키위나무의 바람에 대한 특성연구

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Basic characteristics of wind-blown kiwifruit vines

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Abstract

Kiwifruit vines with broad leaves are easily torn or shed by high-speed wind. In this study, the threshold wind speed at which a cane is broken was investigated experimentally with varying physical parameters of a kiwifruit vine under two different ABL (atmospheric boundary layer) conditions. In addition, the temporal variation of wind-blown young canes was visualized using a high-speed camera. The average threshold wind speeds for ABL types A and B are about 20.5 m/s and 18.9 m/s, respectively. A wind-blown young cane takes periodic up-and-down motion when it is broken off. The mean motion frequency of young canes of the kiwifruit vines was found to be about 4.5Hz.

Key Words :   Kiwifruit cane, Temporal variation, Threshold wind speed, Wind damage

1. Introduction

Some direct mechanical effects of strong wind on plants include bending of branches, uprooting, and physical leaf damages arising from leaf tearing, stripping, and abrasion. (Cleugh et al., 1998). Plants respond in a variety of ways to these mechanical impacts. However, their main response is to change their growth rate for the whole plant or for some parts of the plant, to modify morphology, and finally, to reduce grain yields. Many responses of plants, from changes in plant morphology to lodging, depend less on the mean wind speed than the intermittent and turbulent features of the oncoming wind (Nobel, 1981; van Gardingen and Grace, 1991).

Strong winds lead to the burial of newly emerged crops, young seedlings being pulled out of the soil, or partial expose of the roots (Komlev, 1960; Woodruff et al., 1972). As the crop grows taller, the wind force can lodge the crop either by breaking its stems or by collapsing the roots.

Plants frequently exposed to strong wind have different anatomical and morphological characteristics such as increased leaf thickness, decreased leaf size, and decreased height (Nobel, 1981; Grace, 1988). This kind of morphological modification is a direct response to the mechanical stresses caused by violent plant motion such as shaking or stroking of branches, which reduces the extension growth (Neel and Harris, 1971; Jaffe, 1973; Rees and Grace, 1980; Grace et al., 1982). At high-speed wind, the allocation of assimilates is shifted from the production of leaf materials to the production of stems and roots, leading to the reduction of the leaf area (Grace, 1988). Russell and Grace (1978) mentioned that the tillering rate of grasses was markedly reduced at high-speed wind.

Among horticultural fruit crops, the kiwifruit (Actinidia deliciosa Planch.) is largely affected by wind, especially during the spring season. Because the tillering young canes of kiwifruit vines are very tender, the vegetative canes carrying next season's fruiting buds have been known to be broken at a gentle breeze of 8-12 m/s. The leaves of kiwifruit vines are easily torn or shed by wind due to their broad leaf size and shortage of elasticity. The wind-broken canes and torn leaves would delay the growth of kiwifruit vines and reduce the production yield of kiwifruits. Therefore, it is important

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to minimize wind damage to kiwifruits.

McAneney et al. (1984) evaluated the performance of windbreak and trellis on harvest of kiwifruits at two orchards. The wind damage of kiwifruits was increased with the increase in distance from windbreaks. The field evaluation was carried out for standard "T-bar" trellised vines during a particular windy season, and shelter spacing was selected to reduce wind speed adequately. McAneney and Judd (1987) explained the shelter strategies for kiwifruits based on wind damage measurements. As mentioned, most previous studies on physical wind damage to the kiwifruit have been focused on the performance of windbreaks.

As far as we have surveyed, there is no previous experimental study on the physical wind damage of kiwifruit canes in the fluid mechanical point of view. In this study, we measured the threshold wind speed at which the physical wind damage occurs for a total of 140 samples of kiwifruit canes. The effect of atmospheric boundary layer (ABL) configuration on the physical damage of kiwifruit canes was investigated using two different ABL configurations. In addition, the temporal variation of wind-blown kiwifruit canes was analyzed by capturing dynamic consecutive images with a high-speed camera.

