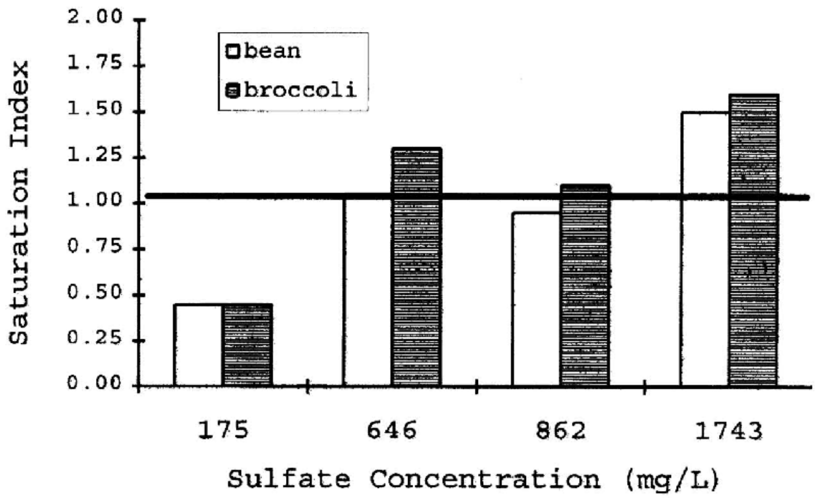

Fig. 3. MINTEQA2 calculated saturation index values for gypsum in saturation paste extracts from soil samples collected after treatment with sulfate containing irrigation water.

increased. Increasing concentrations of Ca and S in the soil suggests that gypsum saturation has been achieved in soils irrigated with waters containing >646 mg SO_4^{2-}/L. Results presented here suggest that bean and broccoli can be successfully grown in the short term using high-SO_4^{2-} waters for irrigation purposes. Further research is needed to determine the response of other vegetable crops to elevated levels of SO_4^{2-} in irrigation water and the long-term effects of using these waters on sulfate and salt accumulation in the soil.

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Critical Comparison of an Accelerometer and a Laser Doppler Vibrometer for Measuring Fruit Firmness

Noboru Muramatsu,[1] Naoki Sakurai,[2] Naoki Wada,[3] Ryoichi Yamamoto,[4] Keiichi Tanaka,[1] Toshikazu Asakura,[1] Yuko Ishikawa-Takano,[1] and Donald J. Nevins[5]

Additional index words. resonance frequency, phase shift, kiwifruit, Japanese pear, citrus, apple

Summary. To examine the feasibility of using a laser Doppler vibrometer (LDV) for fruit quality evaluation, measurements of firmness derived by this method were compared with those acquired using a contact accelerometer. Apples (*Malus pumila* Miller var. Domestica Schneider 'Fuji'), kiwifruit [*Actinidia deliciosa* (A. Chev.) Liang et Ferguson, 'Hayward'], Japanese pear [*Pyrus pyrifolia* (Burm. f.) Nakai var. Rehd. 'Nijusseiki'], and Hassaku (*Citrus hassaku* Hort. ex Tanaka) were used. Fruit were subjected to sine waves at frequencies from 5 to 2000 Hz at the

[1]Department of Breeding, National Institute of Fruit Tree Science, Ministry of Agriculture Forestry and Fisheries, Tsukuba 305, Japan.

[2]Environmental Studies, Faculty of Integrated Arts and Science, Hiroshima University, Kagamiyama, Higashi-Hiroshima 739, Japan.

[3]Research and Development Laboratory, Mastushita-Kotobuki Electric Industries Ltd., Saijo 793, Japan.

[4]Laboratory of Biology, Tezukayama College, Nara 631, Japan.

[5]Department of Vegetable Crops, University of California, Davis, CA 95616.

