天播放 12 小時或 24 小時。在第 3 天，第 5 天和第 7 天記錄發芽率。在第 7 天進行測量胚根長度和胚軸長度。

結果顯示，不論播放時間，不同類型的音樂在第 3 天，第 5 天和第 7 天萵苣種子的發芽率沒有顯著差異。然而，在 12 小時音樂處理的苜蓿種子則觀察到顯著差異（P = 0.027），發芽率最低的是搖滾樂（91.7%）。在播放音樂處理中種子發芽率最高（100%）的是古典音樂，自然音樂和華爾滋音樂。

在萵苣的研究上與對照組（沒有音樂）相比，除了爵士樂之外，任何類型音樂連續播放（24 小時）整體胚根增加了長度。在苜蓿幼苗中也有同樣的趨勢，與對照組（沒有音樂）的發芽相比，除了爵士樂和自然音樂（12 小時），以及新世紀音樂和華爾滋音樂（24 小時），在全

部的音樂處理中觀察到苜蓿胚根長度普遍增加。這些發現顯示，在發芽期間播放音樂，萵苣和苜蓿幼苗的胚根生長都有增加的趨勢。

就胚軸生長而言，當萵苣幼苗處於音樂環境中，無論音樂類型或播放時間，似乎都對胚軸生長具有刺激作用。相反的，除了古典和華爾滋音樂，以及 12 小時和 24 小時處理的爵士樂和華爾滋音樂外，苜蓿幼苗整體胚軸的生長則受到抑制。

關鍵詞：苜蓿、萵苣、胚軸、音樂處理、胚根、種子萌發

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Chapter 1

Introduction

1.1 Research Background

Music is one of the most mysterious human phenomena. Its research attracts the attention of both the public and scientists across various disciplines worldwide (Rauscher, Shaw, & Ky, 1993). The ancient Greek mathematician Pythagoras believed that music can: harmonize the soul, purify the soul, heal the body, restore and maintain health (Hopkins, 2019). The ancient Chinese medical classics text "Huangdi Neijing" has a "five-tone therapy" (or Five Phases Music Therapy) describing the therapeutic effects of music on people. Several studies have showed that listening to Mozart music can enhance one’s spatial skills (Xing et al., 2016). Listening to music can also help improve the memory of the elderly (Borella et al., 2017). As more and more research are conducted on music, the scope of research studies expanded to organisms other than human beings. Music not only has a profound impact on people, but also produces the same effect on other organisms.

1.2 Aim of his Research Study

Humans “listening” to music often begins with "hearing" for "the ability to detect vibration and perceive sound with the organ of the ear, which then enters into the inner ear and then through the brain to create inner feelings and responses. Research on the relationship between human and music is often biased because of the subject's preferences (Creath, 2003). Plants are complex multicellular organisms that respond to music as humans do (Ramekar & Gurjar, 2016). In order to avoid people's preferences, and the auditory and psychological effects that melodies and forms of music can have on people, the present study selected plants as test subjects. The experimental conditions were designed to determine whether music has a direct physical effect on plant development processes such as seed germination and seedling growth.

The objectives of this study were:

1. To study the effects of different types of music on lettuce and alfalfa seed germination and seedling growth.
2. To analyze the effects of the speed and frequency of different music on seed germination and seedling growth.

Chapter 2

Literature Review

2.1 Musical Sounds

In the most basic sense, sound is a kind of vibration, a transverse pressure wave. The definition of music according to Merriam Webster dictionary (2019) is: “A tone or sound is ordered in a continuous, combined, and temporal relationship to produce a science or art of a combination of unity and continuity”. It can also simply be described as a harmonious sound produced by vocals, musical instruments, or mechanical sounds. (Howard & Angus, 2017; Pierce, 1992; Radocy & Boyle, 2012). Music generally has the following elements: rhythm, melody, harmony and timbre. Sound, vibration, and time elements can be organized in a way that create sounds we consider as music or non-musical.

2.2 History of Plants and Music

The study of the relationship between music and plants has had a long history. Back in the 11th century, in one of the earliest literatures about music and plants – Brush Talks from Dream Brook – local legend has it that when hearing “The Melody of Beautiful Yu”, a flower which was also called “Beautiful Yu” would shake from side to side. But when other music was played, it would not move. This experiment was reportedly carried out several times, and the results were found to be true (Shen, Wang, & Zhao, 2011).

In the 19th century, Darwin monitored the effects of his own bassoon music on plant growth by seeing if his bassoon could induce the leaves of Mimosa plants to close (Chamovitz, 2012). Sir Jagdish Chandra Bose was one of the pioneers to study and experiment with plants’ response to environmental stimuli. He concluded the plants are sensitive to external factors such as light, cold, movement, and noise (Bose, 1902, 1906). The botanist T.C. Singh studied the effects of music on plant growth. He discovered that the growth of balsa plants accelerated in response to certain sounds. From the results of numerous experiments in this field, Singh concluded that the violin had the biggest impact on the overall growth of plants. Another discovery demonstrated that "feeding" seeds with music before and during germination resulted in larger plants with more leaves (Ekici, Dane, Mamedova, Metin, & Huseyinov, 2007; Petrescu, Mustatea, & Nicorici, 2017).

Another study by Eugene Canby showed that wheat yield increased by 66% when the plants were subjected to recordings of violin sonatas by J.S. Bach (Wicke, 2002). In 1973, Dorothy Retallack developed an experiment using three biotronic control rooms, in which she carried out the first scientifically controlled experiment showing the different responses of plants to different types of music (Retallack & Broman, 1973). The book 'The secret life of plants'(Tompkins & Bird, 1973) describes among others, the sense of 'hearing' in plants (Tompkins & Bird, 1989). There have been many studies and experiments on the effects of musical sound on plant growth, some of which attempted to refute the viewpoint that music influences plant growth. Although there have been much controversy about these claims, it has, however, led to an increase in scientific research in plant and acoustics (Chowdhury, Lim, & Bae, 2014; Collins & Foreman, 2001; Ekici et al., 2007; Gagliano, 2012; Jeong et al., 2008; Mauck, De Moraes, & Mescher, 2014; Miller, 1983).

2.3 Review of Prior Research

In past research, studies on the influence of sound on plants made a differentiation between acoustic waves and music, and explored their effects on plant growth. In addition to plant growth, there are also numerous literature reporting on how music affects seed germination.

Music can be described as a harmonious and coherent blend of various frequencies and vibrations (Chowdhury & Gupta, 2015). It is generally accepted that loud and unharmonious sounds can negatively affect the health of a plant and its flowers (Chowdhury & Gupta, 2015). On the other hand, soft rhythmic music have positive effects on plant growth and flowering, and as a result may increase plants' growth rate, plant size, and have an effect on their overall health.

In a study on the germination of *Cicer arietinum* (chickpea) seeds exposed to light Indian music, results showed that it promoted the growth and development of these plants (Chowdhury & Gupta, 2015). However, when noise was used during germination, seed growth was hindered. Findings from another study showed that protein content in plants such as soya, spinach, and wheat were positively affected by Indian classical ragas (Creath & Schwartz, 2004; Reddy & Ragavan, 2013). Furthermore, it was also found that the germination of okra and zucchini seeds were stimulated by musical vibrations.

Yi et al. (2003) investigated the effects of sound on the growth of chrysanthemum. Their results showed an increase in metabolism in the roots, which led to improved overall growth of chrysanthemums. An interesting study by Vanol & Vaidya (2014) exposed guar plants to classical music, rhythmic rock music and non-rhythmic traffic noise with varying frequencies. Data on seed germination percentage, plant height, and number of leaves demonstrated that, compared to untreated plants, classical music and rhythmic rock music showed positive effects, whereas non-rhythmic traffic noise negatively affected the plants. However, results of other studies reported that, in comparison to a silence treatment, growth of bean plants was promoted when exposed to any kind of sound (Singh, Jalan, & Chatterjee, 2013; Vanol & Vaidya, 2014).

Previous research has also showed music to have an adverse effect on seed germination. In a study by Petrescu, et. al (2017), *Beta vulgaris* seed germination were found to be negatively impacted by the six Bach music used in their treatments. They concluded that it could be due to the music source being too close to the seed, which caused the pressure generated by the sound waves to have a negative effect on the seeds. Another possible reason mentioned was that it could have been the number of music playbacks used in the treatments, which adversely affected the germination process.

2.4 Acoustic Responses of Plants

The general definition of human hearing is the ability to perceive sound by detecting vibrations via an organ such as the ear (Chamovitz, 2012). Sound or sound wave can be described in 2 different dimensions: volume and pitch (Gagliano, Mancuso, & Robert, 2012). Volume (amplitude) is represented by the height of the waves. The larger the amplitude of the waves, the louder the sound. Pitch (frequency) is represented by the spacing of the waves. The closer together the waves are, the higher the pitch of the sound. Acoustic transmission is the transmission of sounds through and between medium materials, including air, ground, and musical instruments. During the transmission, the waves may cause the medium materials or its surface to generate vibrations (Gagliano, Mancuso, et al., 2012).

