International Journal of Horticultural Science and Technology
Vol. 6, No. 2; December 2019, pp 273-282
Print ISSN: 2322-1461 Online ISSN: 2588-3143
DOI: 10.22059/ijhst.2019.282693.298
Web Page: https:// ijhst.ut.ac.ir, Email: ijhst@ut.ac.ir

The Effects of Simulated Vibration Stress on Plant Height and Some Physical and Mechanical Properties of *Coleus blumei* Benth

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(Received: 21 April 2019, Accepted: 10 September 2019)

Abstract
Non-chemical control of plant growth is an important goal for the production of ornamental pot plants. In the present study the effects of simulated vibration on plant height and some physical and mechanical properties of Coleus stem were investigated. The study was conducted as a factorial experiment based on a completely randomized design with three replications. Vibration stresses were performed using a laboratory vibration simulator and the effects of vibration parameters such as frequency and duration on the stem characteristics of Coleus plants were examined. Vibration frequency included three levels of 7.5, 10 and 12.5 Hz and vibration duration included three levels of 0 (control), 5 and 10 min. Based on the obtained results, vibration stress caused significant decrease in the height and surface area of the stems. Vibration frequency of 12.5 Hz with 10 min duration caused 31% decrease in plant height in comparing to the control samples. Mechanical properties of stems including modulus of elasticity, bending force, and bending stress were reduced by increasing vibration frequency and duration when compared to the control samples. In conclusion, the results of the current study indicated that vibration stress on Coleus decreased plant height while increased the elasticity and resistance to the fracture caused by mechanical forces of the stem.

Keywords: Bending stress, Deflection of stem, Modulus of elasticity, Plant height, Vibration stress.

Introduction

Coleus or Painted nettle (*Coleus blumei* Benth) belongs to Laminaceae family. This species is an herbaceous ornamental plant with beautiful variegated leaves that makes it distinctively attractive for ornamental plant industry (Khalighi, 1997). Plants that belong to this genus are characterized with stems that are quadrangular in cross section, reciprocal leaves with 2.5 to 10 cm lenght, with or without petiole (Nagpal et al., 2008). This plant is mostly used as a pot plant for indoor uses. Most of producers of ornamental plants, aim to control plant growth in order to meet some targets. For example, producing dwarf plants increases efficiency of labor works in greenhouse and also increases speed of agricultural practices in field (Graham Wheeler, 2017). Moreover, because transplants are grown compactly and are highly exposed to shade of neighboring plants, their stem are thin and tall; this makes their transport and application of

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some horticultural practices like grafting difficult. Therefore, controlling plant height is of particular importance (Garner Langton, 1997). Besides, producing dwarf plants, controlling plant growth is also in vital importance for ornamental pot plants from the aspect of marketing. Ornamental pot plants with proper height, not very tall or very short, are of more economical value than plants in non-standard height (Clifford et al., 2004).

There are various methods of applying mechanical tension, among them, rubbing plants (Suge, 1978) or shaking pots (Pontinen Voipio, 1992) are more commercially useful than other methods. Shaking pots with the power of wind (Bossdrof Pigliucci, 2009) or shaking column (Pontinen Voipio, 1992) have been previously investigated. Mechanical tension by rubbing with sponge on pepper internodes (Graham Wheeler, 2017) and contact tension via brushing on African violet (Brotton Cole, 2009) resulted in reduction of plant height in comparison with the control plants. However, an important issue that rises in this regard is the effect of mechanical stress on other growth parameters of plants such as physical characteristics. Based on material, size and shape of object used for making mechanical stress, different effects can be expected. If the change in the object shape is reversible, it is considered as elastic change and if it is irreversible, it is a plastic change.

When an object is pushed or pressed, internal forces are generated in opposite direction that are against any conformational change. Tension is defined as internal forces in opposite direction that is calculated based on surface area. The quantity of tension is equal to externally applied force on unit surface area. On the other hand, when an object is pressed or stretched by a force, the shape of object changes. This conformational change is called strain force. Modulus of elasticity is the absolute value of elasticity strength that indicates the extend to which an object tolerates a force that cause transformational changes in object, and determines how much it resists and how much it changes against the force (Timoshenko, 1983).