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basal surface, and the vibrations resulting from these transmissions were precisely monitored at the upper surface with a LDV monitor. Measurements on all of the tested single fruit exhibited a distinct phase shift in the applied sine wave and in the resonance frequency, dependent on frequency used. These shifts were also detected by an accelerometer, but in this case the range of frequency was restricted to an upper limit of 400 Hz for kiwifruit and 800 Hz for Japanese pear and Hassaku. Efforts to extend the range using a greater vibrational mass with the accelerometer resulted in anomalous tissue behavior, most likely due to excessive compression when the weight exceeded 1 g. Hence firmness measurements of fruit depended on the phase shift and resonance frequency, which were achieved with more precision by LDV than accelerometer. Since LDV measurements of fruit firmness were made without directly contacting the fruit surface, it could be potentially used for on-line quality evaluation and fruit sorting.

When quantifying consumer expectations for safe and high-quality food, it is imperative that the relevant characteristics of fruit are identified and monitored during harvest and the postharvest period. Since firmness, together with color and fruit size, represent important quality criteria, many methods have been suggested for measuring these physical properties of fruit nondestructively. Shumlevich et al. (1996) listed methods by which firmness could be measured under four headings: 1) detection of fruit responses when exposed to forced vibrations, 2) detection of responses to mechanical or sonic impulse, 3) impact force analysis, and 4) evaluation of the rate of dissipation of ultrasonic sound. In most of these methods, an accelerometer was used to transform the tissue vibrations on surface of the fruit to a detectable signal (Abbott et al., 1992; Finney, 1970).

In current attempts to apply a laser Doppler vibrometer (LDV) for this purpose the Doppler shift is determined as a means of perceiving a movement in mass. The frequency of a light wave reflected from an irradiated surface is altered in response to the degree of movement of the target surface. Thus, the vibrational motion of an object can be monitored by LDV without touching the surface. This method was shown to be effective for vibrational analysis of biological materials in situ such as tree leaves (Martens, 1990) and tympanic membranes of insects (Michelsen and Larsen, 1978), but this approach has not been evaluated for determining properties of large objects. We suggested that fruit surface vibration is a functional tissue texture.

In this study LDV analysis was compared with that of an accelerometer for measuring fruit firmness. Both approaches take advantage of the analysis of an imposed vibration. The objectives of this research were to 1) assess the validity of both types of sensors for measuring the firmness of several kinds of fruits, 2) check the relative sensitivity of both sensors, and 3) investigate the consequences of having a given mass placed directly on a sample fruit, especially with regard to the effect additional mass would have on vibrational measurements.

Materials and methods

PLANT MATERIALS. Apples, kiwifruit, Japanese pears, and Hassaku were subjected to firmness measurement. Hassaku is a pummelo x mandarin hybrid, representative of medium to large citrus (9 to 10 cm in diameter). Apples and kiwifruit were obtained from Ishikawa Agricultural College and Grape and Persimmon Research Center, National Institute of Fruit Tree Science, Hiroshima, respectively. Japanese pears and Hassaku were purchased at the local market. Apples and kiwifruit were stored under 5 °C before being subjected to the measurement. To eliminate the effect of differences in fruit weight on measurement, the approximately equal fruit weights were selected with the same fruit species. Four fruit were used in each of four replications in this study. The comparison between LDV and accelerometer was made by *t* test at 0.05.

REMOTE SENSING OF FRUIT FIRMNESS. Two types of sensors—an LDV (LV-1300; ONO SOKKI Co. Ltd, Yokohama, Japan) and an accelerometer (NP-3110; ONO SOKKI Co. Ltd., mass = 5.1 g)—were compared in this studies. Fruit were placed on a stage of a vibration generator (model 512A; EMIC Co. Ltd., Tokyo) with a small amount of soft clay installed directly between the vibrator and sample to ensure vibrational transmission. A vibration generator served as the source of a sine waves imposed on the fruit through a frequency range of from 5 to 2000 Hz. The vibration transmitted through the sample was detected at the top surface of the fruit surface by the LDV or the accelerometer and analyzed by fast Fourier transformation (FFT) (CF-360; ONO SOKKI Co. Ltd.). The actual signal from top fruit surface was displayed on the FFT screen monitor and the phase shift between the input and output signal

Table 1. Phase shift at four frequencies as measured by a laser Dopplar vibrometer (LDV) and an accelerometer.

