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Short Communication

Growth Promotion by Vibration at 50 Hz in Rice and Cucumber Seedlings

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Vibration at 50 Hz significantly stimulated seed germination and root elongation in both rice and cucumber plants. The vibration barely affected the elongation of cucumber hypocotyls but stimulated the elongation of rice coleoptiles. Thus, plants' responses to vibration at a particular frequency differ from those to other mechanical stimuli.

Key words: *Cucumis sativus* L. (cucumber) — Growth promotion — Mechanical stimulation — *Oryza sativa* L. (rice) — Vibration.

The effects of mechanical stimuli on plant growth and development have been studied in various ways (Boyer 1967, Hiraki and Ota 1975, Jaffe 1973, Jeong and Ota 1980, Mitchell et al. 1975, Neel and Harris 1971, Suge and Tokairin 1982, Takahashi and Suge 1980, Turgeon and Webb 1971). In many cases, touching, rubbing, shaking, brushing or wind have been used as the mechanical stimulation. Such mechanical stimulation causes the inhibition of shoot elongation. Mechanical stimulation by natural soil also inhibits root growth (Barber and Gunn 1974, Barkley 1962).

In certain environments, for example in some types of growth chamber, or when motor-operated apparatus is used, plants are exposed to high-frequency vibration caused by the motors. The effects of such high-frequency vibration on plant should be assessed and compared with the effects of other mechanical stimuli. In this study, we asked whether or not high-frequency vibration induces the same responses in plants as those induced by shaking or wind. Vibration at 50 Hz was used in this study.

Seeds of rice (*Oryza sativa* L., cv. Tan-ginbozu) and cucumber (*Cucumis sativus* L. cv. Otone No. 1) were placed on moist filter paper in covered Petri dishes (90 mm in diameter, 15 mm deep). Rice seeds were also submerged in distilled water of 5 mm in depth in similar Petri dishes in some experiments. Between 20 and 30 seeds of rice or cucumber were placed in each Petri dish. When the seedlings were grown in plastic containers (80 mm in diameter, 50 mm deep) filled with vermiculite, two cucumber seeds or ten rice seeds were sown in each container. The containers of vermiculite for rice were further filled with distilled water.

Vibration was applied to whole plants by using a board speaker-operated vibrating plate. The speaker used ("Body Sonic" Type DS-700 4B; Tohoku Pioneer Co., Tendo, Japan) was different from ordinary sound speakers and was originally designed for vibrating attachable boards. The vibrating apparatus was assembled with a plastic tray (28×21 cm^2) attached to the board speaker, "Body Sonic", and car stereo components (Model KE-4000SD/WG; Tohoku Pioneer Co.). A signal of 50 Hz was obtained from a speaker oscillator (Type OG-241; Onkyo Sokki Co., Tokyo, Japan) and recorded on a 30-min cassette tape. The plastic tray was vibrated at 50 Hz through the speaker by playing the cassette tape. Then, samples in Petri dishes or plastic containers were placed directly on the vibrating plate. Control plants were also placed on the same device except that the "Body Sonic" speaker was turned off. The amplitude of the vibration was controlled by turning a volume knob, and approximately the same amplitude was used throughout all experiments. The vibration was clearly visible to the naked eye and could also be felt by hand. All experiments were carried out under controlled conditions in a growth chamber (Koitotron Type KG; Koito Industries Ltd., Yokohama, Japan). Experiments for the observation of the germination and the early grwoth of seedlings were performed in total darkness at 25 ± 1°C. Rice and cucumber plants in the vermiculite-filled containers were placed under a photoperiod of 16 h of light at 25 ± 1°C. The light source in the growth chamber consisted of twenty-two 80-W fluorescent lamps (Toshiba, Tokyo, Japan), nine 400-W extra-high pressure mercury lamps (Metal Haloid "Yoko"; Toshiba) and twelve 200-W refractor lamps (Toshiba), provided plants with an irradiance of 13 W m^{-2} (250–800 nm). Each experiment was replicated at least three times. Statistically significant differences were identified by the Z-test.