2. Experimental Methods

The surface boundary layer is commonly formed as a consequence of interactions between the atmospheric wind and the underlying ground surface over time scales of one day or less. The present experiments were conducted in a closed-return type subsonic wind tunnel of which the test section is 6.75 mL×0.72 mW×0.6 mH in size. A toothed barrier (Cook, 1978) spanning the floor of the test section near was installed at the leading edge of the test section and a square section, biplanar wooden-type grid was followed across the entire test section to yield logarithmic velocity profiles over a significant portion of the test section. The turbulence stresses and power spectra were also tried to satisfy the prerequisites of the neutrally stable atmospheric boundary layers. In particular, in order to establish strong turbulence intensity for ABL type B, an artificial grass with height 10 mm and length 6 m was glued on the bottom surface of the test section. For comparison, the same experiment was repeated for ABL type A over the original wind tunnel test section surface without the upstream barrier, mixing grid, and artificial grass.

The mean velocity and turbulence intensity profiles of the simulated ABLs were measured using a hot-wire anemometer (TSI IFA-100) at the location of the experimental sample, 4.5 m downstream from the leading edge of the test section. For this, gold-coated X-wire probes (DANTEC 55P51) were used, and the effective cosine-law method was employed to calibrate the X-wire (Perry et al., 1987; Lim et al., 2007). At each measurement point, 16,300 velocity data were acquired at a sampling rate of 2-10 kHz after low-pass filtering at 800 Hz. The streamwise pressure gradient was nearly negligible due to the presence of corner fillets and small adjustable breathers located between the wind tunnel test section and the first diffuser.