		Phase shift (-deg)			
		Imposed frequency (Hz)			
Species	Measurement method	400	800	1200	1600
Fuji apple	LDV	375.1[z]	464.8	643.2	836.9
	Accelerometer	376.2[NS]	575.7*	778.4*	980.6*
Hayward kiwifruit	LDV	392.3	763.0	1112.3	1322.4
	Accelerometer	526.3*	ND[y]	ND	ND
Nijusseiki pear	LDV	402.2	688.7	942.0	1266.6
	Accelerometer	508.7*	842.6*	ND	ND
Citrus hassaku	LDV	397.5	742.9	1066.1	1402.3
	Accelerometer	490.0*	894.3*	ND	ND

[z]The data are the mean of four replications.
[y]ND = not detected.
[NS],*Nonsignificant or significant by *t* test at $P \leq 0.05$, respectively.

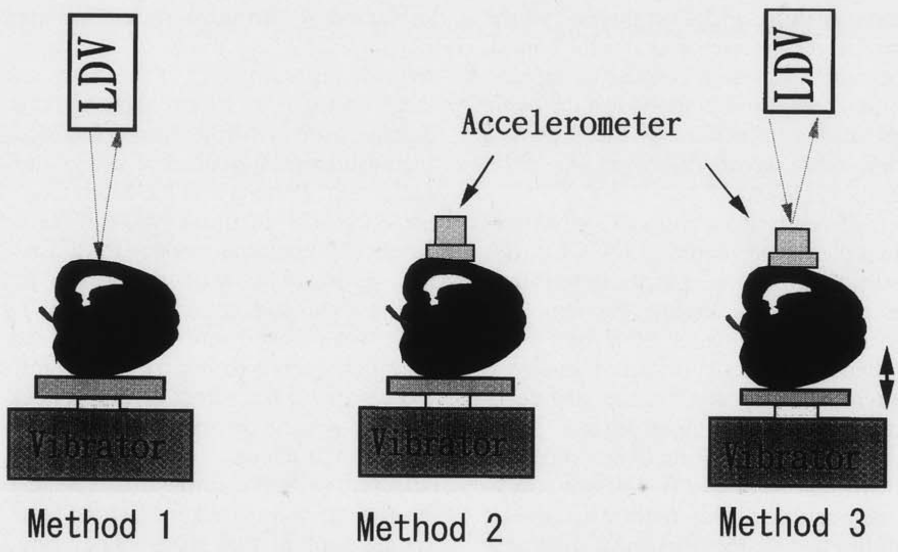

Fig. 1. Schematic representation of three methods used in vibration measurements. Method 1, the vibration of fruit surface was directly measured by the laser Doppler vibrometer (LDV) ; method 2, the vibration of fruit surface was measured by an accelerometer; method 3, the fruit vibration was determined by LDV at the head of the accelerometer

was determined. The phase shift at 400, 800, 1200, and 1600 Hz was determined as well as the amplitude of vibration in order to measure the resonance frequency. Abbott et al. (1992) had previously revealed that the correlation coefficient between resonance frequency and firmness of fruit was significantly high. Moreover, we showed that the phase shift increased as the function of fruit maturation (Muramatsu et al., 1996). Thus, the phase shift and resonance frequency are suitable parameters for estimation of fruit maturation.

Since the LDV and accelerometer measure velocity and acceleration, respectively, the LDV values were differentiated to transform values of acceleration, hence the output of both sensors were adjusted for comparison in the same physical unit.

Results and discussion

When subjected to frequencies from 5 to 2000 Hz, the vibrational motion at the top surface of all fruit tested could be directly monitored by LDV and phase shift can be determined at imposed vibrations up to 1600 Hz (Table 1). Over this same range of frequencies, we found that measurements determined with the accelerometer exhibited a distinct decrease in sensitivity due to vibrational motion as a function of increasing input frequency. The one exception was with apple, where reliable measurements could be achieved up to 1600 Hz. For most fruit tested, the phase shift determinations based on accelerometer responses were restricted to frequencies <400 Hz in kiwifruit and <800 Hz in Hassaku and Japanese pear. The actual values in phase shift measured directly by LDV and by an accelerometer were different for all the frequencies imposed, and all of the fruit tested yielded different values for each of two methods of assessment. More consistency in the values was observed at lower frequencies but, as the imposed vibrational frequency increased, the differences in the values increasingly deviated when the two sensor systems were compared.

