Music for Plants? An Investigation into the Impact of Exposure to Acoustic Stimulus in Bok Choy (Brassica rapa) Plants

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Abstract

The study aimed to investigate the influence of different types of acoustic stimulus (classical vs. rock music) on the growth of bok choy (Brassica rapa) plants. Three separate groups of bok choy plants were exposed to classical music, rock music, or else no music, during growth and development and the influence on yield was observed. The results reveal that those plants exposed to classical music exhibited significant differences in shoot characteristics with the highest total fresh weight, shoot fresh weight, and mean leaf numbers. Meanwhile, those plants exposed to rock music demonstrated values that were the lowest across all plant parameters. Plants treated to classical music had the lowest root length but the highest root volume, indicating that the roots were significantly stouter and more compact as compared to those plants treated to rock music and no music. This study therefore serves as a future reference for the use of music in plant growth.

Keywords: Bok choy, classical music, rock music, plant growth, acoustic stimulus.

Interest in how music affects plant growth is on the rise (Chandrakala & Tivedi, 2019; Frongia et al., 2020; Hussain et al., 2023; Lopes & Rodrigues, 2021; Patel et al., 2022). A number of research groups have demonstrated that plants respond to sound in profound ways which not only influences their overall health but also increases the speed of growth and thus the size of the plant (Chowdhury et al., 2014; Gagliano et al., 2012; Mishra et al., 2016; Qin et al., 2003). Classical music has often been used in studies that have assessed the impact of exposure to acoustic stimulus on plant growth. One of the earliest and most frequently cited scientific studies on the use of music on plants was by Indian botanist, Singh (1962; cf. Retallack, 1973) who reported that the growth rate of balsam (Impatiens balsamina) plants accelerated by 20% in height, and 72% in biomass when exposed to classical music as compared to no music.

When comparing two vastly different styles (classical vs. rock), a seemingly positive correlation between classical music and the growth of plants has often been observed. For instance, a study by Hemamali et al. (2021) demonstrated that those chilli plants (Capsicum annuum L.) that had been exposed to classical music had the highest length of shoots, followed by no music; while those exposed to rock music had the lowest shoot length. Similarly, Rachieru et al. (2017) reported that wheat (Triticum aestivum) seeds that had been exposed to classical music resulted in higher growth and brighter leaf colour than those plants exposed to Led Zeppelin's rock music. The results demonstrated that plants in the classical music condition grew an average of 3.33cm per week, controls grew at 2.33cm per week, and plants in the rock music condition grew at only 1.33cm per week. Similarly, playing techno music and noise a negative impact on the growth of cowpea (Vigna unguiculata) plants when compared to classical music (Alavijeh et al., 2016).

Rock music has not only been shown to be detrimental to growth, but a study by Chivukula and Ramaswamy (2014) reported that roses (Rosa chinensis) exposed to rock music had a significantly higher number and density of thorns as compared to those plants that had been exposed to classical music. The propensity for growth does not only refer to shoots, but also to roots. In a study comparing classical music to a no-music baseline, Ekici et al. (2007) demonstrated a correlation between the elongation of the roots in the onion (Allium cepa) and the rate of cell division at the tip of the root. The authors suggested that the strong, complex and rhythmic accent in the classical music may have given rise to these results. Nevertheless, even with the use of classical music, consistency in volume is a factor to consider. Take, for example, a study by Prasetyo and Raju (2012) in which the authors played Pachelbel's Canon in D which had a frequency range of 550-1200 Hz, and exposed green mustard seeds to three levels of dB, namely, 70-75 dB, 80-85 dB, 90-95 dB, and a no music condition. The authors found that exposure to music produced a significantly higher rate of germination, plant height, leaf area and root length compared to the no music condition. However, plants that had been exposed to 70-75 dB generally produced the highest values for all morphological characteristics.

