

Music for plants? An investigation into the impact of exposure to acoustic stimulus in bok choy (*Brassica rapa*)

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Abstract— A study was designed 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: classical music, rock music, plant growth, acoustic stimulus

MUSIC AND PLANTS

Interest in how music affects plant growth is on the rise [1--5]. 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 [6--9]. In spite of the optimism on the effects of the use of classical music, in contrast to rock music, the studies to date have not been replicable for 3 specific reasons. Firstly, in most studies variables were either left unspecified, or presumably beyond the control of the experimenters, sometimes leading to conflicting results. Secondly, although the genre of music is stated in these experiments, it should be noted that not all classical music is 'calm', and/or 'soothing'. A more specific description of the music (e.g. tempo, instrumentation) is required. Thirdly, not all parameters (e.g. duration, music frequencies, volume) of the experiments were reported, and to complicate matters, plants' response to acoustical stimulus have been found to be species-specific. The study here, therefore, aims to investigate the effects of classical vs. rock music with precise methodology in a controlled environment to enable possible replications in the future.

One of the earliest and most frequently cited scientific studies on the use of music on plants was by an Indian botanist, [10]; who reported that the growth rate of balsam (*Impatiens balsamina*) plants accelerated in height, and 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. [11] demonstrated that those chilli plants (*Capsicum annum* 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. [12] 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 [see also 13].

Rock music has not only been shown to be detrimental to growth, but a study by Chivukula and Ramaswamy [14] 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, a group of

researchers [15] demonstrated that the strong, complex and rhythmic accent in the classical music may have given rise to positive results. Nevertheless, even with the use of classical music, consistency in volume is a factor to consider [16].

Duration of exposure to acoustic stimulus

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 [17] determined that classical music compositions should be played intermittently for several hours per day [18,19] (although it should be noted that no statistical support was provided to substantiate these claims). 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 [20]). Popescu and Mocanu [21] 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 [22] 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 [23,24].

Music not only affect 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 significant positive effect on the morphological measurements, growth rates, and the number of leaves compared to no music condition rate [25].

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 [26]. More recently, Lai and Wu [27] 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. [28] exposed chilli seed plants (*Capsicum annum* 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, while those exposed to rock music showed the least. Rachieru et al. [29] 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, There was significant height growth (3.33 cm average) and with bright green leaves in those plants that were exposed to classical music, while Led Zeppelin's music led to 1.33 cm growth and with yellowish green leaves. A more complex schedule was set by Alavijeh et al. [30] 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 [see also 31].

Sound waves and plant growth

Sound waves are characterised by frequency/pitch (Hz) and intensity/volume (dB). Acoustic waves with higher frequencies, or also known as ultrasounds (>20kHz) have been successfully used in priming seed germination [32--36]. Nevertheless, current studies have also shown that those sounds that humans can hear (from about 20 Hz to 20 kHz) can be used as a positive growth regulator [37--39]. In the context of acoustic stimulus, a study by Uchida and Yamamoto [40] demonstrated that thale cress (*Arabidopsis thaliana*) seeds exhibited an increased rate of germination when exposed to pure tones between 70 and 100 Hz. Along similar lines, Vicient [41] 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. [42]).

Taken together, the research that has been published to date suggests that different seed species react differently to different sound frequencies, and even within the same plant gene pool, there have been conflicting results on the use of sound frequencies. For example, Wang [43] 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. [44] reported that playing classical music at 357 Hz and 350 Hz simulated paddy rice seeds' growth (see also [45]). Sound frequency has been shown to be a relevant variable, with a slight increase [32, 46,47] or decrease [48--50] in intensity and/or frequency being found to be detrimental and possibly inhibiting plant growth when compared to no music [51--54].

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*) [55]. 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. However, the authors did not discuss how varying the distance of the speakers, which presumably 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 [56,57], indicating also that distance of speakers is an important element in plant growth.

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 [see 58]). 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., 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. 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 is not able to justify how timing, duration, and music frequency was calculated. Furthermore, sound frequencies has typically been found to be species-specific. Hence, the study that is reported here sets 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.

MATERIALS AND METHODS

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; and upon successful germination (shoots which displayed 2-3 leaves) 50 healthy plants were then selected and transferred to an indoor cabin, with 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 [59] and [60], 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 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 hourly 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, plants were harvested randomly from different rows, and data in terms of root and shoot parameters were measured and recorded.

RESULT AND DISCUSSION

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.

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

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 [61]. 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 approx. here]

The effects of music type on root growth

The roots are a crucial part of every plant as they absorb, provides nutrient uptake, not to mention anchoring and supporting the plant [62]. 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 [63].

[Table 2 approx. here]

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 Figs. 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 attached as Appendix A).

[Figure 1 approx. here]

[Figure 2 approx. here]

[Figure 3 approx. here]

CONCLUSION

Consistent with the findings of previous research [64--67], 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 [see also 68,69].

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.

However, the results here further add to the complex literature available 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? The study here aimed at investigating two very different musical genres, and yet there are numerous different

musical elements that can still be manipulated (e.g., dynamics, key, tonality, rhythms, pitch range) [70,71]. 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 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 [72].