On the other hand, based on equation 3, it can be conceived that, the modulus of elasticity and displacement of stem are inversely related. This means, the more the stem move, the less module is expected. This indicates that, the stem flexibility increases and the stems bends more without being broken. The more the plant stem is elastic, the more resistant is against any external forces such as, any movement or impact during transport, wind, etc. Besides, reducing plant height, mechanical stress increases plant elasticity and plant resistance against ambient stresses. Previous researches has shown that, applying mechanical force on Poplar (*Populus hybrid*) resulted in increased bending force and reduced modulus of elasticity in stressed plants (Pruyn et al., 2000). It was also reported that, applying mechanical force (wind) on *Abutilon theophrasti* resulted in increased bending forces (Henry Thomas, 2002). In pot plants and transplants, mechanical and physical traits of stem are of particular importance. Because these plants are so much exposed to mechanical forces during transfer, increase in their flexibility enhance their resistance against breaking. In current study, effect of duration and frequency of mechanical force in form of shaking, generated by vibration simulation device, was evaluated on reducing plant height and physical and mechanical traits of Coleus stem in order to introduce the best frequency and duration of mechanical stress for commercial application.

Materials and methods

The present study was carried out during the spring of 2017 in research greenhouse of Faculty of Agriculture, Lorestan University (33˚43ˈ9 N and 48˚ 26 W and 1170 meter above sea level). The greenhouse was in north-south direction, covered by polyethylene layer and equipped with air conditioning system, The temperature of 22-28 °C, 60-70% relative humidity and 600 photosynthetic photon flux density were recorded. This experiment was conducted as a factorial experiment based on a completely randomized design with three replications. Treatments included mechanical stress with duration of 0, 5 and 10 min and frequency of 7.5, 10 and 12.5 Hz.

Plant materials were prepared from herbaceous cuttings. Cuttings with 2-3 buds and 2 leaves were planted in pots with 20 cm diameter. The soil mixture was manure, clay and sand (1:1:1). When the cuttings were rooted and established in the pots, treatments were applied every morning at the time of sunrise on plants that have developed 3-4 buds and 4 leaves. Treatments were applied by means of a shaker instrument that was available in Lorestan University. The same device was also used for simulation of vibration during postharvest study of apricot watermelon (Shahbazi et al., 2010) and rose cut flowers (Alizadeh Pouri et al., 2017). The designed device is shown in Figure 1. As can be seen in Figure 1, the device consists of a vibrating table that has two counter-rotating shafts that rotate in opposite direction. Counterweights are powered by an electric motor. On the counter-rotating shafts, two Counterweights are located acentricall. The vibrating-table is placed on two horizontal columns. The table is holded by spring-made configuration. A spring is attached to both ends of columns and the other sides of the columns are attached to vertical columns in a hinged manner. The speed of the electric motor was adjusted by means of a speed control unit (inverter). As the rotating rate changes, counter-rotating shafts and thus Counterweights angular speed change and make the vibrating table to vibrate. The frequency is calculated base on Hz. unit, which is calculating by number of counter-rotating shafts ratation per min that is recorded by invertor on the basis of 60-minute duration. For adjusting the device acceleration, weights and their location on central axis and the location of table on columns are modified. After four weeks of applying stress, plant height and physical characteristics of stem was measured.