<u>Duration of exposure to acoustic stimulus</u>

One of the important factors in relation to music is the duration of exposure required for optimum plant growth. This topic has been controversial, to say the least: Retallack (1973) determined that classical music compositions should be played intermittently for several hours per day (see also Tomkins & Bird, 1973). In her study, Retallack argued that plants died after exposure to 8 hours of a continuous tone for 14 days in a row. However, when plants were exposed to three hours of music every day, the plants grew more abundantly and were extremely healthy (although it should be noted that no statistical support was provided to substantiate these claims). In another study, those plants that had been exposed to soothing music were found to recline toward the source of music by 15-20 degrees; resulting in growth (Retallack, 1973). It was also noted that musical genre played a crucial influence in that when rock music was played using a similar methodology, the plants bent away from the sound source, with most of them having small leaves and stunted growth (see also Chivukula & Ramaswamy, 2014). Popescu and Mocanu (2013) conducted a study showing that salad crops and apple fruits cultivated in solariums that were exposed to pipe flute music playing 3 hours daily had the highest weight compared to control and music played for an hour each day.

Creath and Schwartz (2004) reported that playing Native American flute music continuously for 16 hours per day to okra and zucchini seeds resulted in a significant increase in the number of seeds sprouted, as compared to control, pink noise, and healing energy. The healing energy condition was a relatively new therapeutic modality which required the transmission of divine energy (intention) from the practitioner to the receiver which, in this study, happened to be plants.

Music not only affects those plants grown in soil, but can also influence growth in plants sown in vermiculite and hydroponic environments. A study conducted at Simak University's Department of Horticulture in Turkey found that playing classical music for 4 hours a day (11:00-15:00) to bean plants in both vermiculite and hydroponic environments resulted in a significant positive effect on the morphological measurements, growth rates, and the number of leaves compared to no music condition rate (Akhoundnejad, 2019).

When should music be played to plants?

Although most of the studies that have been published fail to specify the exact times at which music was played to plants, a study in 2007 by Jeong in South Korea reported that playing Beethoven's Moonlight Sonata, even in the dark, in open rice fields, allowed for plant genes to respond positively by stimulating the process of DNA code translation into biological growth (Smith, 2007). More recently, Lai and Wu (2020) investigated the effects of 9 musical genres from Gregorian chant to New Age music on the seed germination and growth of lettuce and alfalfa. Music was played for 12 hours daily for a week from 07:00 to 19:00, and the results demonstrated that alfalfa plants treated with rock music had a significantly lower germination rate. In contrast, the highest percentage of alfalfa seeds germinated in treatments with music was in the classical, nature sound, and waltz treatments.

Meanwhile Hemamali et al. (2021) exposed chilli seed plants (Capsicum annuum L.) to no music, classical music and rock music from 07:00 to 10:00, and from 13:00 to 16:00 for 30 days at 82dB; and found that chilli plants exposed to classical music showed a significant difference in the mean length of shoots. The chilli plants that had been exposed to the classical music showed the highest length of shoots while those exposed to rock music showed the least. Rachieru et al. (2017) played either classical music, Led Zeppelin's music or no music to wheat (Triticum aestivum) seeds for 2 and a half hours a day for 6 weeks, and found significant height growth in those plants that were exposed to classical music with 3.33 cm average growth per week, and the colour of these plants bright green at the end of the study. Meanwhile plants subjected to Led Zeppelin's music grew at an average of 1.33cm per week and these plants were yellowish green in colour by the end of the experiment. A more complex schedule was set by Alavijeh et al. (2016) whereby the authors exposed cowpea seedlings for 8 hours of music from 09:00 to 17:00, and then replicated the next 16 hours alternating between 1 hour of music exposure and 1 hour of silence. Significant results were seen in all aspects of plant traits demonstrating that playing classical music, instead of traditional Iranian, techno and noise, impacted growth and yield. Despite the varying hours and times that plants were exposed to acoustic stimulus (specifically music), there were no specific reasons cited above for how this was derived.

Whilst there is much optimism about the use of classical music, given that the use of classical music has been widely studied in human behavior, studies on music and plants have produced conflicting results. For example, a study by Petrescu et al. (2017) found that playing classical music on the germination of beet (Beta vulgaris L.) seeds had a detrimental effect when compared to no music. The authors played (on repeat) music by J. S. Bach for approximately 10 hours daily every morning from 07:00 for a total of 28 days inside an aquarium housing the designated beet seeds. Despite all of the environmental conditions being similar in both experimental and control, the authors hypothesise that the music source was possibly too close to the plants and hence resulted in some kind of acoustic stress. A possible speculation could also be that the number of hours the music was played may have interfered with the plant's normal life cycle.