In the past, scientists believed that plants cannot hear and process sound waves because plants do not possess structural organs that allow them to detect sound. Nevertheless, it is now known that plants can detect the vibration generated from music sounds. Plants are multi-cellular organisms that may not 'hear' sounds, but several current studies have shown that plants can respond to music similar to how humans do. Sound wave can be transmitted by medium materials, and plants' response to music can cause drastic changes in plant metabolism, which can affect plant growth (Creath & Schwartz, 2004; Ramekar & Gurjar, 2016).

The research by Gagliano, et al. (2012) demonstrated the ability of plants' roots to detect vibrations caused by sound. Furthermore, in addition to detecting vibrations, plant roots also exhibit a frequency-selective sensitivity that generate behavioral modifications. The young roots of the corn used in their study generated structured, spike-like, acoustic emissions illustrated this point (Gagliano, Mancuso, et al., 2012).

Other research have shown that roots are able to locate a water source by sensing the vibrations generated by water moving inside pipes (Gagliano, Grimonprez, Depczynski, & Renton, 2017). However, the presence of noise affects the root's ability to respond correctly to surrounding soundscapes. Plants have also been shown to be able to communicate similarly through acoustic vibration (Gagliano, Renton, Duvdevani, Timmins, & Mancuso, 2012; Mishra, Ghosh, & Bae, 2016).

According to Haswell, Phillips, & Rees (2011), plant membranes comprise a large number of mechano-sensitive channels that are believed to be responsive to mechanical vibrations (Haswell et al., 2011). There is an increasing number of studies that suggest sound vibrations of certain frequencies can positively influence seed germination, root elongation, callus growth, cell cycling, and other plant processes (Chowdhury et al., 2014; da Silva & Dobránszki, 2014; Gagliano, 2012).

It is known that plants continuously sense and respond to their dynamic and complex surroundings, which involves identifying important environmental cues and reacting with appropriate responses (Mishra et al., 2016). Moreover, findings from research carried out in the past have established that plants modulate their growth and development in response to environmental factors such as sound waves and other mechanical perturbations.

Chapter 3

Materials and Methods

3.1 Plant Material and Growth Conditions

The lettuce (*Lactuca sativa*) and alfalfa (*Medicago sativa*) seeds used in this study were purchased from Known-You Seed Co. Ltd. The lettuce seed cultivar was 'Hong-Cui' (Chinese: 紅翠), and the alfalfa cultivar was 'Zi-Hua' (Chinese: 紫花). These seeds were untreated, and were randomly selected for use in this study.

The seeds were placed in 90-mm sterile Petri-dishes lined with two pieces of 90-mm filter paper. Six milliliters of reverse osmosis (RO) water were added to each Petri-dish. Each Petri-dish contained 12 seeds, which were arranged in a 3 x 4 layout (Fig. 3.1). The Petri-dishes were sealed with two layers of Parafilm® and placed in a box (33 x 33 x 33 cm). Each box, which represented a single treatment, had five Petri-dishes inside. The Petri-dishes were evenly spaced out with a cellphone placed vertically facing the Petri-dishes (Fig, 3.2). Each box was fitted with 23-mm thick sound-absorbing Nitrile Butadiene Rubber (NBR) on all 6 sides (Fig. 3.2). The seeds were germinated in total darkness. The temperature inside the boxes was 23.7±1 ºC, which was measured using a Benetech GS320 Standard Instrument Infrared thermometer.

All the boxes with different music treatments were placed far apart at different areas inside a plant factory. The temperature inside the plant factory was adjusted to 25±2ºC (daytime) and 20±2ºC (nighttime). The relative humidity was 70% ~ 80% during the day and 50% ~ 60% during the night.

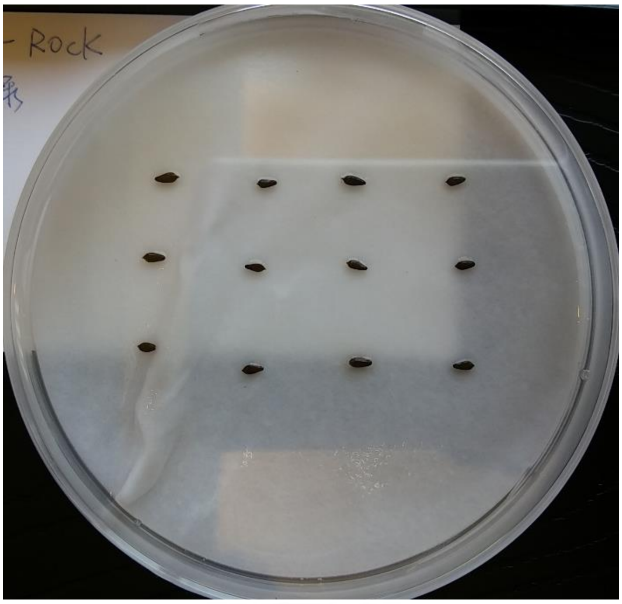

Fig. 3.1 Arrangement of seeds in Petr-dish during germination

Fig. 3.2 Layout of Petri-dishes in sound-absorbing box

3.2 Music Treatments and Playback Conditions

The types of music used in this study were selected based on the frequency and tempo of the musical instrument and composition. Furthermore, different vocals and a range of instrumental music such as brass, strings, electric guitars, drums, and piano were chosen to compare their effects on seed germination and seedling growth. In addition, nature sound was also included as a treatment.

In total, 9 music treatments were used, namely: 1) Control (no music); 2) Gregorian Chant; 3) Baroque; 4) Classical; 5) Jazz; 6) Rock; 7) Nature sound; 8) New-age; 9) Waltz (Table 3.1). The Gregorian chant was chosen because it is a type of religious music, and it consists of inconsistent tempo with low vocals. The baroque was composed with a violin, which has been reported in literature to have a positive effect on plant growth. The 'Spring' track used is considered to have a fast tempo, with high vocals. The Mozart track used is a classical music that has been found to be one of the top ten most relaxing music of all time. Its high female vocals are in contrast to the low male vocals of the Gregorian chant. The jazz music used is a fast composition that consists of brass instruments with deep, low sounds. The rock music was selected in this study because it consists of fast, heavy metal music with high pitched sounds. The nature sounds track was used to represent sounds from water, insects, and birds. It is considered to be a type of pink noise that is a good contrast to the other music types. These six tracks were sourced online, while the final two tracks (New-age and Waltz) were composed by the author of the thesis. The new-age track is a quadruple meter composition with a fast, smooth, piano tempo. The waltz track is a fast triple meter piano composition. It has a distinctly different tempo to the new-age track. A digital sound level meter (Smart Sensor AS804B, Sensor Instruments) was placed inside each box to record the decibel values of each music track (Table 3.1).

The tempo (bpm, beats per minute) and frequency range of each type of music used are shown in Table 3.2 and Figure 3.3. The URL and composer or performer of the tracks sourced online are shown in Table 3.3. For each track, a 4-min piece was extracted and played at specific durations. In each music treatment, the track was played for either 12 h (7:00 am to 7:00 pm) or 24 h daily for the duration of the study (7 days). Identical cellphones with 2 speakers were used for music playback in each music treatment. The cellphones were installed with Automatelt® software program and set up to play music automatically at the set time period and duration.

3.3 Statistical Analysis

A total of 9 music treatments with 2 playback conditions per plant type were used in the experiment (Fig. 3.4). Sixty replicates per treatment were used. The seeds were germinated for 7 days, during which the following data were collected: Germination percentage was collected on the 3^{rd}, 5^{th}, and 7^{th} day. On the 7^{th} day, the radicle length and hypocotyl length of all germinated seedlings were measured (Fig. 3.5). Data were analyzed using Chi-square test and Duncan's Multiple Range Test to compare germination % and treatment means, respectively, using SPSS v. 17 software.