The samples of kiwifruit canes tested in this study were grown following the standard cultural practices in open orchards, receiving full sunlight on the pergola system. Young canes of 25-35 cm in length, newly sprout from one-year old canes of kiwifruit vines, were collected in late April. Fig. 1(a) shows a typical test sample of a young kiwifruit cane with large-size leaves L
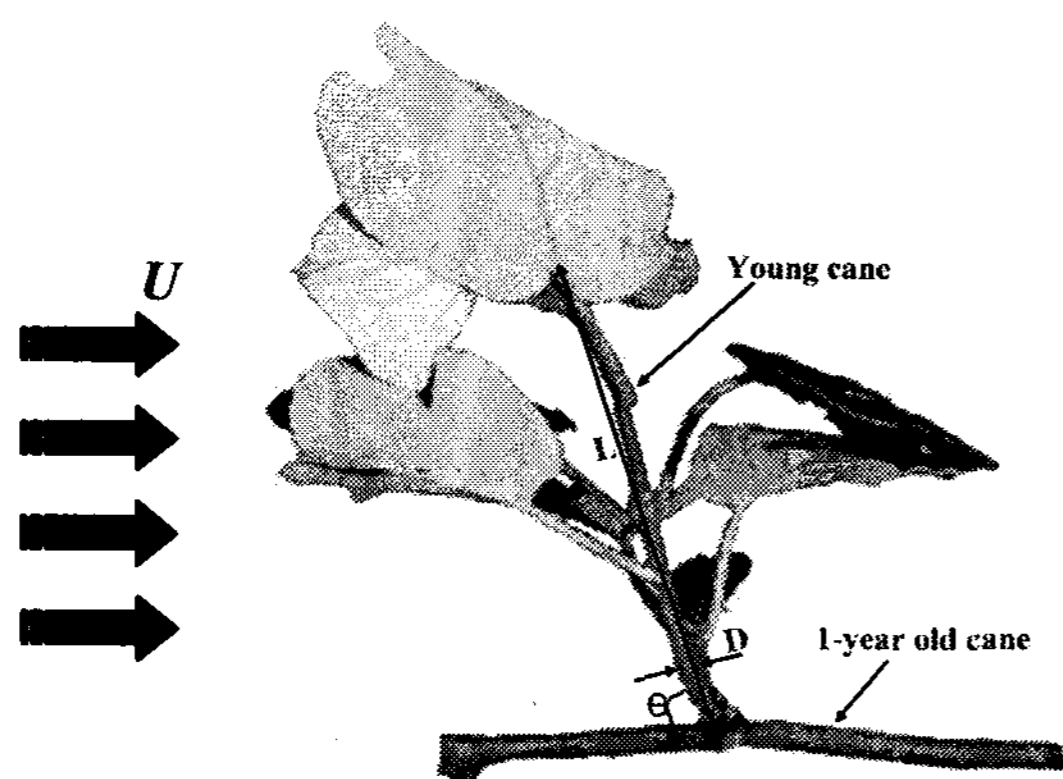
(a) Parameters of a young cane
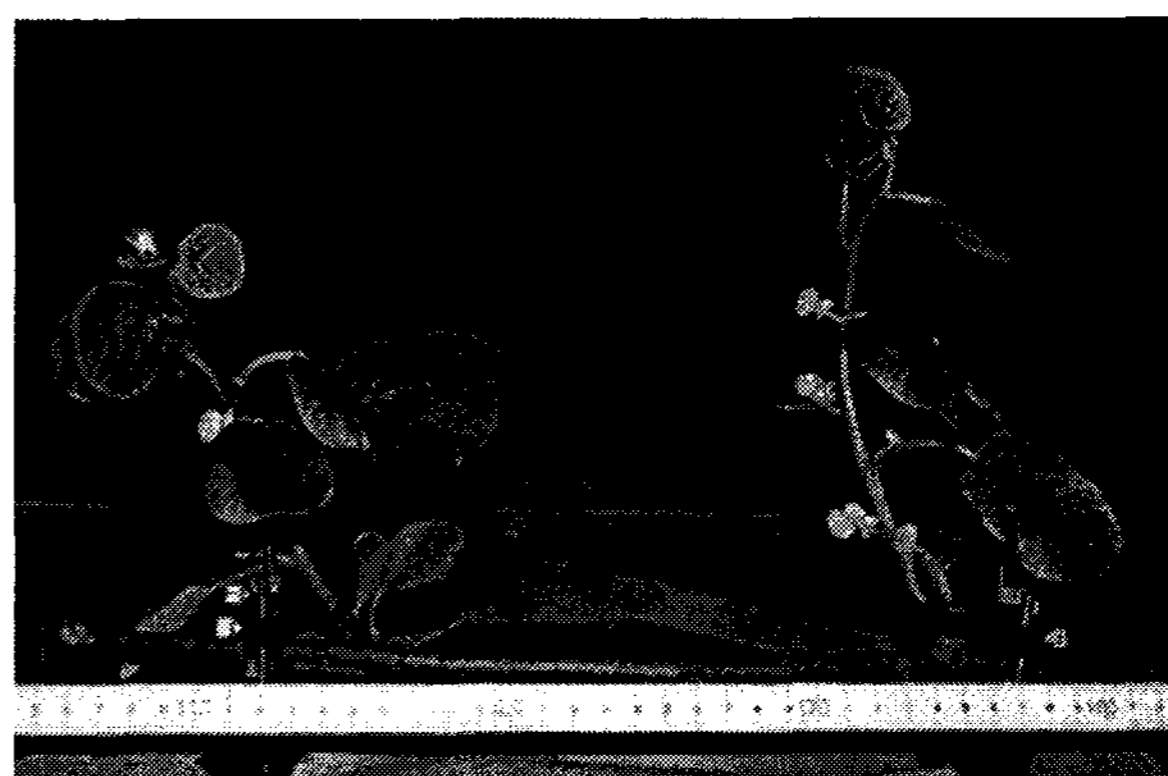
(b) Experimental set-up of samples

Fig. 1 Main parameters for a test sample and photograph of young kiwifruit canes installed at the wind tunnel test section

and D indicate the length and diameter of the young cane, respectively. Meanwhile, the symbol θ represent the curved angle between a young cane and a one-year old cane.