Sound waves and plant growth

Sound waves are characterised by frequency/pitch (Hz) and intensity/volume (dB). Sound frequencies that are perceptible to the human ear range from about 20 Hz to 20 kHz, and the volume of a normal conversation is about 60dB, while concerts can go up to 110dB. Acoustic waves with higher frequencies, or also known as ultrasounds (>20kHz) have been successfully used in priming seed germination (Liu et al., 2016; Miano et al., 2015; Nazari et al., 2014; Toth et al., 2012; Yaldagard et al., 2007). Nevertheless, current studies have also shown that those sounds that humans can hear can be used as a positive growth regulator (Bailey et al., 2013; Cai et al., 2014; Hassanien et al., 2014; Lai & Wu, 2020). In the context of acoustic stimulus, a study by Uchida and Yamamoto (2002) demonstrated that thale cress (Arabidopsis thaliana) seeds exhibited an increased rate of germination when exposed to pure tones between 70 and 100 Hz (see also Choi et al., 2017; Ghosh et al., 2017; Jeong et al., 2004; Li et al., 2008; Qin et al., 2003). Along similar lines, Vicient (2017) manipulated white noise and found that the rate of germinating maize seeds (Zea mays) increased to about 10% when exposed to white noise for 5 hours at 300 Hz, 80 dB, compared to silence (cf. Gagliano et al., 2012).

Taken together, the research that has been published to date suggests that different seed species react differently to different sound frequencies. However, even within the same plant gene pool, there have been conflicting results on the use of sound frequencies. For example, Wang et al. (2003) reported positive effects on the growth stimulation of paddy rice (Oryza sativa) seeds when exposed to 400 Hz sound waves at 106dB; while Jusoh et al. (2023) reported that playing classical music at 357 Hz and 350 Hz simulated paddy rice seeds' growth; and Jeong from South Korea exposed paddy rice plants to pure tones of 125 Hz and 250 Hz and found significant increase in genetic activity of two specific genes (Smith, 2007).

Sound frequency is a relevant variable, with a slight increase (Hassanien et al., 2014; Liu et al., 2002; Ozkurt & Altuntas, 2016; Weinberger & Measures, 2011) or decrease (Collins & Foreman, 2001; Measures & Weinberger, 2011; Pujiwati et al., 2018; Smith, 2007) in intensity and/or frequency is found to be detrimental and possibly inhibiting plant growth when compared to no music. For example, Collins and Foreman (2001) found that playing pure tones of 6000 Hz for 28 weeks resulted in significantly enhanced growth in bean plants compared to pure tones at 500 Hz, 5,000 Hz, 12,000 Hz, and 14,000 Hz, control and noise. When impatien plants were treated using similar frequencies, it was noted that 14,000 Hz resulted in optimum impatien plant growth. The authors suggested that optimum growth was made possible when plants were exposed to pure tones in which the wavelength coincided with the average dimensions of the leaf (measurements taken across the surface of the leaf). Along similar lines, when Jeong exposed rice paddy plants to pure tones of 125 Hz and 250 Hz, a significant increase in genetic activity was observed, while 50 Hz resulted in a significant decrease of genetic activity (Smith, 2007). Similarly, in a study by Qi et al. (2009), the authors noted that strawberries planted in greenhouses stimulated by frequencies which were determined by the temperature and humidity (although exact measurements were not specified) of the greenhouse resulted in strawberry leaves developing a deeper green colour, and bearing fruit a week earlier than untreated control. The authors also argued that the strawberry plants exposed to sound frequencies had a higher resistance to disease and insect pest compared to untreated control (see also Hou et al., 2009; Yu et al., 2013).