Table 3.1 The category, instrument, and decibel value of the music treatments used in this study

Track	**Category**	**Instrument**	**dB value**
Control Group	None	None	49 ±3
Gregorian Chant	Religious	Male chorus	79 ± 9
Baroque	Class	String instruments	91 ± 9
Classical	Class	Female voice duet	84 ± 7
Jazz	Modern	Brass instruments	93 ± 4
Rock	Modern	Vocal Electric guitar Electric bass Drum set	87 ± 8
Nature Sounds	Not applicable	None	90 ± 6
New Age Music (Self-composed)	Modern	Piano	87 ± 4
Waltz (Self-composed)	Modern	Piano	85 ± 4

Table 3.2 The source of the tracks used in the music treatments of this study

	Track and URL	Composer or Performer
Gregorian Chant	Ave Mundi Spes Maria (Sequenza (Modos VII Y VIII))	Choir of the Benedictine Abbey of Santo Domingo de Silos
	https://www.youtube.com/watch?v=_MbDqc3x97k&t=51s	
Baroque	The Four Seasons, Spring (La Primavera), 1st movement	A.L.Vivaldi
	https://www.youtube.com/watch?v=e3nSvIiBNFo	
Classical	Duettino Sull'aria Le nozze di Figaro	W.A.Mozart
	https://www.youtube.com/watch?v=CQ8ZHilxdm8	
Jazz	In the swing	Upbeat Brass
	https://www.youtube.com/watch?v=7w46aeZ_4qo	
Rock	All Shall Fall	Immortal
	https://www.youtube.com/watch?v=sOOebk_dKFo	
Nature Sound	Relax 8 Hours-Relaxing Nature Sounds-Study-Sleep-Meditation-Water Sounds-Bird Song	None
	https://www.youtube.com/watch?v=eKFTSSKCzWA	
New-age	None	(Self-composed)
Waltz	None	(Self-composed)

MIDI number	MIDI number	Frequency Hz	Frequency Hz	Period ms	Period ms
21	22	27.500	29.135	36.36	34.32
23		30.868		32.40	
24	25	32.703	34.648	30.58	28.86
26	27	36.708	38.891	27.24	25.71
28		41.203		24.27	
29	30	43.654	46.249	22.91	21.62
31	32	48.999	51.913	20.41	19.26
33	34	55.000	58.270	18.18	17.16
35		61.735		16.20	
36	37	65.406	69.296	15.29	14.29
38	39	73.416	77.782	13.62	12.86
40		82.407		12.13	
41	42	87.307	92.499	11.45	10.81
43	44	97.999	103.83	10.20	9.631
45	46	110.00	116.54	9.091	8.581
47		123.47		8.099	
48	49	130.81	138.59	7.645	7.216
50	51	146.83	155.56	6.811	6.428
52		164.81		6.068	
53	54	174.61	185.00	5.727	5.405
55	56	196.00	207.65	5.102	4.816
57	58	220.00	233.08	4.545	4.290
59		246.94		4.050	
60	61	**261.63**	277.18	**3.822**	3.608
62	63	293.67	311.13	3.405	3.214
64		329.63		3.034	
65	66	349.23	369.99	2.863	2.703
67	68	392.00	415.30	2.551	2.408
69	70	**440.00**	466.16	**2.273**	2.145
71		493.88		2.025	
72	73	523.25	554.37	1.910	1.804
74	75	587.33	622.25	1.703	1.607
76		659.26		1.517	
77	78	698.46	739.99	1.432	1.351
79	80	783.99	830.61	1.276	1.204
81	82	880.00	932.33	1.136	1.073
83		987.77		1.012	
84	85	1046.5	1108.7	0.9556	0.9020
86	87	1174.7	1244.5	0.8513	0.8034
88		1318.5		0.7584	
89	90	1396.9	1480.0	0.7159	0.6757
91	92	1568.0	1661.2	0.6378	0.6020
93	94	1760.0	1864.7	0.5682	0.5363
95		1975.5		0.5062	
96	97	2093.0	2217.5	0.4778	0.4510
98	99	2349.3	2489.0	0.4257	0.4018
100		2637.0		0.3792	
101	102	2793.0	2960.0	0.3580	0.3378
103	104	3136.0	3322.4	0.3189	0.3010
105	106	3520.0	3729.3	0.2841	0.2681
107		3951.1		0.2531	
108		4186.0		0.2389	

Keyboard

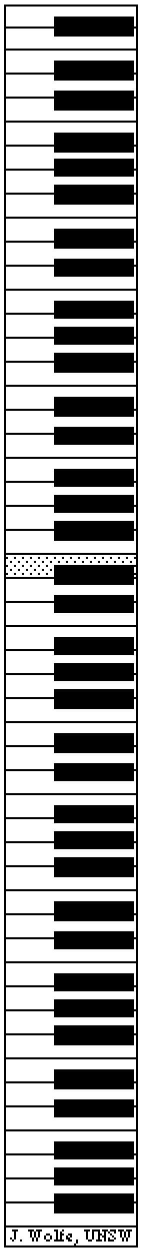

Fig. 3.3 Frequency chart

(Source: https://newt.phys.unsw.edu.au/jw/notes.html)

Table 3.3 Tempo/Meter/Frequency range of the music treatments used in this study

Music	Tempo	Time signature	Frequency range
Control Group	None	None	None
Gregorian Chant	≑ 54 bpm	None	D3 (131 Hz) F4 (349 Hz)
Baroque	108 bpm	4/4	B3 (123 Hz) #G6 (1661Hz)
Classical	96 bpm	6/8	bB5 (466 Hz) F6 (1397 Hz)
Jazz	180 bpm	4/4	bA4 (207 Hz) bD5 (554 Hz)
Rock	100 bpm	4/4	G3 (196 Hz) D4 (294 Hz)
Nature Sounds	None	None	None
New Age Music (Self-composed)	116 bpm	4/4	D2 (73 Hz) A7 (1760 Hz)
Waltz (Self-composed)	160 bpm	3/4	D3 (147 Hz) E6 (1319 Hz)