As shown in Fig. 1(b), the test sample of a young cane was placed horizontally inside the wind tunnel test section to simulate the real growth environment of a kiwifruit vine. To increase the wind load acting on the test sample, the windward side of the test sample was determined to have a curved angle θ of a young cane less than 90°. The test sample was fixed to the ground surface of the test section using holders which can adjust the height of the test sample easily.

To record the critical wind speed at which the test cane is just broken, the movement of the test cane was recorded using a digital video camera. In addition, to investigate the temporal variations of the wind-blown kiwifruit canes, the dynamic images were captured consecutively using a high-speed CMOS camera (Photron FASTCAM-APX) with a spatial resolution of 1024×1024 pixels at a frame rate of 2000 fps (frames per second).

3. Results and Discussion

To investigate the threshold wind speed, the instantaneous wind speed at which a young cane is broken off from the one-year old cane was recorded. Fig. 2 represents the threshold wind speed of the wind-broken canes for two ABL configurations. As shown in Fig. 2, the threshold wind speed is evenly distributed from 11 m/s to 27 m/s. In the range of 11-17 m/s, the effect of ABL configuration on wind-broken speed is not significant. About half of the 140 test samples were broken in the wind speed range of 18-22 m/s. In this range, the threshold wind speed at which young canes were broken has different values with respect to ABL
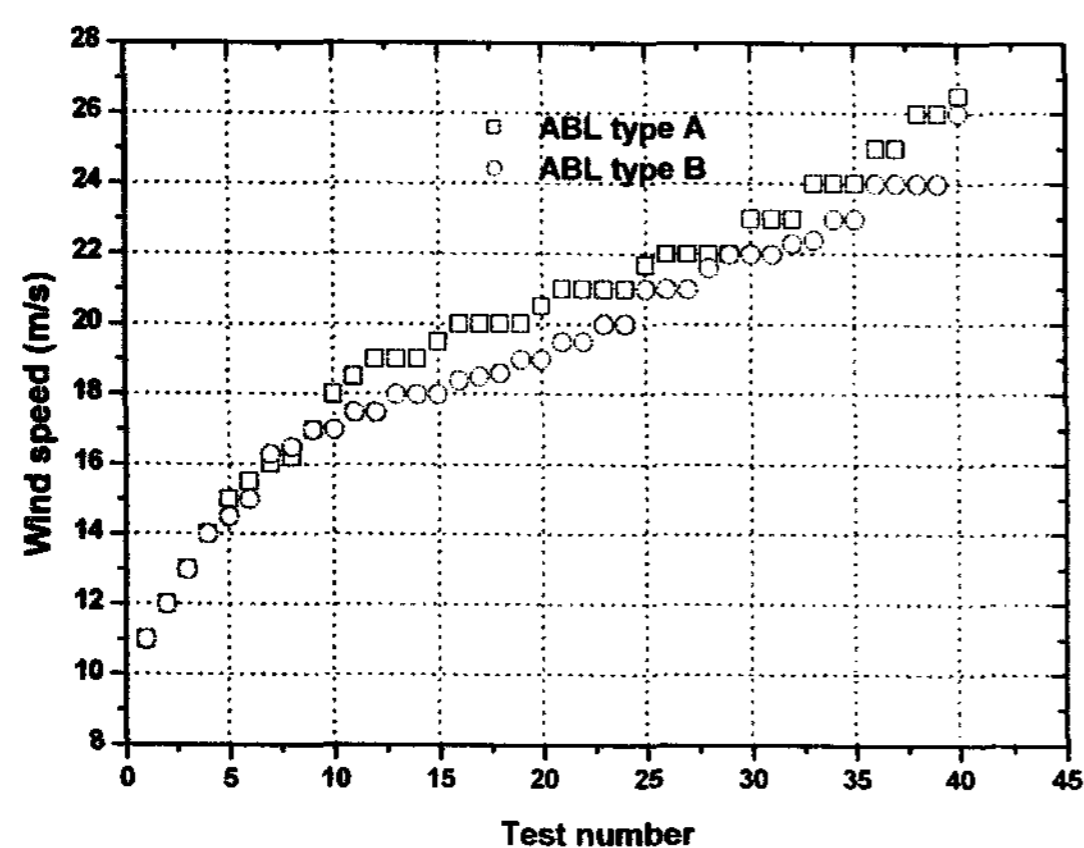
configuration. For the case of ABL type B, the young canes newly sprout were broken at 5-10% lower wind speed, compared to ABL type A. This is attributed to the fact that young canes with large-size leave sway more severely under a wind of strong turbulent velocity fluctuations. On average, the threshold wind speeds for the case of ABL types A and B are about 20.5 m/s and 18.9 m/s, respectively. These threshold wind speeds are similar to the previous results (16.7-29.6 m/s) of Vogel (1989) tested for other plants with broad leaves. From these results, we can see that the turbulent flow characteristics of the oncoming wind have a noticeable influence on the wind-broken physical damage of the young canes of kiwifruit vines.