The varying distance of speakers playing classical music, which resulted in volume differences has also been shown to affect the growth of rice seeds (Oryza sativa; Jusoh, et al., 2023). The authors in this particular study played Mozart's music to pots at varying distances (80, 160, 240, 430 and 400cm respectively) and reported that those rice seeds that happened to be situated 240 cm and 400 cm away from the speakers promoted plant performance significantly by increasing assimilation rate, stomatal conductance, and plant height. However, the authors did not discuss how varying the distance of the speakers, which presumably affected the acoustic stimulus incident on the plants, from the plants induced these significant effects. A study in an Italian vineyard had contrasting findings. The vineyard Il Paradiso di Frassina, together with plant scientists from the University of Florence, studied the effects of Mozart's music on vines and found that the grapes closest to the speakers were nearly 50 percent larger than those that were further away from the source of music, albeit the exact distance of the speakers was not reported (Rizzi, 2018; see also Demorgenzon Wine Estate, 2017), indicating also that acoustic stimulus is an important element in plant growth.

Anecdotal support from farmers

Although by no means scientifically rigorous, it is interesting to note how a number of farmers have also started to experiment with playing music to their crops. In particular, in 2007, Canadian engineer and farmer Eugene Canby, exposed his wheat fields to Bach's violin sonatas and observed a 66% greater than average yield with larger and heavier seeds (Kinzler, 2021). Interestingly, one of Britain's leading gardeners, Beardshaw claimed that playing a constant diet of heavy metal music, rather than soothing music helped flowers to bloom (Furness, 2013). Beardshaw had four separate glasshouses playing either classical music, the music of Cliff Richard, Black Sabbath heavy metal music, or else no music. The results demonstrated that continuous exposure to the music of Black Sabbath resulted in plants being the shortest but having the best flowers with the best resistance to pest and disease. However no statistical analysis was included in the article. Similarly, Sulong et al. (2016) argued that although music (instrumental, rock, hip hop, ballad) exposure to orchids (Grammatophyllum Hybrid) resulted in a positive effect on seeds' germination compared to control, it was noted that exposure to rock music resulted in the highest number of shoots. Meanwhile, the botanist and agricultural researcher George Smith claimed to have produced 40% higher yields in corn and 24% higher yields in soybeans by playing Gershwin's 'Rhapsody in Blue' on a loop (Alchimiaweb, 2022). Farmers at Mono Premium Melon in Malaysia regularly play classical music over speakers in their greenhouses where Japanese muskmelons are grown because they are convinced that it helps stimulate growth (Reuters, 2021). Given the growing interest amongst both farmers and plant enthusiasts in the potentially beneficial effects of delivering acoustic stimulus (typically in the form of music) to plants, this should clearly be further investigated in a scientifically rigorous manner.

Purpose of the present study

Although most of the studies that have been conducted to date have shown positive effects of the use of classical music and contradictory effects of rock music, not all studies comparing these two genres support the existence of differential effects (i.e., benefits for one but not the other). For example, a study by Vanol and Vaidya (2014) found that exposing guar (Cyamopsis tetragonoloba) plants to both classical and rock music for an hour daily promoted growth. Parameters such as the number of seeds germinating in petri-dishes, plant height, and the number of leaves were recorded every two days for 13 days and results revealed some positive trends when plants were exposed to both classical and rock music, respectively, and negative effects when exposed to traffic noise.

By contrast, a study by Singh et al. (2013) on the common bean plant (Phaseolus vulgaris) failed to observe any difference between those plants that had been exposed to rhythmic violin music and non-rhythmic traffic noise However, positive effects in terms of height and the number of leaves on exposure to both forms of auditory stimulation were observed, (although it should be noted that no statistical support was provided to substantiate these claims) when compared to its natural environmental condition (control). The authors argued that the growth of the plants was not differentially affected by the nature of the auditory stimulation that the plants were exposed to. The effect of other sources of sound may not always be clear, but the key point to note here is that exposure to classical music has once again been shown to deliver positive results in terms of plant growth.