As shown in Figure 1, vibration at 50 Hz promoted the germination of rice and cucumber seeds under submerged conditions or on filter paper. The vibration also promoted the elongation of roots and coleoptiles of rice and the elongation of roots of cucumber seedlings (Table 1; Experiment I). When cucumber seedlings were subjected to vibration for 3 days, from the time of imbibition of seeds, the elongation of roots was significantly promoted. However, no significant differences in growth of hypocotyls was observed between the control and the vibrated cucumber seedlings. In rice, by contrast, the elongation of both roots and coleoptiles was substancially promoted by the vibration under submerged conditions or on moist filter paper. Since vibration causes a constant movement of water and of plants, the effect of vibration on root elongation in particular can be attributed, at least in part, to the enhancement of aeration. The promotion of seed germination by vibration might also result in the subsequent promotion of growth of both roots and coleoptiles. However, it seems unlikely that an aeration effect alone can explain the promotion of elongation of rice coleoptiles both in water and on moist filter paper. As seen in Table 1, rice seedlings generally show a tendency toward root elongation under moist-air conditions and a tendency toward elongation of coleoptiles under submerged conditions early in development (Takahashi 1984). If vibration mediates only an enhancement of the supply of oxygen, one might expect that the ratio of growth of roots to that of coleoptiles in water would be simply reversed when seedlings were placed on moist filter paper, even under vibrating conditions. However, such a reversal was not observed in the present study. Other types of mechanical stimulation, such as touching, stimulate the production of ethylene (Biro and Jaffe 1984, Hiraki and Ota 1975, Suge and Tokairin 1982) and ethylene promotes the elongation of rice coleoptiles (Ku et al. 1970). Therefore, the possibility of the mechanically-induced evolution of ethylene, due to the vibration, should also be considered.

The promotion of elongation of roots and coleoptiles or rice seedlings and of roots of cucumber seedlings was observed even when the vibration was applied to the already germinated seedlings (Table 1; Experiment II). Also, elongation of rice roots was significantly promoted when the vibration was initiated at the later 2-leaf stage (Table 1; Experiment III). Similarly, the vibration promoted root growth but not shoot growth in cucumber seedlings when the vibration was applied from the cotyledonary

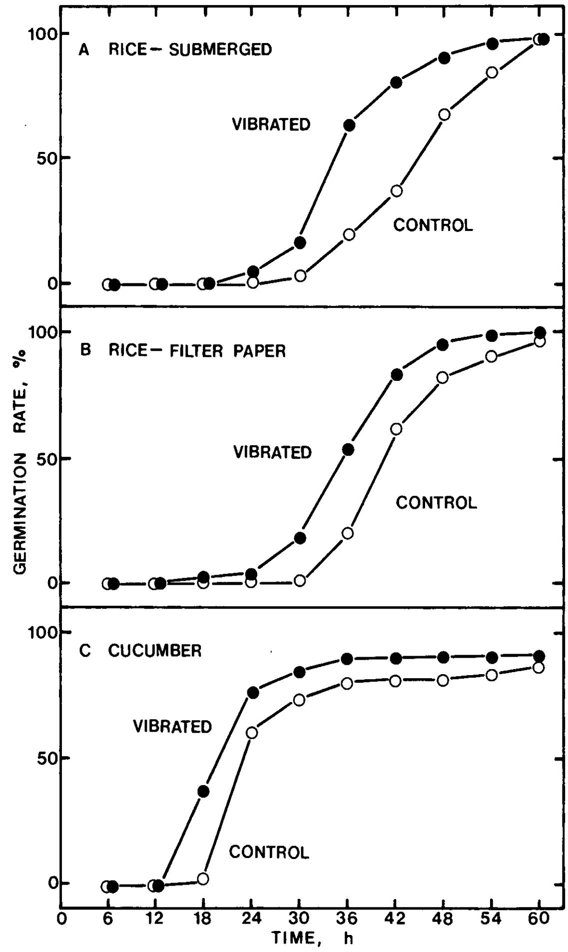

Fig. 1 Germination of rice and cucumber seeds as affected by vibration at 50 Hz. Data are shown as the percentage of germinated seeds in a time-course study. Top (A), rice seeds under submerged conditions; middle (B), rice seeds on filter paper; bottom (C), cucumber seeds on filter paper. Open (○) and closed (●) circles indicate the control and the vibrated seeds, respectively. One hundred seeds were used for each treatment.