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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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 (cm²)
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 letter in each column are significantly different at Tukey alpha level of 0.05.

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. (cm³)
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.

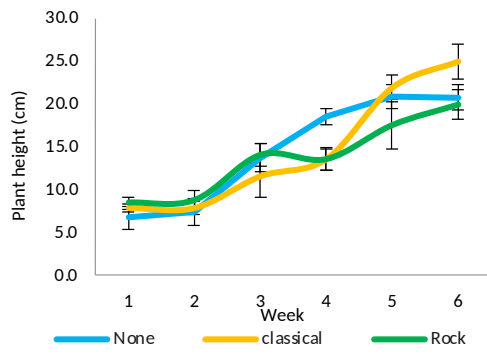


Fig. 1. The effects of music type on the height of the plant.

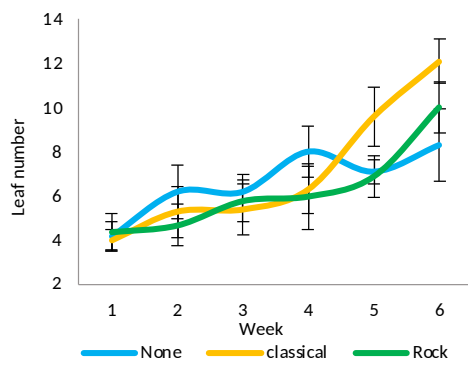


Fig. 2. The effects of music type on the number of leaves

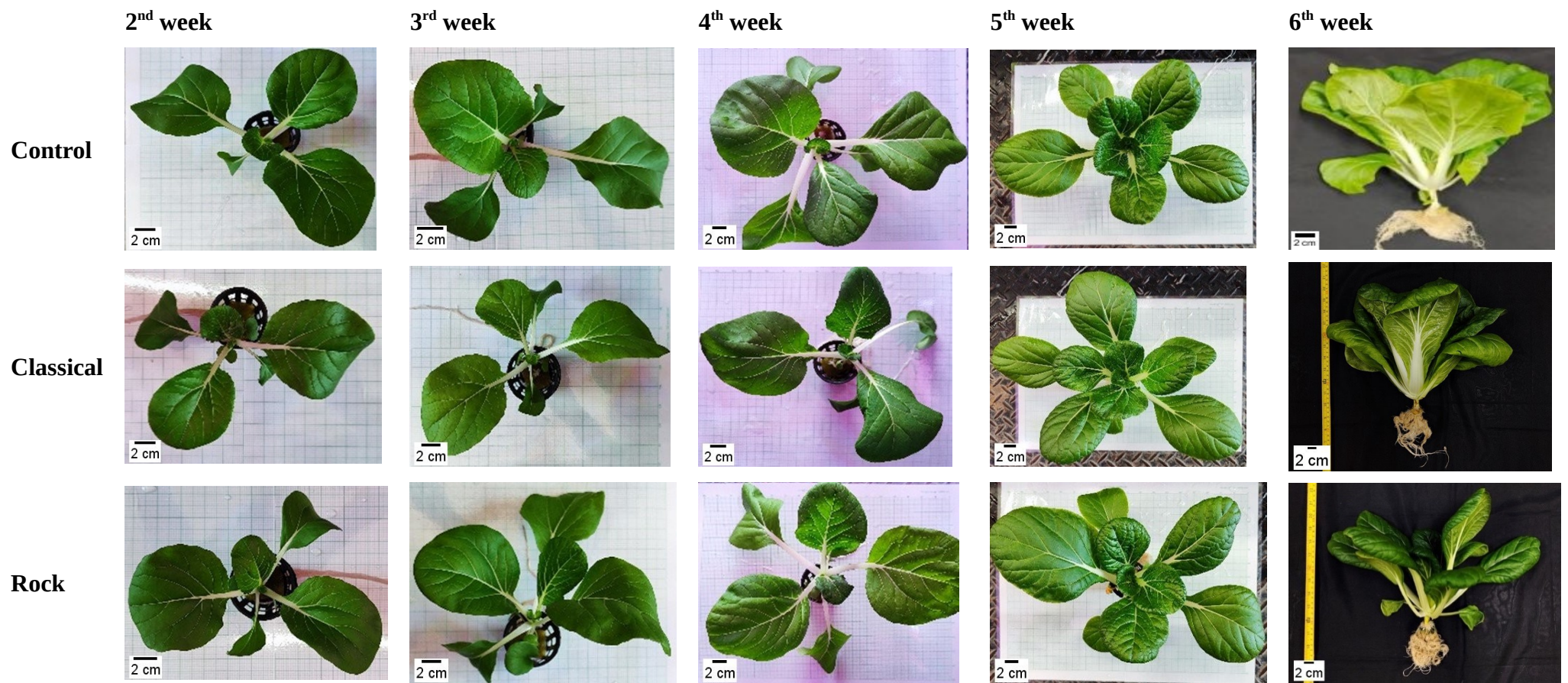


Fig. 3. The growth of bok choy grown in chambers with no music, classical and rock music on the second, third, fourth, fifth and sixth week.