Despite the promise of the use of acoustic stimulus (specifically music) on plant growth, to date, there is insufficient evidence concerning the effects of sound on plant morphology and physiology that would translate into an increased yield. First, it would be almost impossible to replicate the studies mentioned above due to a number of variables that are either left unspecified or else presumably beyond the control of the experimenters. Take, for example, the control of temperature and humidity in an open field. Even when plants are grown in solariums and glass houses, variables such as seed DNA, soil composition, or even the potential of infection can be particularly challenging to control experimentally. Second, whilst musical genre has been shown to influence plant growth, much of the literature that has been published to date has failed to provide sufficient details concerning the exact pieces of music and volume that were used.

Furthermore, when considering the literature on the effects of classical music on plant growth, it is worth noting that the classical music genre comprises examples that stretch all the way from calming (e.g., think only of Beethoven's Moonlight Sonata) through to anxiety-inducing (e.g., Stravinsky's The Rite of Spring). Hence simply stating that classical music was played is simply not sufficiently descriptive for the purposes of scientific understanding and replication (Yeoh & Spence, 2023). Third, there has been no consistency in the reporting of physical parameters, for example, the placement of speakers, the measurement of tempo, volume, frequency/frequency range, time and duration of music playback. Precise experimental conditions have not been specified and the current literature has not been able to justify how timing, duration, and music frequency was calculated. Complicating matters further, no one study has been replicated successfully since the response of plants to music and particular sound frequencies has typically been found to be species-specific. Hence, the study that is reported here set out to control as much as possible, the variables by investigating the effects of music (classical vs. rock) on bok choy (Brassica rapa) in a controlled hydroponic environment to enable possible future replication of these findings.

Bok choy is a globally popular vegetable crop. Known for its light, sweet, crisp and aromatic flavour, it is a certified geographical product of China (Lu, 2007; Shen et al., 2016). The market demand of this vegetable has recorded an increase of 727,467 tonnes in Indonesia alone for the year 2021 (Bani & Bani, 2023). There have been several studies on the amendment of soil composition, control of nutrient levels, and fertiliser and its effects on the bok choy (Kaleri et al., 2020; Kano et al., 2021; Zhao et al., 2017) but, to date, no study has yet been published concerning the effects of music and the growth of bok choy. Additionally, bok choy is a good choice in crop selection as it can be cultivated in a controlled hydroponic environment, requiring less light than general crops, and is able to thrive in an indoor facility (Kumpanalaisatit et al., 2022), thus enabling better control of the growing environment.

Methods

Materials & Design

This experiment was conducted in an enclosed cabin owned by the Department of Agriculture, located in Serdang, Malaysia. The bok choy seeds were purchased from City Farm Puncak Serdang and were germinated in a germination cup containing rock wool for a week. Upon successful germination (shoots which displayed 2-3 leaves) 50 healthy plants were then selected and transferred to an indoor cabin, with a controlled temperature at 21.4°C, relative humidity at 70%, artificial lighting and equipped with a hydroponic system. This process was repeated three times sequentially, giving rise to 50 plants in the classical condition, 50 plants in the rock condition, and 50 plants as control. The selected bok choy plants were randomly lined up into grids and organised into 5 rows of 10 plants. Four rectangular HiFi speakers (20 x 3 x 3 inches) were placed horizontally on the floor, 28 inches from the grid and parallel to the rows of plants. Music was played back from a digital mp3 player. All four speakers were placed below the 3rd row of plants to ensure an even spread of sound across the 5 rows. A sound meter app 'Decibel X' was used to measure volume (dB) and the frequency range (Hz). A water reservoir tank which consisted of diluted nutrient solution A and B in the ratio of 1:100 was pumped into the polyvinyl chloride (PVC) canal every day.

The bok choy plants were treated with either classical music, rock music, or no music (control). The pieces of classical music and rock music used in this study were downloaded from YouTube channels (HarpsichordVal, 2015) and (Best Music Compilation, 2015), respectively. The classical music used was Bach's Brandenburg Concertos nos. 1-6; while the rock music was an instrumental compilation. The instrumentation in the classical music genre comprised of the harpsichord, orchestral strings, light winds and brass instruments; and tempo ranged between 54bpm and 158bpm. Meanwhile, dense electric guitars and drums were featured in the rock genre with a tempo ranging from 80bpm to 205bpm.