In an attempt to account for discrepancies in the phase shift, the following experiment was conducted with three apples (Fig. 1). The vibration at the fruit surface was measured by the LDV (method 1) and by the accelerometer (method 2) and, in addition, the vibration at the head of the accelerometer was measured by the LDV (method 3) in a tandem arrangement. The same apples were used in all methods. We found that the measured phase shifts were nearly the same with methods 2 and 3 at all frequencies, and the extent of the shift was always smaller when measured by method 1 than with methods 2 and 3 (Table 2). The data clearly show that the physical presence of the accelerometer at the surface altered the vibration behavior of fruit and lowered the value of phase shift.

To investigate the influence of the accelerometer mass on fruit vibration, a range of weights were placed on four apples and the vibration at the head of the weight was monitored by the LDV. The phase shift was substantially altered by the presence of weight >1 g (Fig. 2). The differences increased proportionally as a function of frequency.

The impact of load on the amplitude of perceived vibration was also measured under the same conditions and found to decrease when the applied external load was more than 5 g (Fig. 3). This raises questions concerning the reliability of second resonance values with this configuration, since the mass of the accelerometer itself was 5.1 g and, hence, exceeded the limits that were found to adversely affect fruit vibration. The weight of the accelerometer tended to restrict free vibration of fruit. Therefore, the results of experiments preclude the use of an accelerometer unless there is a minimum inherent load in monitoring fruit, especially if phase shifts are to be detected. We recognize that the second resonance frequencies that were previously reported to reflect apple firmness (Abbott et al., 1992) might

Table 2. Phase shift by alternative methods of vibration measurement of apples.

Measurement method	Phase shift (-deg) Imposed frequency (Hz) 400	800	1200	1600
1[z]	376.2	485.8 b[y]	672.5 b	853.3 b
2[x]	386.0	603.5 a	806.2 a	1016.4 a
3[w]	384.3	605.0 a	809.8 a	1014.9 a
Significance	NS	*	*	*

[z]On the surface of the sample by the laser Doppler vibrometer.
[y]Mean separation in columns by *t* test at $P < 0.05$ (n = 3).
[x]On the surface of the sample by the accelerometer.
[w]On the top of the accelerometer by the laser Doppler vibrometer.
[NS,*]Nonsignificant or significant by *t* test at $P \leq 0.05$, respectively.

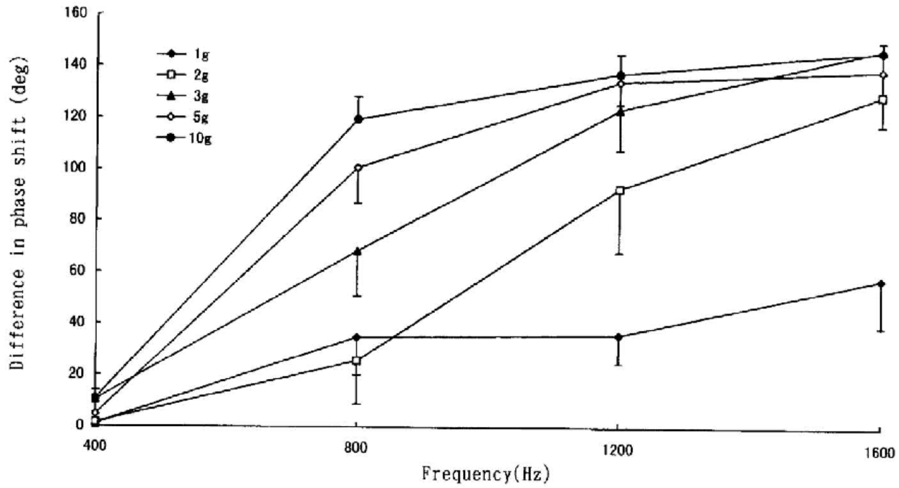

Fig. 2. Changes in the phase shift at four different frequencies in response to added weight. The data show the extent of differences in phase shift between free vibration and vibration restricted by applied weight. Data are mean value ±SE of the four replications.

be expected to be affected by a heavy accelerometer (>5 g). Since Abbott et al. (1992) used an accelerometer with a mass of 0.5 g for measuring the apple firmness, their measurements were vindicated as an accurate reflection of the second resonance frequency.