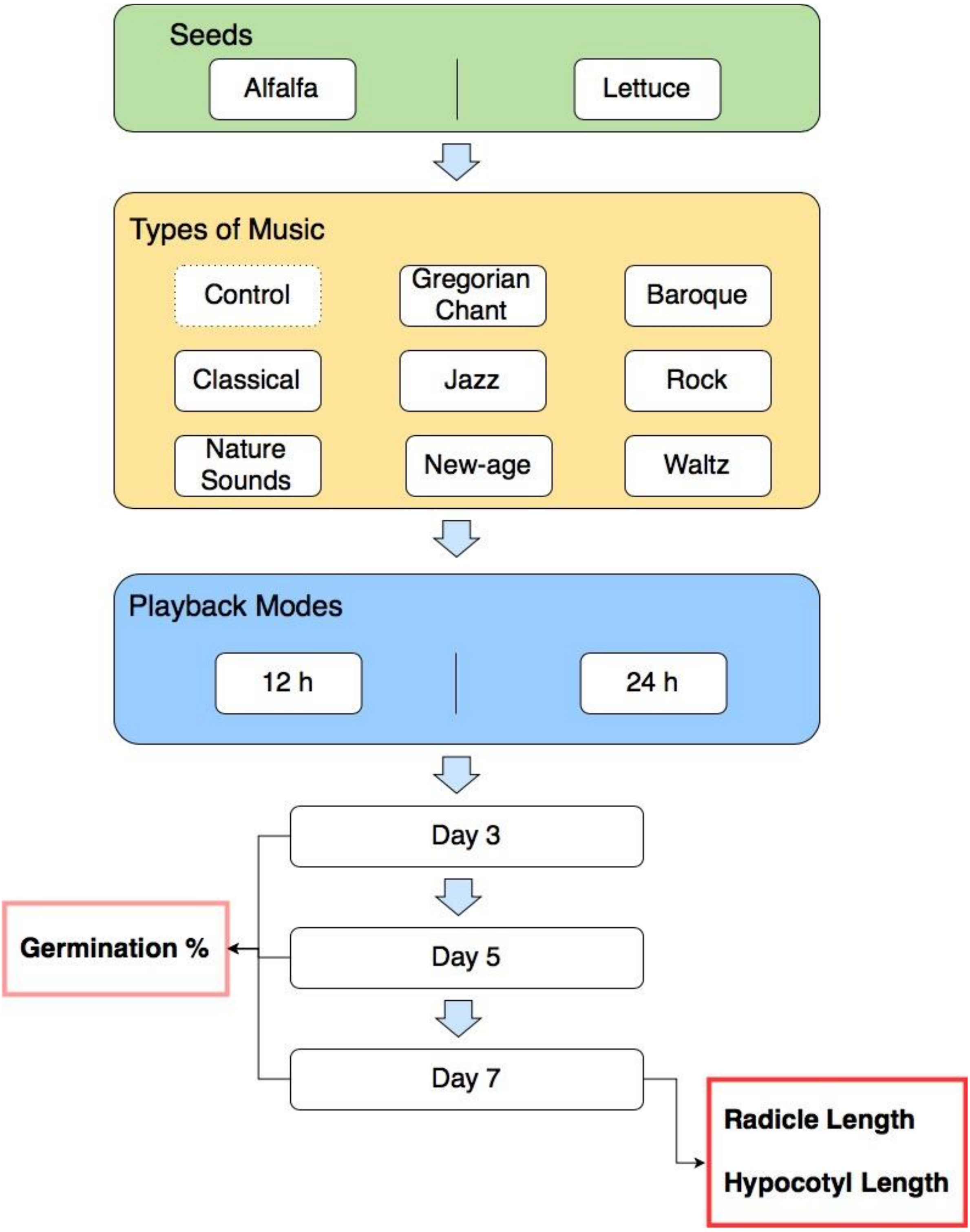

Fig. 3.4 Experimental flowchart

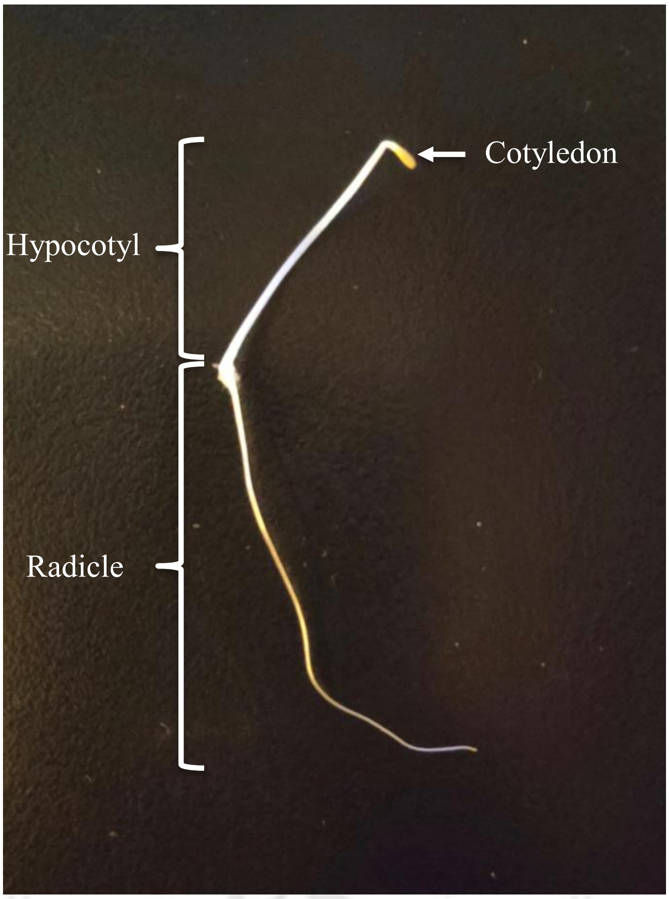

Fig. 3.5 Structure of seedling

Chapter 4

Results

4.1 Effect of Different Types of Music and Playback Duration on Germination Percentage

Germination of lettuce and alfalfa seedlings in different types of music are shown in Fig. 4.1 and Fig. 4.2, respectively. An interesting result from the lettuce seedlings exposed to classical, jazz, and rock music could be seen in Fig. 4.1, whereby these seedlings seemed to grow in the same direction toward the source of the music (cellphone speaker). Although the direction of growth was not within the scope of this study, this observation is nevertheless noteworthy for future studies.

In lettuce seeds, high germination percentages were evident throughout all music treatments in both the 12 h and 24 h playbacks. In fact, by the 3rd day of germination, the lowest germination percentage had already reached

93.3% for classical in the 12 h treatment, and rock and nature sound in the 24 h treatment (Table 4.1). Results showed that no significant differences were found between the different types of music on the germination percentage of lettuce seeds on day 3, 5, and 7, irrespective of the playback duration (Table 4.1; Table 4.2; Table 4.3).

However, significant differences (P=0.036) were observed in alfalfa seeds exposed to different types of music when played for 24 h on the 3rd day of germination. In particular, significantly lower germination percentage were found in the Gregorian chant treatment (86.7%), compared to those exposed to baroque music (100%) (Table 4.1). By the 5th day, a similar germination percentage of alfalfa seeds was observed throughout all music treatments with 24 h playbacks (Table 4.2). In contrast, in the 12 h playbacks, significant differences (P=0.029) were observed between alfalfa seeds in several music treatments, namely, alfalfa seeds exposed rock music (91.7%) germinated significantly less than those in the control (100%), classical (100%), nature sound (100%), and waltz (100%) music.

On the 7th day of germination, significant differences ($P=0.027$) were observed between alfalfa seeds exposed to different 12-h music treatments (Table 4.3), with the lowest germination percentage being rock music (91.7%). On the contrary, the highest percentage (100%) of seeds germinated in treatments with music being played were those in the classical, nature sound, and waltz treatments. No significant differences were observed between these three treatments and the control, which also produced 100% germination. The germination percentage of the remaining treatments did not differ significantly regardless of the type of music or playback duration used (Table 4.3).

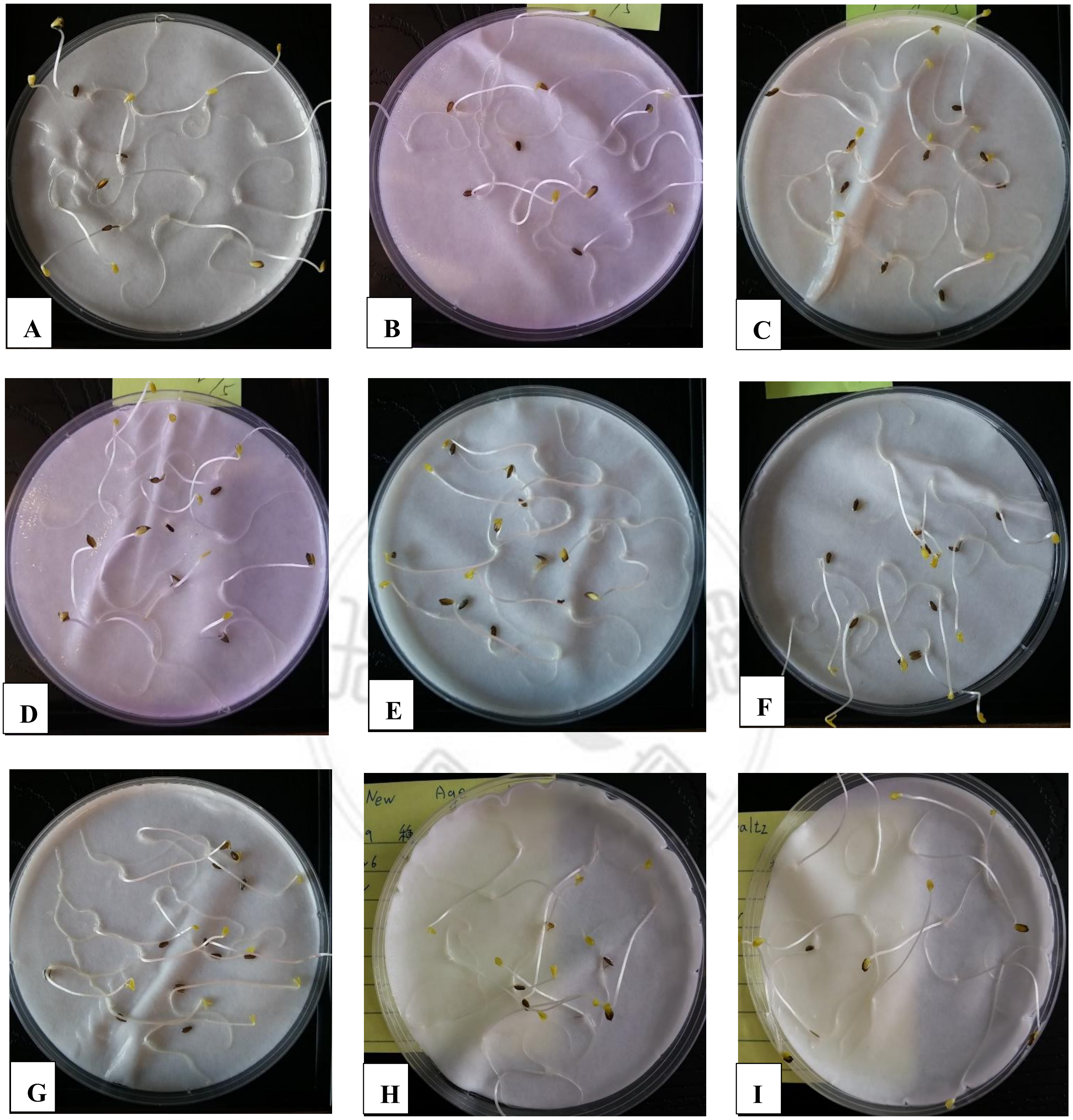

Fig. 4.1 Lettuce seed germination. (A) Control; (B) Gregorian Chant; (C) Baroque; (D) Classical; (E) Jazz; (F) Rock; (G) Nature Sound; (H) New-age; (I) Waltz