Procedure

Lights and music were turned on and off every 2 hours starting at 00:00 until 16:00. Lights and music would then be switched off for the next 8 hours from 16:00 to 24:00. This cycle was maintained throughout until harvest. The duration of music playback was synchronized with the lighting (LED fluorescence) in the cabin which was controlled by a timer. The reason for the scheduling of LED lights to be on a 2-hour interval for 16 hours a day was based on previous research conducted in the cabin, whereby the protocol was found to result in a shorter 25-day harvest (as compared to the conventional 30-day harvest). The music was looped to ensure continuity in sound when the lights were turned on. Volume was obtained by measuring the background humming noise created by the lights and the water pump tank first (average of 61dB). To ensure consistency in sound intensity, the volume of the music playback in both the classical and rock conditions was adjusted to an average at 61dB. From the second week onwards, non-destructive data such as the number of leaves and the height of the bok choy plants were taken on a weekly basis. On the sixth week, upon harvest, three plants were harvested randomly from different rows, and data in terms of root and shoot parameters were measured and recorded.

Results

The effects of music type on shoot growth

Bok choy plants cultivated in the presence of music vs. control (no music) displayed specific changes in shoot growth. There was an overall increase in plant growth parameters in the classical music treatment as compared to the control, while plants exposed to rock music showed negative effects on growth. The total plant fresh weight of bok choy cultivated under the influence of classical music increased by thirty-eight percent to 136.4 g, as compared to the control at 98.7 g, while a significant decrease was noted for the plants cultivated in the rock music treatment at 66.74 g (see Table 1). The total fresh weight of bok choy is a crucial parameter as this vegetable is normally sold in its fresh state; and higher fresh weight values would presumably translate to higher revenue.

However, the dry weight provides a measure of the weight of a plant after all its water content has been removed by drying. In the evaluation of plant growth rate, the fresh weight is unreliable and inaccurate as hydroponic plants tend to have a higher moisture content and lower ash value compared to traditionally grown plants (Lei & Engeseth, 2021). Plant dry weight and plant height, instead, are common parameters that are used to indicate plant growth rate in many crop species (Ali & Muhammad, 2009; Korner, 1991; Marcelis, 1992). The dry weight of bok choy was found to be significantly higher in the classical music treatment at 8.99 g, as compared to control (6.33 g), while rock music treatment recorded a significantly lower dry weight (3.12 g), thus suggesting that classical music provided certain enhancing effects while the rock music inhibited plant growth. The bok choy that had been exposed to classical music also produced the highest number of leaves with 16.67 leaves with the highest total leaf area of 1316.8cm2, as compared to control with 11.67 leaves and leaf area of 1160.9cm2, and rock music with 10 leaves and a leaf area of 1220.6cm2. The measurement of leaf numbers and leaf area are equally important as they correlate directly with photosynthesis and crop productivity (Jo & Shin, 2020). Although there was no correlation between the number of leaves and the plant's dry weight, nevertheless, a higher number of leaves could be an attractive trait from a consumer's point of view.

Table 1. The effects of music type on shoot growth of bok choy

	Plant fresh weight (g)	**Plant dry weight (g)**	**Max shoot length (cm)**	**Mean leaf numbers**	**Total leaf area (cm^2)**
Control	98.7^{ab}	6.33^{b}	25.67^{a}	11.67^{a}	1160.9^{a}
Classical	136.42^{a}	8.99^{a}	26.03^{a}	16.67^{b}	1316.8^{a}
Rock	66.74^{b}	3.12^{c}	23.83^{a}	10.00^{b}	1220.6^{a}

Means with different letters in each column are significantly different at Tukey's alpha level of 0.05.