Plant height was measured by a ruler (cm). The second internode of stem was considered for preparing plant material for measuring physical and mechanical characteristics of the stems. Physical properties of the stems included, length and width, cross section area and the second moment of inertia. Length and width of the stems were measured by calipers. Due to the fact that Coleus stem is quadrangular, stem cross section area (A) was calculated based on the equation 1.

$$A = hb \quad (1)$$

In equation 1, h is width of stem cross section, b is length of stem cross section. Regarding that Coleus stem is quadrangular, the second moment of inertia of stems (I), calculated according to equation 2 (Shahbazi Nazari Galedar, 2012).

$$I = {bh^3}/{12} \quad (2)$$

In equation 2, I is the second moment of inertia for cross section. For measuring modulus of elasticity, stem was placed on two metal bases. Bases were 50 cm far from each other, attached to Instron Universal Testing Machine, manufactured by SMT – 1, SANTAM Company, Tehran, Iran. The stem was exposed to electrical charge via charging plate attached to movable plate that was connected with upper joint of Instron Universal Testing Machine (Fig. 2). The speed of the loading rate was adjusted for 10 mm per min. Because, based on the reports, this is a standard speed in experiments related to the agricultural crops (Shahbazi Nazari Galedar, 2012).

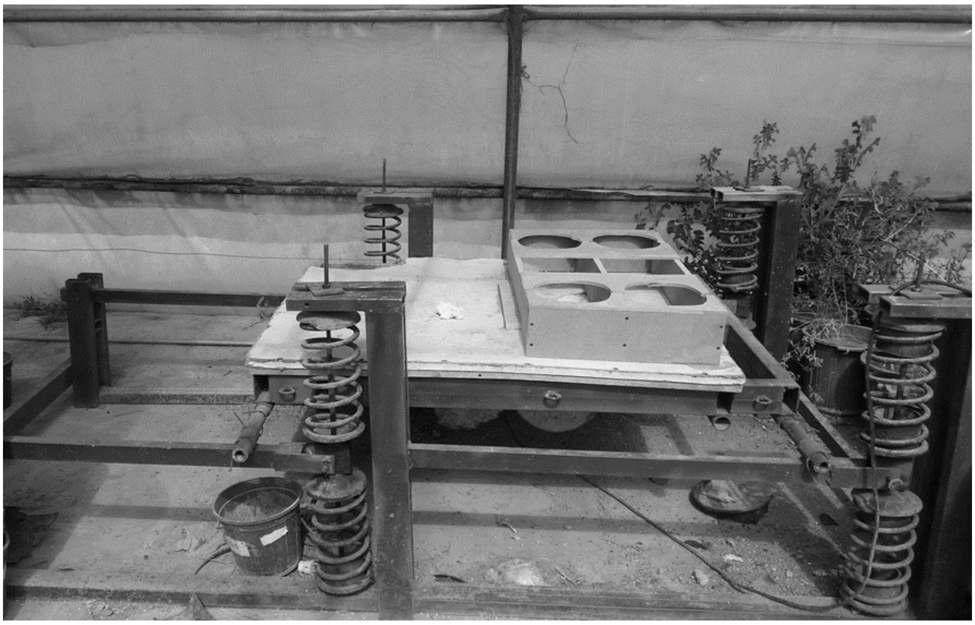

Fig. 1. The vibration simulator device used in the present experiment for applying mechanical stress