to the 2-leaf stage (data not shown). These results imply that the promotion of seedling growth is not merely a result of the promotion of seed germination. Since elongation of shoots was inhibited in rice when the seedlings were subjected to the vibration at the 2-leaf stages (Table 1; Experiment III), the promotion of shoot growth by vibration may be limited to the early stages of growth of the seedlings. Thus, the reponses of plants to vibration may differ depending upon the growth stage, the tissue, and the plant species.

The results of the present study suggest that plants respond differently to different mechanical stimuli. Vibration may, in part, have an aeration-promoting effect. However, it is noteworthy the promotion of growth of the roots and the coleoptiles by the 50-Hz vibration occurs in spite of

Table 1 Elongation growth of rice and cucumber seedlings as affected by vibration at 50 Hz

Plant and treatment	Shoot length (mm ± SE)	Root length (mm ± SE)	(n)
Experiment I			
Rice (Submerged)			
Control	2.6±0.29	0.1±0.04	50
Vibrated	5.6±0.33 [b]	4.6±0.47 [b]	50
Rice (Filter paper)			
Control	1.9±0.04	6.6±0.21	50
Vibrated	3.3±0.11 [b]	14.6±0.30 [b]	50
Cocumber (Filter paper)			
Control	6.9±0.28	34.9±0.65	30
Vibrated	7.5±0.48 [ns]	51.5±0.67 [b]	30
Experiment II			
Rice (Filter paper)			
Control	5.1±0.13	14.4±0.36	40
Vibrated	6.8±0.16 [b]	17.6±0.57 [b]	40
Cucumber (Filter paper)			
Control	14.5±1.05	35.8±0.95	23
Vibrated	14.2±1.33 [ns]	44.4±1.57 [a]	23
Experiment III			
Rice (2-leaf stage; vermiculite)			
Control	94.6±1.99	56.3±3.10	26
Vibrated	82.2±2.20 [b]	76.3±3.00 [b]	26

The vibration was started at the time of seed imbibition and continued for 3 days in Experiment I. In Experiment II, 2-day-old seedlings (0.5 to 1.0 mm long) of rice and 1-day-old seedlings (2.0 to 3.0 mm long) of cucumber were subjected to the 50-Hz vibration for 2 days. In Experiment III, the vibration was started at the 2-leaf stage and continued for 8 days. Shoot length indicates the length of coleoptiles or hypocotyls in Experiment I and II and shoot height in Experiment III. Seed or seedlings were placed on moist filter paper or submerged in Experiment I and II and grown in vermiculite in Experiment III. Means denoted [a] and [b] are significantly different from those of control at a 5% and a 1% level, respectively. [ns] indicates the absence of a significant difference.

a constant and greater movement of the experimental plants. Moreover, vibration at 50 Hz does not apprently inhibit the elongation of cucumber hypocotyls. These are interesting results becuse a transient and brief exposure to gentle touching, gyratory shaking or wind, or contact with natural soil can cause a substantial retardation of growth of seedlings (Barber and Gunn 1974, Barkley 1962, Jaffe 1973, Jeong and Ota 1980, Mitchell et al. 1975, Suge and Tokairin 1982, Takahashi and Suge 1980). Although the vibration used in the present study differs from such gyratory shaking only in terms of the frequency or amplitude, plants appear to respond to the two types of stimulus in different ways. The two vibratory motions may not be the same type mechanical stimulation. To clarify such differences, the effects of vibrations at various frequencies need to be studied.

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