The sensitivity and capability of LDV and accelerometer detection were also compared using Hassaku (Fig. 4). As shown in Table 1, the vibration did not transmit well through Hassaku. At imposed vibrations >800 Hz, we found that the accelerometer could not clearly monitor fruit behavior (method 2). But when the LDV was used to monitor the vibration at the head of the accelerometer, measurements were extended up to 1600 Hz (method 3). These data indicated that the vibrations of 800 to 1600 Hz could not be monitored because of the low sensitively of the accelerometer, although the vibration traveled to the head of the accelerometer. The data support the observation that sensitivity and reliability of vibration measurements were improved with the LDV when directly compared with values derived with an accelerometer.

Clearly, to suppress the anomaly exerted by mass on fruit vibration, a light accelerometer (one with a mass <1 g) is required for assessing fruit firmness. The LDV not only detects the amplitude of vibration, but it also senses the phase shift and resonance frequency at least as accurately as an accelerometer without actually having contact with the fruit surface. This ap-

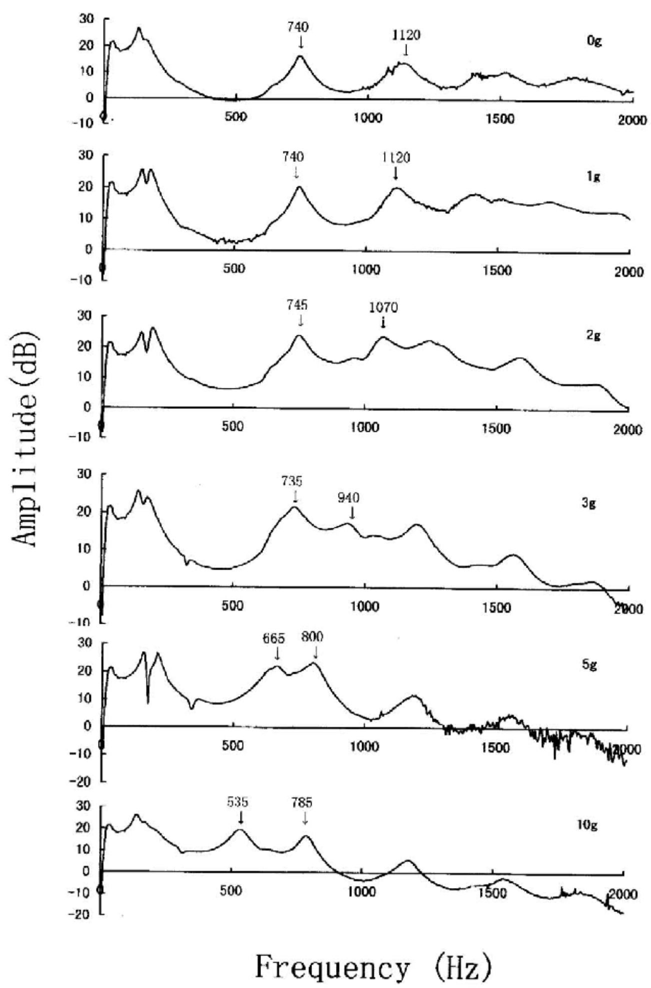

Fig. 3. Representative example of changes in resonance frequency (Hz) affected by the various weights of 0 to 10 g applied to the top of the fruit. The arrows indicate the resonance peak and frequency, respectively.