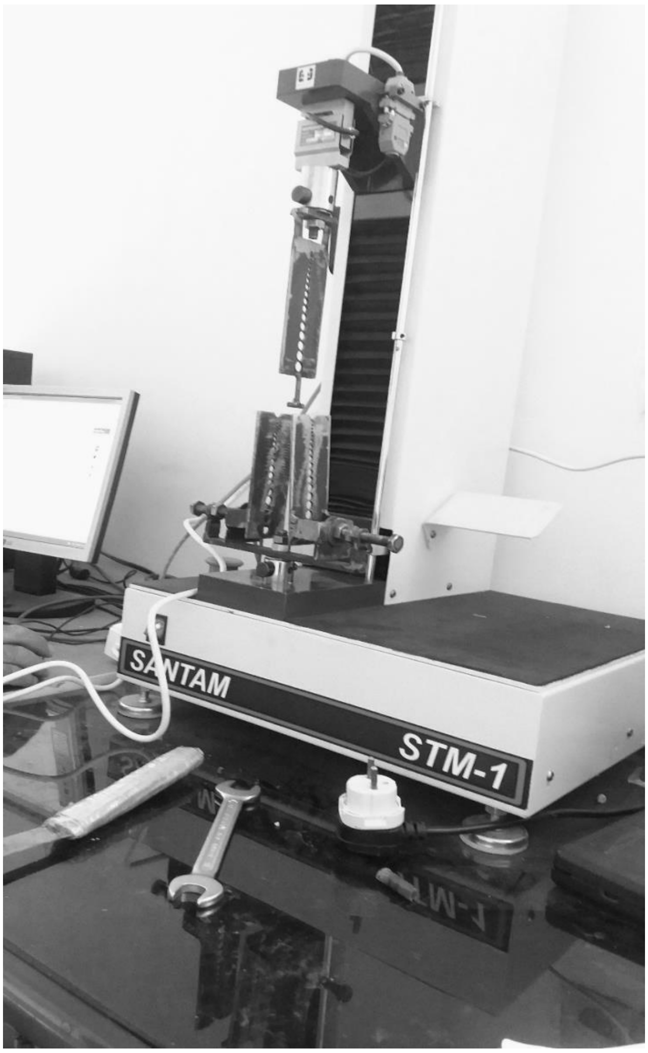

Fig. 2. Measuring bending resistance for evaluation of bending stress and modules of elasticity

Bending force was measured using load cell strean cage. Alternation in force-transformation (displacement) recorded to the point were plant samples were ruptured. The bending force and deformation at the bio yield peak and at the inflection point were calculated by Santam software. Crooke and Ennos (1995) reported that, for the column that have simple base, and the force is exposed to it from the middle, calculation of modulus of elasticity is according to the equation 3. Where, E is stem modulus of elasticity (MPa), F_b is the maximum bending force (N), L is, distance between two simple bases (50 mm) and δ is the deflection at the specimen center. Maximum beding stress of stem calculated according to the equation 4. (Ennos, 1997), where, σ is maximum bending stress of the stem (MPa) and a is stem diameter.

$$E = {F_b L^3}/{48\delta I} \quad (3)$$

$$\sigma = {Fal}/{4I} \quad (4)$$

Analysis of variance was conducted by Minitab software (2017) and Microsoft Excel (2013). Mean comparison of data was calculated using PLSD test. Graphs were drawn using Prism 5 software.

Results

Analysis of variance showed that, both main effects and interaction of duration and intensity of stress on plant height were significant on 1% probability level (Table 1). Mean comparison revealed that, vibrating stress reduced plant height (Fig. 3). There was no difference between effect of stress duration on plant height in 7.5 and 10 Hz and between 5 and 10 min stress duration. Applying stress in frequency of 12.5 Hz for 10 min reduced plant height in comparison to 5 min duration. Vibration with frequency of 12.5 Hz with 10 min duration caused 31% decrease in plant height in comparison with the height of control plants (Fig. 3). Moreover, it was shown that, after treating plants for 4 weeks, different treatments resulted in various plant heights in the present research (Fig. 4).