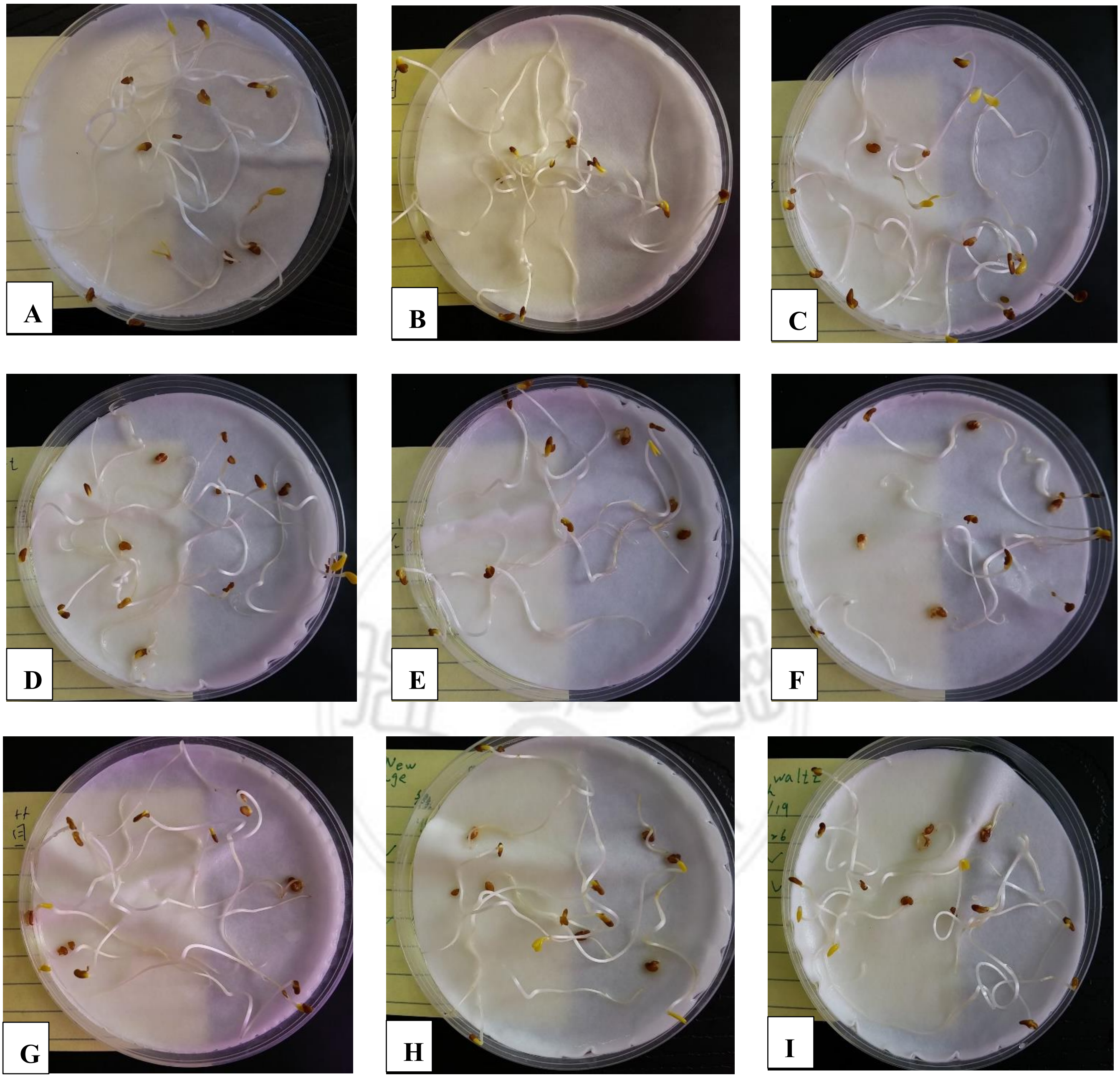

Fig. 4.2 Alfalfa seed germination. (A) Control; (B) Gregorian Chant; (C) Baroque; (D) Classical; (E) Jazz; (F) Rock; (G) Nature Sound; (H) New-age; (I) Waltz

Table 4.1 The effects of different types of music and playback duration on germination % of *Lactuca sativa* (lettuce) and *Medicago sativa* (alfalfa) seeds after 3 days

Seed	Duration	Control	Gregorian Chant	Baroque	Classical	Jazz	Rock	Nature Sound	New-age	Waltz	P-value
Lettuce	12 h	98.3	95	98.3	93.3	96.7	95	100	98.3	98.3	0.447
	24 h	98.3	98.3	100	98.3	95	93.3	93.3	95	98.3	0.317
Alfalfa	12 h	98.3	96.7	93.3	100	96.7	91.7	98.3	93.3	98.3	0.201
	24 h	98.3	86.7	100	95	95	95	98.3	95	96.7	**0.036***

Table 4.2 The effects of different types of music and playback duration on germination % of *Lactuca sativa* (lettuce) and *Medicago sativa* (alfalfa) seeds after 5 days

Seed	**Playback Duration**	**Control**	**Gregorian Chant**	**Baroque**	**Classical**	**Jazz**	**Rock**	**Nature Sound**	**New-age**	**Waltz**	**P-value**
Lettuce	12 h	98.3	95	98.3	93.3	96.7	95	100	98.3	98.3	0.447
	24 h	98.3	98.3	100	100	98.3	93.3	95	95	98.3	0.219
Alfalfa	12 h	100	96.7	95	100	96.7	91.7	100	93.3	100	**0.029***
	24 h	100	98.3	100	95	98.3	95	98.3	96.7	96.7	0.510

Table 4.3 The effects of different types of music and playback duration on germination % of *Lactuca sativa* (lettuce) and *Medicago sativa* (alfalfa) seeds after 7 days

Seed	**Playback Duration**	**Control**	**Gregorian Chant**	**Baroque**	**Classical**	**Jazz**	**Rock**	**Nature Sounds**	**New -age**	**Waltz**	**P-value**
Lettuce	12 h	98.3	95	98.3	93.3	98.3	98.3	100	98.3	98.3	0.371
	24 h	98.3	98.3	100	100	98.3	96.7	98.3	95	98.3	0.612
Alfalfa	12 h	100	96.7	96.7	100	96.7	91.7	100	93.3	100	**0.027***
	24 h	100	98.3	100	95	100	98.3	98.3	96.7	96.7	0.419

4.2 Effect of Different Types of Music on Radicle Growth

In lettuce seedlings, results showed that after 7 days, significantly higher mean radicle lengths were observed in the 12 h Gregorian chant, new-age, and waltz treatments compared to the control (Table 4.4). Of these three treatments, seedlings in the Gregorian chant and waltz treatments produced the longest radicles, which were significantly longer than those exposed to new-age music. On the other hand, in the 24 h playback treatment, lettuce seedlings exposed to baroque produced the longest radicle (44.39 mm). Furthermore, except for the classical and jazz treatments, radicle growth in all the other music treatments were significantly longer than the control (Table 4.4).

With regard to the radicle growth of alfalfa seedlings, no significant differences were found between all treatments when exposed to 12 h of music (Table 4.5). Nevertheless, results indicated that alfalfa seeds grown with jazz music tend to have shorter radicles, whereas those germinated in

Gregorian chant and classical music tend to produce the longest radicles.

Similarly, the mean radicle lengths of alfalfa seedlings exposed to different music played for 24 h did not differ significantly to the control treatment (Table 4.5). However, significant differences were found between seedlings grown in the nature sound treatment (43.85 mm) and those exposed to new-age music (37.07 mm), which produced the longest and shortest radicles, respectively.

Table 4.4 The effects of different types of music and playback duration on radicle growth in lettuce seedlings after 7 day

Treatment	Radicle Length (mm)		Frequency	Volume
	12 h	24 h	(Hz)	(dB)
Control	32.49±8.88^{ab}	32.49±8.88^{a}		49±3
Gregorian Chant	43.77±9.38^{d}	38.83±9.11^{b}	131 ~ 349	79±9
Baroque	32.44±8.80^{ab}	44.39±9.35^{c}	123 ~ 1661	91±9
Classical	29.26±10.23^{a}	34.87±10.40^{a}	466 ~ 1397	84±7
Jazz	31.48±8.86^{ab}	30.28±12.05^{a}	207 ~ 557	93±4
Rock	34.53±11.01^{b}	41.23±11.09^{bc}	196 ~ 294	87±8
Nature Sound	34.22±10.83^{b}	40.49±11.76^{bc}	Pink Noise	90±6
New-age	39.76±9.95^{c}	40.92±11.95^{bc}	73 ~ 1760	87±4
Waltz	43.58±12.71^{d}	42.28±12.07^{bc}	147 ~ 1319	85±4

Different letters in the same column indicate values differ significantly according to Duncan's Multiple Range test ($P < 0.05$).

Table 4.5 The effects of different types of music and playback duration on radicle growth in alfalfa seedlings after 7 days

Treatment	Radicle Length (mm)		Frequency	Volume
	12 h	24 h	(Hz)	(dB)
Control	39.75±15.89[a]	39.75±15.89[ab]	-	49±3
Gregorian Chant	43.36±17.15[a]	41.92±12.88[ab]	131 ~ 349	79±9
Baroque	41.62±13.59[a]	41.67±13.90[ab]	123 ~ 1661	91±9
Classical	43.93±15.87[a]	42.33±19.18[ab]	466 ~ 1397	84±7
Jazz	38.32±12.88[a]	43.23±12.78[ab]	207 ~ 557	93±4
Rock	40.33±14.37[a]	41.35±15.27[ab]	196 ~ 294	87±8
Nature Sound	39.17±16.59[a]	43.85±16.54[b]	Pink Noise	90±6
New-age	41.76±15.00[a]	37.07±13.69[a]	73 ~ 1760	87±4
Waltz	41.02±16.59[a]	38.39±15.11[ab]	147 ~ 1319	85±4

Different letters in the same column indicate values differ significantly according to Duncan's Multiple Range test ($P < 0.05$).