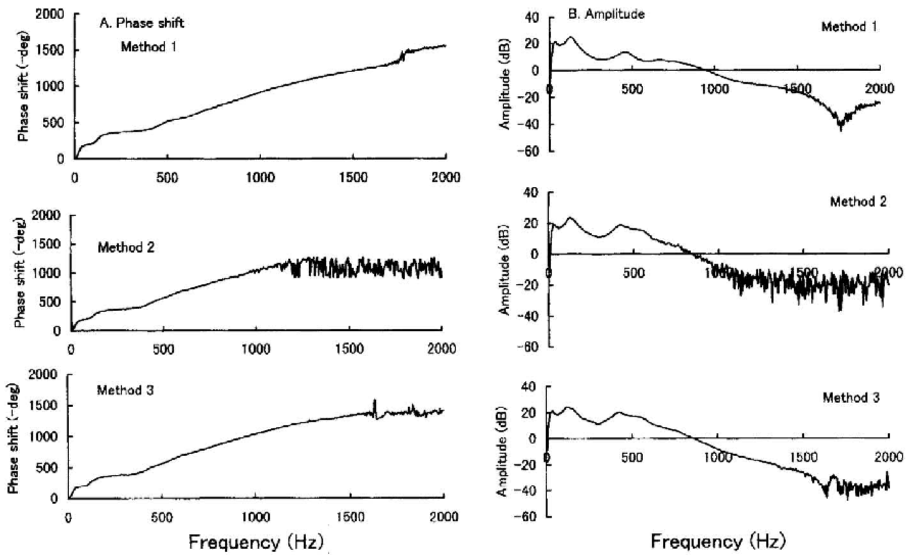

Fig. 4. Representative example of sensitivity comparison and the range of resonance in laser Dopplar vibrometer (LDV) and accelerometer. Hassaku was subjected to the measurement of two parameters—(A) phase shift, (B) amplitude)—that were related to the firmness. See Fig. 1 legend for details concerning the method of the measurement.

proach involving the LDV has a higher sensitivity and is less intrusive than an accelerometer. Because of these features, the LDV has advantages over an accelerometer for detecting fruit firmness, and it could potentially lead to online quality evaluation and fruit sorting.

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Consumers Prefer Red Poinsettia Cultivars

Bridget K. Behe,[1]
Paul B. Redman,[2] and
John M. Dole[3]

ADDITIONAL INDEX WORDS. survey, floral

SUMMARY. Consumer flower-color preferences are of interest to market researchers, plant producers, and retailers because this information can help them to anticipate accurately the sales product mix. Our objective was to determine consumer bract-color preferences for 47 poinsettia (*Euphorbia pulcherrima* Willd. ex Klotzsch) cultivars. Visitors (124) to the Franklin Park Conservatory in Columbus, Ohio, rated 'Sonora', a red cultivar, highest (4.6 of 5.0) of any cultivar. Nine of ten highest rated cultivars were red. We compared the ratings of poinsettia buyers with those of nonpoinsettia buyers and found only one difference: nonpoinsettia buyers rated 'Jingle Bells III', a marble cultivar, higher (4.3) than poinsettia buyers (3.8). We also compared consumers who had purchased a red poinsettia to those who had purchased nonred colors and found that red poinsettia buyers rated 'Sonora' higher (4.9) than nonred poinsettia buyers (4.5). Men rated 'Red Elegance' higher (3.7) than women (3.3), whereas women rated 'Freedom White' higher (3.1) than men (2.4). We found few differences

Alabama Agricultural Experiment Station and the Auburn University Department of Horticulture, Auburn University, Alabama 36849-5408.

Alabama Agricultural Experiment Station journal no. 11-965747. We thank Laura Tucker, Dept. of Discrete and Mathematical Science, Auburn University, for her statistical assistance, and the Central Ohio Flower Growers Association for providing all of the poinsettias in the display.

[1]Associate professor, Department of Horticulture, Plant and Soil Sciences Building, Michigan State University, East Lansing, MI 48824.

[2]Executive director, Franklin Park Conservatory and Botanical Garden, 1777 East Broad Street, Columbus, OH 43203.

[3]Associate professor, Department of Horticulture and Landscape Architecture, Oklahoma State University, Stillwater, OK 74078.

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