The dynamic response of a wind-blown young cane for the oncoming ABL wind was captured using a high-speed camera at a frame rate of 2000 fps.

Vogel (1989) mentioned that broad leaves were reconfigured into a cone shape, and the cone angle became increasingly acute with the increase of wind speed. The wind-blown reconfiguration of unfold leaves into a cone shape seems to be caused by long petioles and bilaterally lobed or heart-shaped leaf configuration.

For the unbroken cane, large-scale affixed at the upper part of the young cane were wrapped together and reconfigured into a cone shape. With the lapse of time, the cone shape of the wrapped leaves around the young twig was maintained without noticeable fluctuations for a long time. Therefore, the young cane is almost locked and its motion frequency is nearly zero. Due to reconfiguration into a cone shape and mutual sheltering, the windward surface exposed to the wind is largely reduced. Therefore, the drag coefficient of the young cane is smaller even at a high wind speed as compared to that of wind-broken canes at a low speed. From these results, we can see that the wind load on unbroken young canes is small and the corresponding bending moment acting on the joint between the young cane and the one-year old cane is also consequently small.

However, for the case of wind-broken canes, even though each leaf was reconfigured into a cone shape, the nearby leaves did not wrap together around the young twig and flutter irregularly. In this case, the length of young canes used to be long, and the curved angle θ is relatively small. This kind of morphological features seem to prevent the wrapping of affixed leaves. The drag coefficient of the wind-broken cane would be much larger than that of unbroken canes, because the windward area of the young cane with fluttering leaves increases largely. The young cane deflected down by the wind was raised due to the lift force generated by the flutter of large leaves. Then it was deflected down again as the magnitude of drag force was increased more than the lift force. This up-and-down motion of the wind-broken cane
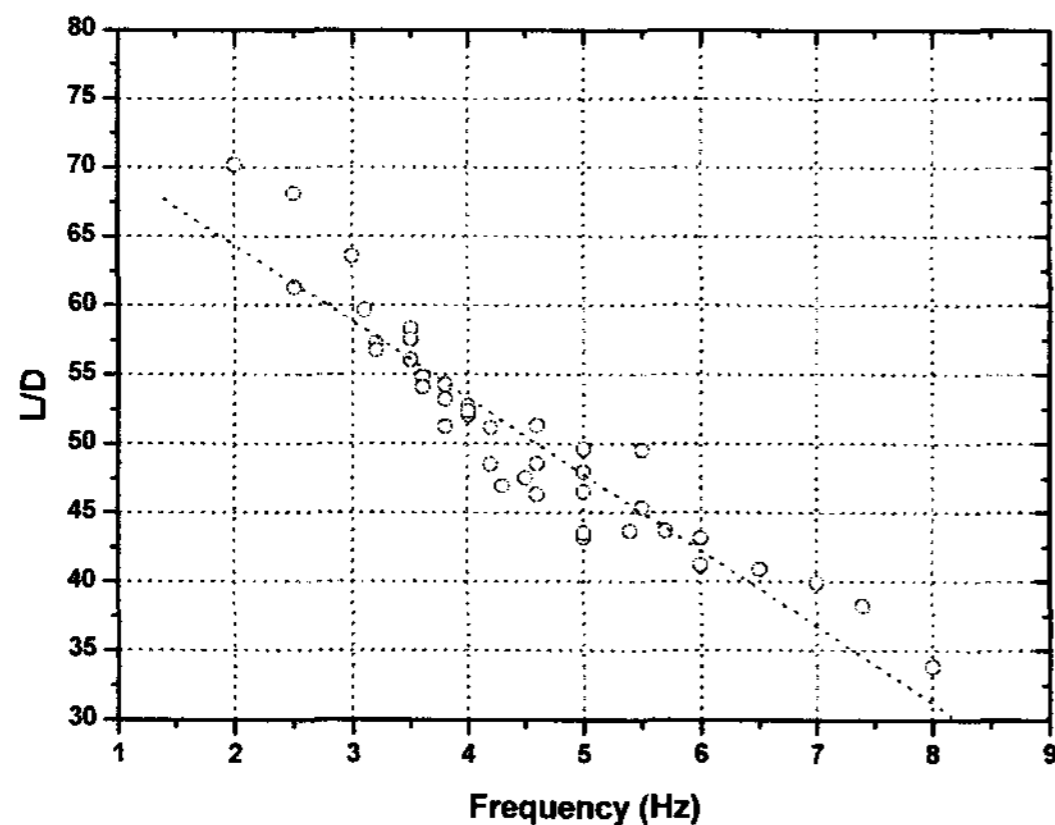