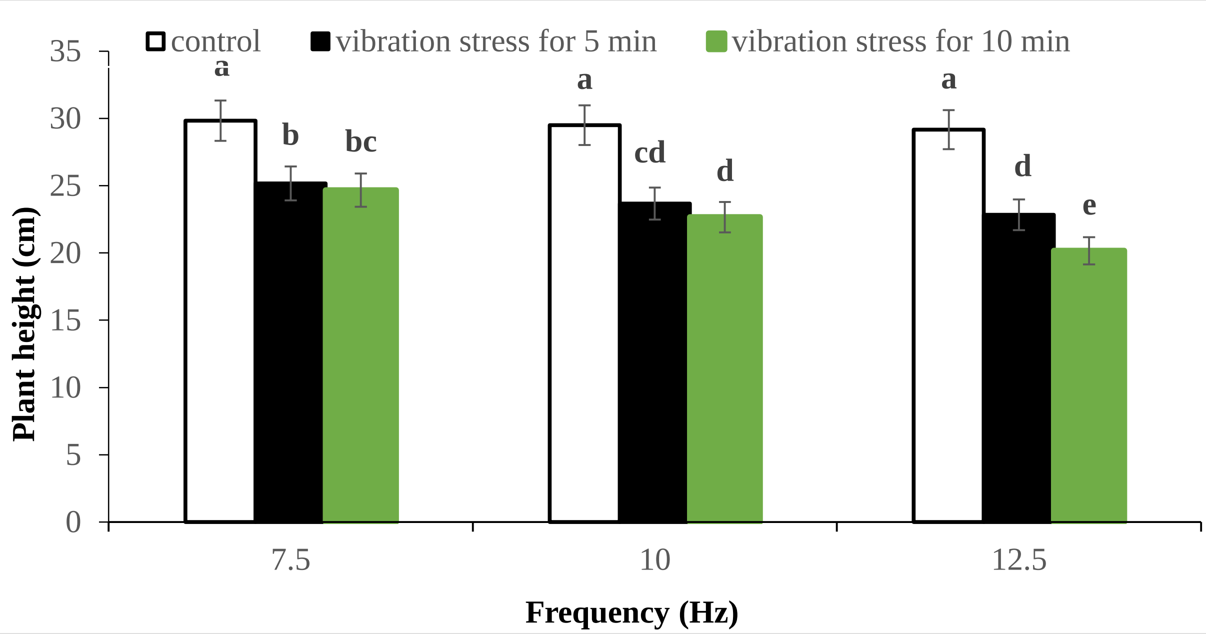

Fig. 3 Mean comparison of the effect of duration and frequency of vibrating stress on plant height of Coleus. Vertical columns are indicating standard errors. Means with different letters denote significant differences at 0.05% probability level beased on LSD test.

Fig. 4 Comparison of plant height due to the effect of different frequency and duration of vibrating stress after 4 weeks on Coleus plants. A. control, B. 5 min and 7.5 Hz, C. 10 min and 7.5 Hz, D. 5 min and 10 Hz, E. 10 min and 10 Hz, F. 5 min and 12.5 Hz, G. 10 min and 12.5 Hz.

Table 1. Analysis of variance (mean square) of the effect of frequency and duration of mechanical stress on plant height and some physical and mechanical traits of Coleus stem

	Mean square						
CV	**Modules of Elastisity**	**Bending stress**	**Displacement**	**Bending force**	**Second moment of inertia**	**Stem diameter**	**Stem height**
Stress duration	0.94**	0.000415**	22.02**	2.528**	606449**	70**	123.62**
Frequency	0.14**	0.000026**	3.55**	0.69**	519622**	34.347**	14.06**
Duration*Frequency	0.0038**	0.000014*	1.61**	0.19**	128791**	7.53ns	2.85**
Error	0.00067	0.00004	0.193	0.0137	10806	3.723	0.46
% C.V.	6.99	0.0056	5.3	4.87	4.79	4.3	2.67

CV: Coefficient of Variation, ns, * and ** denoting non-significant difference and significant difference at probability level of 5% and 1%, respectively

The main effect of duration and frequency of mechanical stress in stem cross section area was significant at 1% probability level, but the interaction of two variables was not significant (Table 1). Mean comparison demonstrated that, applying mechanical stress reduces the cross section area and the minimum value of cross section in pot plant was related to 10 min and 12.5 Hz (Fig. 4). Increase in stress duration, reduced area of stem cross section (Table 2), but in the case of stress frequency only 12.5 Hz stress frequency caused significant reduction in area of stem cross section. Vibration with frequency of 12.5 Hz with 10 min duration caused a 17% decrease in stem cross section in comparison with the control (Table 3).