4.3 Effect of Playback Duration Within the Same Music Treatment on Radicle Growth

In lettuce seedlings, when comparing between the 12 h and 24 h playback durations within the same music treatment, those exposed to 24 h of baroque, classical, rock, or nature sound produced significantly longer radicles than those grown in 12 h treatments (Table 4.6). Conversely, seedings germinated in the 12 h treatment of Gregorian chants produced significantly longer radicles than the 24 h treatment. Playback duration did not significantly affect radicle growth of lettuce seedlings grown in jazz, new-age, and waltz music treatments.

In alfalfa seedlings, no significant differences in radicle length were found between the 12 h and 24 h treatments in all music types (Table 4.7). Nevertheless, seedlings germinated in 12-h playbacks of Gregorian chant, classical, new-age, and waltz tended to have longer radicles than those in the 24 h treatment, whereas the opposite is true for baroque, jazz, rock, and nature sound treatments.

Table 4.6 The effects of different playback durations in the same type of music on radicle growth in lettuce seedlings after 7 days

Treatment	**Radicle Length (mm)**		**P value**	**Frequency**	**Volume**
	12 h	**24 h**		**(Hz)**	**(dB)**
Gregorian Chant	43.77±9.38[a]	39.38±9.11[b]	**0.02**	131 ~ 349	79±9
Baroque	32.44±8.80[b]	44.39±9.35[a]	**0.00**	123 ~ 1661	91±9
Classical	29.63±10.23[b]	34.87±10.40[a]	**0.01**	466 ~ 1397	84±7
Jazz	31.48±8.86[a]	30.28±12.05[a]	0.57	207 ~ 557	93±4
Rock	34.53±11.01[b]	41.23±11.09[a]	**0.00**	196 ~ 294	87±8
Nature Sound	34.22±10.83[b]	40.49±11.76[a]	**0.01**	Pink Noise	90±6
New-age	39.76±9.95[a]	40.92±11.95[a]	0.58	73 ~ 1760	87±4
Waltz	43.58±12.71[a]	42.28±12.07[a]	0.58	147 ~ 1319	85±4

Different letters in the same row indicate values differ significantly according to Duncan's Multiple Range test ($P \leq 0.05$).

Table 4.7 The effects of different playback time durations in the same type of music on radicle growth in alfalfa seedlings after 7 days

Treatment	Radicle Length (mm)		P value	Frequency	Volume
	12 h	24 h		(Hz)	(dB)
Gregorian Chant	43.36±17.15[a]	41.92±12.88[a]	0.63	131 ~ 349	79±9
Baroque	41.62±13.59[a]	41.67±13.90[a]	0.98	123 ~ 1661	91±9
Classical	43.93±15.87[a]	42.33±19.18[a]	0.69	466 ~ 1397	84±7
Jazz	38.45±12.88[a]	43.23±12.78[a]	0.62	207 ~ 557	93±4
Rock	40.33±14.37[a]	41.35±15.27[a]	0.73	196 ~ 294	87±8
Nature Sound	39.17±16.59[a]	43.85±16.54[a]	0.14	Pink Noise	90±6
New-age	41.76±15.00[a]	37.07±13.69[a]	0.11	73 ~ 1760	87±4
Waltz	41.02±16.59[a]	38.39±15.11[a]	0.39	147 ~ 1319	85±4

Different letters in the same row indicate values differ significantly according to Duncan's Multiple Range test ($P \leq 0.05$).

4.4 Effect of Different Types of Music on Hypocotyl Growth

In lettuce seedlings grown in music with a 12-h playback, the highest mean hypocotyl length was produced in jazz and waltz music (Table 4.8). These were significantly longer than those germinated in the control treatment, which produced the shortest of all treatments. In fact, except for baroque, classical, and rock music, which had similar hypocotyl lengths to those in the control treatment, the hypocotyls of seedlings grown in all the other music treatments were significantly longer than the control.

In the 24 h playback treatment, except for jazz music, all lettuce seedlings in the other music treatments produced significantly longer hypocotyls than those in the control treatment (Table 4.8). This suggests that these seedlings grown in any type of music being played continuously tend to produce longer hypocotyls. In addition, seedlings exposed to 24 h of jazz music produced significantly shorter hypocotyls than those in rock and new-age music treatments.

Unlike lettuce seedlings, a relatively high mean hypocotyl length was observed in alfalfas grown without music (control) (Table 4.9). In fact, significantly shorter hypocotyls were found in the jazz and nature sound of the 12 h treatment, compared to the control. The mean hypocotyl length of seedlings grown without any music was comparable to those exposed to Gregorian chant, baroque, classical, rock, new-age, and waltz music, with those grown in waltz music being the longest (53.25 mm).

In the 24 h playback treatment, alfalfa seedlings germinated in classical, rock, and nature sound had significantly lower mean hypocotyl lengths compared to the control (Table 4.9). Except for these three types of music, all hypocotyl lengths in the remaining music treatments were similar to those of the control. Although not significantly different to the control treatment, the longest hypocotyl length was found in seedlings exposed to jazz music (52.42 mm).

Table 4.8 The effects of different types of music and playback duration on hypocotyl growth in lettuce seedlings after 7 days

Treatment	Hypocotyl Length (mm)		Frequency	Volume
	12 h	24 h	(Hz)	(dB)
Control	33.93±5.57^{a}	33.93±5.57^{a}	-	49±3
Gregorian Chant	38.83±6.71^{cd}	38.84±6.71^{bc}	131 ~ 349	79±9
Baroque	36.20±6.08^{abc}	38.68±7.35^{bc}	123 ~ 1661	91±9
Classical	35.82±7.36^{ab}	37.92±6.61^{bc}	466 ~ 1397	84±7
Jazz	39.98±9.64^{d}	35.49±9.83^{ab}	207 ~ 557	93±4
Rock	36.65±8.01^{abc}	38.87±6.94^{c}	196 ~ 294	87±8
Nature Sound	38.34±7.26^{bcd}	38.22±7.26^{bc}	Pink Noise	90±6
New-age	38.95±6.18^{cd}	38.47±7.64^{c}	73 ~ 1760	87±4
Waltz	39.84±6.74^{d}	38.54±8.26^{bc}	147 ~ 1319	85±4

Different letters in the same column indicate values differ significantly according to Duncan's Multiple Range test ($P < 0.05$).

Table 4.9 The effects of different types of music and playback duration on hypocotyl growth in alfalfa seedlings after 7 days

Treatment	**Hypocotyl Length (mm)**		**Frequency**	**Volume**
	12 h	**24 h**	**(Hz)**	**(dB)**
Control	50.11±15.08^{cde}	50.11±15.08^{de}	-	49±3
Gregorian Chant	49.66±11.13^{cde}	48.81±10.83^{cde}	131 ~ 349	79±9
Baroque	47.89±13.27^{bcd}	47.82±13.90^{bcde}	123 ~ 1661	91±9
Classical	50.94±10.93^{de}	43.35±12.85^{ab}	466 ~ 1397	84±7
Jazz	44.00±9.76^{ab}	52.42±12.74^{e}	207 ~ 557	93±4
Rock	45.66±11.50^{bc}	40.35±10.81^{a}	196 ~ 294	87±8
Nature Sound	39.53±10.35^{a}	43.51±9.22^{abc}	Pink Noise	90±6
New-age	48.17±11.29^{bcd}	45.40±14.07^{abcd}	73 ~ 1760	87±4
Waltz	53.25±13.15^{e}	50.91±11.63^{e}	147 ~ 1319	85±4

Different letters in the same column indicate values differ significantly according to Duncan's Multiple Range test ($P < 0.05$).

4.5 Effect of Playback Duration Within the Same Music Treatment on Hypocotyl Growth

For lettuce seedlings, except for jazz music, differences in playback duration did not significantly affect their hypocotyl growth (Table 4.10). Significantly longer hypocotyls were observed in the 12 h jazz music treatment than the 24 h treatment. Incidentally, seedlings grown in jazz music produced the longest and shortest hypocotyls in the 12 h and 24 h playback treatments, respectively.

The playback duration of a higher number of music treatments had an effect on hypocotyl growth of alfalfa seedlings, namely: classical, jazz, rock, and natural sound, which differed significantly between the 12 h and 24 h playbacks (Table 4.11). However, of these music treatments, hypocotyls were longer in 12-h playbacks of classical and rock music, whereas the opposite is true for the jazz and nature sound treatments.