Source: Authors

The effects of music type on root growth

The roots are a crucial part of every plant as they absorb, provide nutrient uptake, not to mention anchoring and supporting the plant (Hodge et al., 2009) The highest total root volume of bok choy was recorded for those plants that were exposed to classical music (90.13 cm3), compared to control at (76.80 cm3); while plants exposed to rock music recorded the lowest root volume at 30.13 cm3 (see Table 2). Interestingly, the maximum root length (34 cm) and total root length (243.6 cm) of bok choy cultivated while being exposed to classical music was significantly lower than for the control plants (max. length: 50.73 cm; total length: 343.6 cm). The roots in the classical music condition were stouter and more compact compared to control and rock music (see Figure 3). It should be noted that stouter roots are beneficial as they have better resilience and persistence, and have a lower turn-over rate as compared to longer finer roots. This, in turn, reduces the burden on plants by lowering the stimulus and resources expended for root maintenance (Fitter et al., 1991).

Table 2. The effects of music type on root growth of bok choy.

	Root fresh weight (g)	Root dry weight (g)	Max. root length (cm)	Total root length (cm)	Total root vol. (cm^3)
Control	19.37^{a}	1.53^{a}	50.73^{a}	343.60^{a}	76.80^{a}
Classical	15.22^{ab}	1.32^{a}	34.00^{b}	243.60^{b}	90.13^{a}
Rock	6.70^{b}	0.67^{b}	35.17^{b}	176.90^{b}	30.13^{b}

Means with different letter in each column are significantly different at Tukey alpha level of 0.05.

The effects of music type on plant height and leaf numbers

Upon successfully germinating bok choy seedlings, plant height and leaf numbers were recorded weekly. Physiological changes were detected in the early planting stages. As depicted in Figures 1 and 2, bok choy that were exposed to classical music were slightly inferior in the early planting stages, right up until the fourth week, and thereafter leaf numbers and plant height surpassed those in both the rock music and control conditions. Furthermore, the number of bok choy leaves (at week 4) cultivated in the classical music condition can be seen to be the most compact and thickest (see Figure 3).

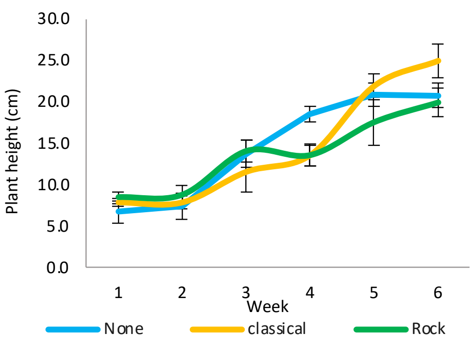

Figure 1. The effects of music type on the height of the plant.

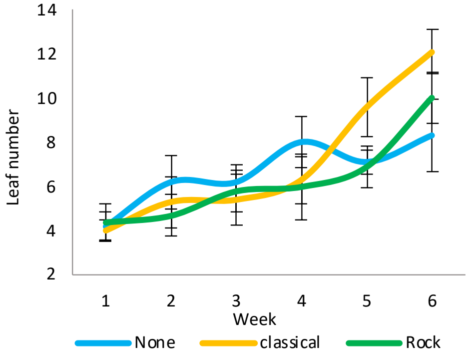

Figure 2. The effects of music type on the number of leaves.

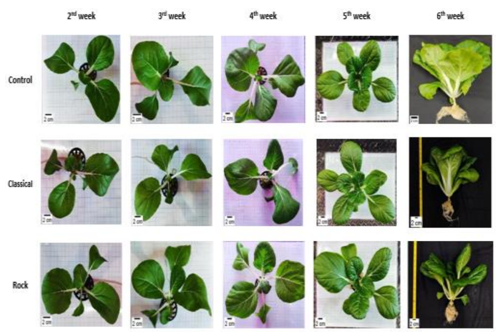

Figure 3. The growth of bok choy grown in chambers with no music, classical and rock music on the second, third, fourth, fifth and sixth week.
Source: Authors

Discussion

Consistent with the findings of previous research (Alavijeh, et al., 2016; Chivukula & Ramaswamy, 2014; Creath & Schwartz, 2004; Hemamali, et al., 2021; Prasetyo & Raju, 2021;

Rachieru et al., 2017), the results of the present study provide converging evidence that exposing plants to acoustic stimulus (specifically, classical music) had a positive effect on their morphology. In the present study, bok choy plant shoots that had been exposed to classical music demonstrated an increase in all of the measured parameters, with a significant difference in total plant fresh weight, dry weight, and the number of leaves as compared to those plants exposed to rock music.