Table 2. Mean comparison of some physical and mechanical traits of Coleus stem as affected by duration of mechanical stress

Duration (min)	**Modules of Elastisity (MPa)**	**Bending stress (MPa)**	**Displacement (mm)**	**Bending force (N)**	**Second moment of inertia (mm^4)**	**Stem Area (mm^2)**
0	0.47a	0.053a	6.409b	2.99a	2409.41a	47.77a
5	0.302b	0.042b	9.05a	2.26b	2195.32b	44.64b
10	0.293b	0.041b	9.33a	1.96c	1892.77c	42.21c

In each columns data denoted by same letter are not significantlydifferent at 5% probability letter based on PLSD test. Each number is the average of 3 replications

Table 3. Mean comparison of some physical and mechanical traits of Coleus stem as affected by frequency of mechanical stress

Stress frequency(Hz)	Modules of Elastisity (MPa)	Bending force (MPa)	displacement (mm)	Bending force (N)	Second moment of inertia (mm^4)	Stem Area (mm^2)
7.5	0.403[a]	0.047[a]	7.6[b]	2.67[a]	2406.13[a]	46.4[a]
10	0.342[b]	0.045[b]	8.45[a]	2.43[b]	2165.81[b]	45.56[a]
12.5	0.326[b]	0.044[b]	8.83[a]	2.12[c]	1925.56[c]	42.67[b]

In each columns data denoted by same letter are not significantlydifferent at 5% probability letter based on PLSD test. Each number is the average of 3 replications

Analysis of variance revealed that, the main effect of duration and frequency of vibration stress and also their interaction on the second moment of inertia was significant (Table 1). Increase in duration (Table 2) and stress frequency (Table 3) reduced moment of inertia and the minimum value (31.6%) obtained in plants exposed to 12.5 Hz for 10 min (Table 4). Analysis of variance revealed that the main effects of duration and frequency of vibration stress and also their interaction on bending force, the bending stress and modulus of elasticity were significant on 1% probability level (Table 1). As the duration (Table 1) and frequency (Table 3) of stress increased, bending force of the stem reduced. The minimum bending force equal to a 46.3% decrease in comparison to control was obtained in plants exposed to 12.5 Hz frequency for 10 min (Table 4). Exposing plants to mechanical stress reduced bending stress in plants that was exposed to stress in comparison with the control plants. However, no significant difference was observed in stress durations of 5 and 10 min (Table 2). Increase in stress frequency reduced the bending stress but increase in frequency from 10 to 12.5 Hz didn't significantly affect bending stress (Table 3). Vibration frequency of 12.5 Hz with 10 min duration caused a 26.9% decrease in bending in comparison with the control plants (Table 4).

Table 4. Mean comparison of some physical and mechanical traits of Coleus stem affected by frequency and duration of mechanical stress

Stress duration (min)	Stress frequency (H_Z)	Modules of Elastisity (MPa)	Bending stress (MPa)	Displacement (mm)	Bending force (N)	Second moment of inertia (mm^4)	Stem Area (mm^2)
	7.5	0.489[a]	0.053[a]	6.59[e]	3.02[a]	2438.62[ab]	48.06[a]
0	**10**	0.454[a]	0.054[a]	6.54[e]	3.05[a]	2458.7[ab]	47.71[ab]
	12.5	0.482[a]	0.053[a]	6.35[e]	2.91[a]	2330.92[ab]	47.55[ab]
	7.5	0.365[b]	0.043[bc]	8.38[cd]	2.51[b]	2495.62[a]	46.71[ab]
5	**10**	0.271[c]	0.042[cd]	9.12[bc]	2.44[b]	2311.48[b]	46.25[ab]
	12.5	0.270[cd]	0.0407[cde]	6.67[b]	1.83[c]	1778.88[c]	40.98[d]
	7.5	0.355[b]	0.046[b]	7.84[d]	2.49[b]	2284.15[b]	44.42[bc]
10	**10**	0.300[c]	0.0401[de]	9.68[b]	1.79[cd]	1727.25[c]	42.72[cd]
	12.5	0.255[d]	0.0387[e]	10.41[a]	1.62[d]	1666.86[c]	39.5[d]