Table 4.10 The effects of different playback time durations in the same type of music on hypocotyl growth in lettuce seedlings after 7 days

Treatment	Hypocotyl Length (mm)		P value	Frequency	Volume
	12 h	**24 h**		**(Hz)**	**(dB)**
Gregorian Chant	38.83±6.71[a]	38.84±6.71[a]	0.88	131 ~ 349	79±9
Baroque	36.20±6.08[a]	38.68±7.35[a]	0.06	123 ~ 1661	91±9
Classical	35.82±7.36[a]	37.92±6.61[a]	0.13	466 ~ 1397	84±7
Jazz	39.98±9.64[a]	35.49±9.83[b]	**0.02**	207 ~ 557	93±4
Rock	36.65±8.01[a]	38.87±6.94[a]	0.13	196 ~ 294	87±8
Nature Sound	38.34±7.26[a]	38.22±7.26[a]	0.93	Pink Noise	90±6
New-age	38.95±6.18[a]	38.47±7.64[a]	0.72	73 ~ 1760	87±4
Waltz	39.84±6.74[a]	38.54±8.26[a]	0.37	147 ~ 1319	85±4

Different letters in the same row indicate values differ significantly according to Duncan's Multiple Range test (*P*≤0.05).

Table 4.11 The effects of different playback duration in the same type of music on hypocotyl growth in alfalfa seedlings after 7 days

Treatment	**12 h**	**24 h**	**P value**	**Frequency**	**Volume**
	Hypocotyl Length (mm)			**(Hz)**	**(dB)**
Gregorian Chant	49.66±11.13^{a}	48.81±10.83^{a}	0.70	131 ~ 349	79±9
Baroque	47.89±13.27^{a}	47.82±13.90^{a}	0.96	123 ~ 1661	91±9
Classical	50.94±10.93^{a}	43.35±12.85^{b}	**0.02**	466 ~ 1397	84±7
Jazz	44.00±9.76^{b}	52.42±12.74^{a}	**0.00**	207 ~ 557	93±4
Rock	45.66±11.50^{a}	40.35±10.81^{b}	**0.02**	196 ~ 294	87±8
Nature Sound	39.53±10.35^{b}	43.51±9.22^{a}	**0.04**	Pink Noise	90±6
New-age	48.17±11.29^{a}	45.40±14.07^{a}	0.28	73 ~ 1760	87±4
Waltz	53.25±13.15^{a}	50.91±11.63^{a}	0.33	147 ~ 1319	85±4

Different letters in the same row indicate values differ significantly according to Duncan's Multiple Range test ($P \leq 0.05$).

Chapter 5

Discussion

Overall, a high germination percentage of lettuce and alfalfa seeds was observed throughout the germination period. Nevertheless, significantly lower alfalfa seeds germinated in rock music compared to those exposed to classical music, nature sound, waltz music, or no music at all, which all had 100% germination (Table 4.3). Findings from the present study agree with those reported by Vanol & Vaidya (2014). In their research, classical music was found to have a positive effect on guar seed germination. Moreover, these results are similar those reported by Pixton (1977), where sprouting of alyssum seeds was increased by music with high frequency sound tones, such as classical and waltz music, whereas random noise, which rock music are often considered to be, had the opposite effect.

These findings are also in agreement with those reported by Galston & Slayman (1979), where rock music containing hardcore vibrations were found to be devastating to plant growth. Similarly, Chivukula & Ramaswamy (2014) reported that plant growth was stunted when rock music was played during the growing period. In addition, the same study also found the effects of western music to be largely similar to the control treatments.

Despite the numerous reports in literature on the adverse effects of rock music or other ‘unharmonious’ music on seed germination, there are studies that found positive influences. Specifically, regardless of the type of music played, it seems those that are considered rhythmic music or with rhythmic frequencies tend to have a positive effect. This was demonstrated clearly in the study by Vanol & Vaidya (2014) where rhythmic rock music showed positive effect on the germination of seeds. Ekici et al. (2007) also found rhythmic music to positively affect root elongation and mitotic division in onion root tips during germination. Similarly, soft rhythmic frequencies have been found to increase germination of chickpea seeds (Chowdhury & Gupta, 2015). Thus, compelling cases demonstrating rhythmic differences in music that directly affect germination seem to be gaining recognition. The results of the present study provide further traction to the possibility that seed germination within the same type of music can be affected by factors such as rhythm, as seen in the present study with rock music compared to those in literature.

With regard to the specific type of instrument used in a music track and its effect on seed germination, the results of both the lettuce and alfalfa seeds that germinated in the 24-h baroque treatment are particularly noteworthy (Table 4.1; Table 4.2; Table 4.3). Of all the different music treatments, seed germination in the baroque treatment is the only one that reached 100% on the 3rd day, irrespective of the seed type (Table 4.1). This rapid germination of seeds under continuous playback of baroque music suggests the importance of the instruments used, which in this case is the violin. Chivukula & Ramaswamy (2014) stated that violin in particular is known to significantly increase plant growth. This finding is indicative of the importance of the different facets that make up music, and how each individual component can affect seed germination or plant growth. According to Titon (1984), the organizational elements that determine the formal structure of a piece of music include rhythm, melody, harmony, repetition or variation, and instruments.

The 12-h and 24-h playback duration used in the present study could also be a factor that affects seed germination and seedling growth. The effects of playback duration on lettuce radicle (Table 4.6) and alfalfa hypocotyl (Table 4.11) lengths were inconclusive, which differed depending on the type of music used. On the other hand, overall results showed that alfalfa radicles (Table 4.7) and lettuce hypocotyls (Table 4.10) were not affected by playback duration (12 h vs 24 h) regardless of the music used. Unfortunately, very little information is available in literature that discusses the effects of playback duration on plants, and therefore further in-depth studies are needed into how plant growth may be affected.

Metabolism in plants can be influenced by music, including its frequency (Hz) (Chowdhury & Gupta, 2015). According to Coghlan (1994), production of protein increases when music at the appropriate frequency is played, which stimulates overall plant growth. Similarly, it has been found that audible sound at 125 Hz and 250 Hz frequencies, plant genes are more active in DNA code translation, and as a result, growth and development are increased (Ekici et al., 2007). In lettuce seeds that were exposed to 12 h of Gregorian chant, which falls within the abovementioned frequencies, their radicle lengths were significantly longer than most of the other music treatments (Table 4.4).

Furthermore, as previously mentioned, violin has been found to have a positive impact on plant growth in numerous studies (Chivukula & Ramaswamy, 2014; Laad & Geetha, 2010; Petrescu et al., 2017; Reddy & Ragavan, 2013). This could be the cause for lettuce seedlings grown in the 24-h baroque to possess the highest radicle lengths. However, these results also indicate that the response to music is highly dependent on the type of plant and/or other factors, since no differences in radicle lengths were observed in alfalfas (Table 4.5).

With regard to the response of plants to green music (nature sounds), which comprises natural sounds such as birds, insects, and water, studies have showed improved plant resistance to diseases and pests, as well as increased plant growth(Lee, 1997). In our study, the hypocotyl growth of lettuce plants was significantly promoted by nature sound compared to the control treatment (Table 4.8). However, when compared to the other music types, it did not seem to possess any particular stimulatory effects on lettuce and alfalfa seedlings.

According to Chowdhury & Gupta (2015), soft rhythmic music have positive effects on plant growth rate and plant size. In addition, music with high decibels and frequencies have been shown to enhance metabolism of roots in chrysanthemums(Yi et al., 2003) . Due to the fact that the waltz music used in the present study are classified as soft, rhythmic music and are of high intensity and frequency, this combination is likely to be the reason for the particularly higher hypocotyl growth in alfalfas, especially when compared to the other types of music (Table 4.9).

From the overall findings of the present study, the following general observation can be made: with regard to radicle growth in lettuces, in comparison with no music (control), continuous playback (24 h) of any type of music, with exception of jazz music, resulted in an overall increase in radicle length (Table 4.4). Though their differences may not be statistically significant, a similar trend was evident in alfalfa seedlings. In comparison to germinating with no music (control), except for jazz and nature sound (12 h), and new-age and waltz music (24 h), a general increase in alfalfa radicle lengths was observed in all music treatments (Table 4.5). These findings indicate that there is a tendency for an increase in radicle growth of lettuce and alfalfa seedlings when music is present during germination.

In terms of hypocotyl growth, when lettuce seedlings were exposed to music, regardless of the music type or playback duration, there seemed to be a stimulatory effect on hypocotyl growth (Table 4.8). The response of lettuce in our study is similar to those reported by (Singh et al., 2013; Vanol & Vaidya, 2014) who found that, in comparison to no sounds, growth of bean plants were promoted when exposed to any type of music treatment. On the contrary, although the hypocotyl lengths of some alfalfas grown with music were not significantly shorter compared to no music at all, overall their hypocotyl growth tend to be suppressed (Table 4.9). The exceptions being classical and waltz music, and jazz and waltz music in the 12 h and 24 h treatments, respectively.