Furthermore, the stouter and shorter roots seen in those plants that had been exposed to classical music vs. rock music and control, highlights another of the benefits of classical music. Similar results have been reported that soothing classical music increased the mitotic index in the onion (Alium cepa) root, when soothing classical music was played (e.g., Mozart's Piano Concerto in D minor, Schubert's Ave Maria, Chopin's Waltzes, and Tchaikovsky's Seasons), compared to the strong, complex music of Wagner, Mussorgsky, and Godunov; resulting in a better rooting system (Ekici et al., 2007; see also Chowdhury et al., 2014; Kim et al., 2021). The sudden increase in plant height and number of leaves from the fourth week of planting could be due to an accumulative effect of the classical music. However, since this study did not use molecular analysis, it is not possible to identify the exact physiological changes.

Considering that the environmental factors in all three conditions were controlled, it is therefore possible to deduce that some combination of instrumentation, tempo, and sound frequencies played a role in stimulating (or not) plant growth. Previous studies and farm enthusiasts have corroborated the beneficial results of plant growth with classical music; albeit speculatively. The findings in this study therefore demonstrate firstly, that the use of electric instruments played at a consistently high tempo between 80-205bpm negatively impacts the morphological processes of the bok choy; while acoustic instruments played at 54-158bpm encourages growth. Second, the rather wide range of sound frequencies in the rock music (180-6,500 Hz); as compared to 180-3,000 Hz for the classical music may have impeded plant growth. Whilst previous literature (see Gagliano, 2013; Jung et al., 2018; Mohanta, 2018 for reviews) showed that individual frequencies in the 100-1000 Hz range increased plant yield and photosynthesis. However, this study used classical music which had fluctuating frequencies and this, at least for the time being, appears to be more effective in encouraging plant growth than exposure to a narrow 'tone' frequency. Interestingly, too wide or volatile a frequency range (e.g., rock music) seems to have the opposite effect (Ekici et al., 2007; Rachieru et al., 2017).

However, the results here further add to the complex literature concerning the impact of exposure to acoustic stimulus (specifically music) on plants. One might wonder whether, for example, if electrical instruments were played at a slower and more relaxing tempo (e.g., light pop music), and a more dramatic piece of classical music (e.g. Stravinsky's The Rite of Spring) were to have been used, would the results be similar? (see also Yeoh, et al. 2023). The study here aimed at investigating two very different musical genres, and yet numerous different musical elements can still be manipulated (e.g., dynamics, key, tonality, rhythms, pitch range). For example, Kwak et al. (2022) found that distinct frequencies and timbres resulted in different outcomes in cell cultures (cf. Ventura et al., 2017). Stability in terms of harmony, melody and rhythm has been shown to affect genetic characteristics of plant cells, whilst music that has an inconsistent rhythm and melody results in lower enzymatic activity (Algieri et al., 2018; Lestard & Capella, 2016).

Conclusion

This study aimed at investigating the effects of acoustic stimulus on plant growth, and based on the results of this study, classical music vs.

rock music has shown significantly positive effects on all parameters of the plants' morphology. Notwithstanding the optimism surrounding the promise of classical music, therein lies the possibilities for future studies. The current study used 2 types of acoustic stimulus, and since both genres of music differ greatly in terms of instrumentation, tempo and frequency fluctuations, future research could employ a more similar acoustic stimulus to measure these morphological differences. Secondly, this study was conducted in a controlled environment, and it is uncertain if similar effects would be present if this was replicated in an open field, since plants in open fields are exposed to various soundscapes. Thirdly, this study did not employ molecular analysis which could have provided a deeper insight into the plants' granular and physiological changes. Despite the promise around the use of classical music to help stimulate plant growths, further studies are undoubtedly still needed before any firm conclusions regarding the potential benefits of exposing plants to an acoustic stimulus can be drawn. Nevertheless, the increasing interest among scientists and farmers alike in the use of acoustic stimulus on plants will serve as an impetus for further research.

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