In each columns data denoted by same letter are not significantly different at 5% probability letter based on PLSD test. Each number is the average of 3 replications

On the other hand, exposing plants to vibration stress resulted in decreased electricity module and the minimum value was equal to a 47.85% decrease in comparison to the control, obtained in plants exposed to 12.5 Hz frequency for 10 min (Table 4). No significant difference was observed between frequency of 10 and 12.5 Hz for 5 or 10 min durations. Moreover, analysis of variance revealed that, main effects of stress duration and frequency and also their interaction on stem displacement was significant on 1% probability level (Table 1). Applying vibration stress increased stem displacement and the maximum value of stem displacement was equal to a 57.9% increase in comparison with the control that obtained in plants exposed to 12.5 Hz for 10 min (Table 4). Increase in duration and frequency of stress consequenced in increased stem displacement, but there was no significant difference between 5 and 10 min (Table 2) and 10 and 12.5 Hz frequency (Table 3).

Discussion

Based on the obtained results of the present research both frequency and duration of mechanical stress can affect morphological and mechanical properties of Coleus plants. Previous studies were also reported the same results as (Biddington and Dearman, 1985; Jeffe et al, 2002; Braam, 2005; Khajepoor et al., 2017). For instance, it was demonstrated that applying contact tension on pea, reduced its height (Lykas et al., 2008). Moreover, applying mechanical stress on rice, maize and barley, resulted in reduced plant height in comparison to their control conditions (Sone et al., 2006). Both vibration and contact stimuli can result in reduced stem height but stem thickening can be achieved under contact stress (Jeffe et al., 1980). In plants undergoing vibration stress, their stem diameters were reduced; while in some cases were not changed (Jeff et al., 1980; Heuchert et al., 1983; Latimer Mitchell, 1988; Jones et al., 1990).

Exposing Arabidopsis seedlings to vibration stress resulted in reduced stem diameter and cross section moment (Paul-Victor et al., 2010). Jeff et al (1980) reported that, mechanical stress increased stem resistance to bending in beans, in such a way that, stem of stressed plants could resist bending more that 90° without being broken. However, control plants could just resist a narrow bending. The reason behind this fact that stem resisted bending in stressed plants was not due to lignification but it was due to increased stem flexibility. Other reports were in agreement with the obtained results of the present study. It was reported by Mitchell (2003) that, mechanical stress reduces modules of elasticity and bending stress on *Pseudotsug menziesii*. Exposing mechanical stress by bending on tobacco, reduced modules of elasticity and bending stress in stressed plants compared to their control (Anten et al., 2005). Furthuremore, bending stress on tobacco was also reduced plant height and modules of elasticity in stressed plants in comparison to the control (Anten et al., 2006).

Plants response to mechanical stress are supposed to be due to adaption to vibration condition because, emerged short stems have more flexible tissues that make them less prone to be broken against external forces (Niklas, 1998 ،Anten et al., 2005). Change in modules of elasticity, is probably due to anatomical changes in stem. For instance, low levels of modules of elasticity in *Capsella bursa pastories* that were exposed to bending stress, resulted in relative increase of parenchyma cells and reduction in vascular tissues (Niklas, 1998).

In conclusion, reduction in plant height is considered as a merit for pot plants, because, rather than its beauty, it makes the transfer of pot plant easier. In case of transplants, short plants are easier to be grafted. Applying mechanical stress in plants caused an increase in stem flexibility besides reducing plant height. Flexible plants are notably resistant against external forces reduction in elasticity module also resulted in increase in stem flexibility against breakage. Among treatments used in this study, vibration stress with frequency of 12.5 Hz for 10 min resulted in the minimum plant height, bending stress and elasticity module and the maximum movement. Therefor, this study proposes this treatment for controlling growth of Coleus pot plants.

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