Chapter 6

Conclusion

This study investigated the effects of different types of music on the germination and seedling growth of lettuce (*Lactuca sativa*) and alfalfa (*Medicago sativa*). The lowest germination percentage was found in rock music (91.7%), whereas the highest percentage (100%) of seeds germinated in classical, nature sound, and waltz treatments.

In lettuce seedlings, compared to the control, significantly higher radicle lengths were evident in the majority of the 24 h music treatments. Radicle growth of alfalfa seedlings was not significantly affected by the presence of music, regardless of the type of music used, however, a trend toward longer radicles was observed. Overall, the hypocotyl growth of lettuce was improved when music was being played, irrespective of the playback duration. In contrast, the hypocotyls of alfalfa seedlings grown in the majority of music treatments tend to be shorter when exposed to any music compared to the control.

Research Limitations

Findings from this study has provided a better insight into the response of lettuce and alfalfa seedlings to different types of music during germination. However, in order to gain a complete understanding of how music affects the growth and development these plants, cultivation in soil or hydroponics can be used in future studies to investigate these effects over a longer growing period. In addition, the use of different types of plants will provide valuable data on the response of a wider range of plants to music. Finally, an investigation that specifically studies the differences in the effects between rhythmic and non-rhythmic music on plant growth would be interesting, and help advance the research in this field.

References

Borella, E., Carretti, B., Meneghetti, C., Carbone, E., Vincenzi, M., Madonna, J. C., . . . Mammarella, N. (2017). Is working memory training in older adults sensitive to music? *Psychological research*, 1-17.

Bose, J. C. (1902). *Response in the Living and Non-living*: Longmans, Green, and Company.

Bose, J. C. (1906). *Plant response as a means of physiological investigation*: Longmans, Green.

Chamovitz, D. (2012). *What a plant knows: a field guide to the senses*: Scientific American/Farrar, Straus and Giroux.

Chivukula, V., & Ramaswamy, S. (2014). Effect of different types of music on Rosa chinensis plants. *International Journal of Environmental Science and Development, 5*(5), 431-434.

Chowdhury, A. R., & Gupta, A. (2015). Effect of Music on Plants–An Overview. *International Journal of Integrative Sciences, Innovation and Technology*, 30-34.

Chowdhury, M. E. K., Lim, H., & Bae, H. (2014). Update on the effects of sound wave on plants. *Res Plant Dis, 20*, 1-7.

Coghlan, A. (1994). Good vibrations give plants excitations. *New Scientist*

142(1927), 10.

Collins, M. E., & Foreman, J. E. (2001). The effect of sound on the growth of plants. *Canadian Acoustics, 29*(2), 3-8.

Creath, K. (2003). Effects of musical sound on the germination of seeds.

Creath, K., & Schwartz, G. E. (2004). Measuring effects of music, noise, and healing energy using a seed germination bioassay. *The Journal of Alternative & Complementary Medicine, 10*(1), 113-122.

da Silva, J. A. T., & Dobránszki, J. (2014). Sonication and ultrasound: impact on plant growth and development. *Plant Cell, Tissue and Organ Culture (PCTOC), 117*(2), 131-143.

Ekici, N., Dane, F., Mamedova, L., Metin, I., & Huseyinov, M. (2007). The effects of different musical elements on root growth and mitosis in onion (Allium cepa) root apical meristem (Musical and Biological Experimental Study). *Asian Journal of Plant Sciences, 6*(2), 369-373.

Gagliano, M. (2012). Green symphonies: a call for studies on acoustic communication in plants. *Behavioral Ecology, 24*(4), 789-796.

Gagliano, M., Grimonprez, M., Depczynski, M., & Renton, M. (2017). Tuned in: plant roots use sound to locate water. *Oecologia, 184*(1), 151-160.

Gagliano, M., Mancuso, S., & Robert, D. (2012). Towards understanding plant bioacoustics. *Trends in plant science, 17*(6), 323-325.

Gagliano, M., Renton, M., Duvdevani, N., Timmins, M., & Mancuso, S. (2012). Out of sight but not out of mind: alternative means of communication in plants. *PloS one, 7*(5), e37382.

Galston, A. W. & Slayman, C. L. (1979). The Not-So-Secret Life of Plants. *American Scientist,* 67, 337-344.

Haswell, E. S., Phillips, R., & Rees, D. C. (2011). Mechanosensitive channels: what can they do and how do they do it? *Structure, 19*(10), 1356-1369.

Hopkins, J. (2019). Pythagorean Harmonix Healing. *[Online]. Available:* http://www.harmonixhealing.com/Htm/AboutUs.htm.

Howard, D. M., & Angus, J. (2017). *Acoustics and psychoacoustics*: Focal press, Oxford.

Jeong, M.-J., Shim, C.-K., Lee, J.-O., Kwon, H.-B., Kim, Y.-H., Lee, S.-K., . . . Park, S.-C. (2008). Plant gene responses to frequency-specific sound signals. *Molecular breeding, 21*(2), 217-226.

Laad, M., & Geetha, V. (2010). The Influence of Sounds of Stringed Instruments on Growth of Medicinal Plant Trigonella Foenum Graecum (Family Fabaceae). *International Journal of Applied Agricultural Research, 5*(2), 275-282.

Lee, W. (1997). The plants growing with music. *Korea Agrofood, 6*, 41-43.

Mauck, K. E., De Moraes, C. M., & Mescher, M. C. (2014). Biochemical and physiological mechanisms underlying effects of C ucumber mosaic virus on host-plant traits that mediate transmission by aphid vectors. *Plant, cell & environment, 37*(6), 1427-1439.

Miller, D. L. (1983). The botanical effects of ultrasound: A review. *Environmental and experimental botany, 23*(1), 1-27.

Mishra, R. C., Ghosh, R., & Bae, H. (2016). Plant acoustics: in the search of a sound mechanism for sound signaling in plants. *Journal of experimental botany, 67*(15), 4483-4494.

Petrescu, Ş., Mustatea, R., & Nicorici, I. (2017). The influence of music on seed germination of *Beta vulgaris* L. var. Cicla. *Journal of Young Scientist, 5*, 67-72.

Pierce, J. R. (1992). *The science of musical sound* (Vol. 174): WH Freeman New York.

Pixton, B. M. (1977). Plant Growth in a sound polluted environment. Botany and Plant Science Department, Brigham Young University.

Radocy, R. E., & Boyle, J. D. (2012). *Psychological foundations of musical behavior*: Charles C Thomas Publisher.

Ramekar, U. V., & Gurjar, A. A. (2016). *Emperical study for effect of music on plant growth.* Paper presented at the 2016 10th International Conference on Intelligent Systems and Control (ISCO).

Rauscher, F. H., Shaw, G. L., & Ky, C. N. (1993). Music and spatial task performance. *Nature, 365*(6447), 611.

Reddy, K. G., & Ragavan, R. (2013). Classical ragas: A new protein supplement in plants. *Indian Journal of Life Sciences, 3*(1), 97-103.

Retallack, D., & Broman, F. (1973). Response of growing plants to the manipulation of their environment. *The Sound of Music and Plants. Santa Monica, CA: DeVorss & Co*, 82-94.

Shen, K., Wang, H., & Zhao, Z. (2011). *Brush talks from dream brook*: Paths International.

Singh, A., Jalan, A., & Chatterjee, J. (2013). Effect of sound on plant growth. *Asian Journal of Plant Science and Research, 3*(4), 28-30.

Titon, J. T. (1984). Worlds of Music. Schrimer. New York.

Tompkins, P., & Bird, C. (1973). *The secret life of plants*: Harper & Row New York.

Tompkins, P., & Bird, C. (1989). The Secret Life of Plants.(1974). *NY: Harper and Row*.

Vanol, D., & Vaidya, R. (2014). Effect of types of sound (music and noise) and varying frequency on growth of guar or cluster bean (cyamopsis tetragonoloba) seed germination and growth of plants. *Quest, 2*(3), 9-14.

Wicke, R. W. (2002). Effects of music and sound on human health. Herbalist Review. *Herbalist Review*

[Online]. Available: http://www.rmhiherbal.org/review/2002-1.html, 2002-2001.

Xing, Y., Xia, Y., Kendrick, K., Liu, X., Wang, M., Wu, D., . . . Yao, D. (2016). Mozart, Mozart Rhythm and Retrograde Mozart Effects: Evidences from Behaviours and Neurobiology Bases. *Scientific reports, 6*, 18744-18744. doi:10.1038/srep18744

Yi, J., Bochu, W., Xiujuan, W., Daohong, W., Chuanren, D., Toyama, Y., & Sakanishi, A. (2003). Effect of sound wave on the metabolism of chrysanthemum roots. *Colloids and surfaces B: Biointerfaces, 29*(2-3), 115-118.