Fig. 2 Threshold wind speed of the wind-broken canes with respect to ABL configuration

Fig. 3 Fluttering frequency of wind-broken young canes as a function of L/D (ABL type B)

repeated periodically up to the instant of its falling apart from the one-year cane.

In order to investigate the morphological aspect of wind-broken young canes, we measured their fluttering frequency as functions of length (L), and diameter (D) of the wind-broken young canes under ABL condition of type B. As shown in Fig. 3, the critical L/D value of wind-broken young canes is in inverse proportion to the characteristic frequency of fluttering motion. The characteristic frequencies of the wind-broken young kiwifruit canes have a mean value of about 4.5Hz. The fatigue load due to this periodic up-and-down motion seems to make the young cane finally be broken by the wind. From these results, we can see that a young cane can be easily broken as the large-scale leaves affixed at the upper part are fluttered individually without wrapping altogether into a cone shape and it takes a periodic up-and-down fatigue motion.

4. Conclusion

Fluid mechanical characteristics of wind-blown young canes of kiwifruit vines were investigated through wind tunnel experiments.

The threshold wind speed at which a young cane was broken off was found to start at 11 m/s. About half of the tested 140 samples were broken in the wind speed range of 18-22 m/s. On average, the threshold wind speeds for ABL types A and B are about 20.5 m/s and 18.9 m/s, respectively. However, in the smaller wind speed range of 11-17 m/s, the ABL configuration does not show significant influence on the threshold wind speed.

For the unbroken-canes, as a section to the on-coming wind, large leaves affixed at the upper part of the young cane were wrapped together and reconfigured into a cone shape. The acute cone shape of the wrapped leaves around the young twig was maintained for a long time without noticeable fluttering motion. On the other hand, for the case of wind-broken canes, each leaf was

reconfigured into a cone shape. However, adjacent leaves did not wrap altogether around the twig and flutter independently in irregular pattern. In this case, the drag acting on the young cane would be much larger than that of unbroken-canes because the windward area of the young cane with fluttering large leaves increases. The wind-broken young canes show periodic up-and-down motion. The young cane was finally broken by the continued fatigue motion. The mean value of fluttering frequency of the wind-blown young canes was about 4.5Hz.

Acknowledgement

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