VIBRATION PROPERTIES OF PEARS

M. S. Kim[*], H. M. Jung[*], I. K. Park[*], and J. M. Park[†]

[*] Departments of Agricultural Machinery Engineering
Chungnam National University
Daejeon 305-764, Korea

[†]Department of Mechanical Engineering
Miryang National University
Miryang 627-130, Korea

ABSTRACT

Instrumentation and technologies are described for determining the vibration response characteristics of the pear with frequency range 5 to 320Hz. The computer program for controlling the vibration exciter and the function generator and for measuring the vibration response characteristics of the pear was developed. Mechanical properties such bioyield deformation, rupture deformation and apparent elastic modulus etc. were compared with the vibration response characteristics of the pear. The resonant frequency of the pear ranged from 53 to 102Hz and the amplitude at resonance was between 1.08 and 2.48g-rms. The resonant frequency and amplitude at resonance decreased with the increase of the sample mass, and they were slightly affected by mechanical properties such as bioyield deformation and rupture deformation. Regression analysis was performed among the relatively high correlated parameters from the results of correlation coefficient analysis.

Key words : Fruit, Pear, Vibration, Resonant frequency

INTRODUCTION

Fruits are subjected to complex dynamic stresses in the transportation environment. During a long journey form the production area to markets, there is always some degree of vibration present. Vibration inputs are transmitted from the vehicle through the packaging to the fruit. Inside, these cause sustained bouncing of fruits against each other and container wall. These steady state vibration input may cause serious fruit injury, and this damage is particularly severe whenever the fruit inside the package is free to bounce, and is vibrated at it's resonant frequency. The determination of the resonant frequencies of the fruit may help the packaging designer to determine the proper packaging system providing adequate protection for the fruit, and to understand the complex interaction between the components of fruit when they relate to expected transportation vibration inputs.

Most of the earlier researches(Abbott et al, 1968; Finney and Norris, 1968; Finney, 1970; Clark and Shackelford, 1973; Stephenson et al, 1973; Cook and Rand, 1973; Clark and Rao, 1978) of the vibration properties of fruits and vegetables have been focused on the evaluation of firmness and ripeness.

Abbott et al (1968), Finney and Norris (1968) and Finney (1970) have reported on the vibration properties of flesh specimens and whole intact fruits. Their efforts have been directed toward the establishment of instrumentation for studying the vibration properties of fruits and vegetables.

During vibration tests, the frequency response characteristics of the vibration exciter, methods for mounting fruit on the vibration exciter, vibration detector and exciter-fruit-detector configurations are important. Finney (1972) pointed out that the exciter should have sufficient capacity in terms of both its force rating and its acceleration capability, and that the frequency response of the exciter should be reasonably flat.

Among many techniques for mounting fruit on the vibration exciter having been explored, the method that a circular metal cap attached directly to the moving element of the exciter with floral clay coupling medium between the fruit and the vibration fixture, has proven to be good for laboratory experiment. However, Yong and Bilanski (1973) suggested that the fruit was allowed to rest freely on the surface of vibrating table instead of mounting the fruit on floral clay as Finney (1970) and Stephenson (1973) did. Their rational for this method was that small oscillations were associated with small displacements about some equilibrium position, and in the vibration of the intact fruit, the small displacement referred to the displacement of its center of mass under its own weight when at rest on the table.

Many techniques have been used to measure the amplitude of vibration for food and agricultural materials. Abott et al (1968), Finney and Norris (1968), and Stephenson et al(1973) used phonograph pickups as vibration detector, and some other researchers used an optical method employing a light source, slit and phototube, and the electrical signal generated in a set of earphone in contact with the vibration fruit. But in recent years, the piezoelectric accelerometer has been widely used for vibration measurement.

The measured response of fruits to vibration is influenced not only by the characteristic of the exciter and detector, but also by the orientation of the fruit on the exciter and the position of the detector on the fruit. Finney (1970) and Yong and Bilanski (1979) reported that locating the detector on the top surface of a fruit with the stem-calyx axis in a horizontal plane was suitable for detecting resonant frequency of fruits.

As more mechanization in fruit distribution system is introduced, the recent interest in the distribution chain between the grower and the consumer has been directed toward the development of techniques for reducing the damage of fruits in the transportation environments.

O'Brien et al (1965) found that in simulated test acceleration levels were positively correlated with position in a column stack of containers. They observed that the natural frequency of pears was inversely proportional to fruit column height and that for pear depths of about 60cm to 30cm the natural frequency was 30Hz to 50Hz, respectively.

Peleg and Hinga (1968) conducted the simulation experiment of vibration damage in containers and unit loads of produce. They reported that the highest acceleration levels were encountered in the bottom tier containers, and that the low frequency end of the spectrum was significantly amplified in the top tier containers, especially then the column were strapped down.

Slaughter et al (1993) reported that pallet loads of Bartlett pears were most susceptible to vibration damage at frequencies below 40Hz. Peleg (1985) reported that the container stack has to be so designed that the resonant frequency of the container stack cannot coincide with the resonant frequency of the fruits and vegetables to reduce damage. Hinsch et al (1993) observed that the top box of pears loaded on the rear pallet exhibited about three times the power spectral density level of the bottom box during the cross-country tests in refrigerated trailers. Slaughter et al(1998) reported that the skin of Bartlett pears can be severely discolored when vibrated at acceleration levels slightly above 0.7 g-rms for periods as short as 30 min.

Most of the research thus far has been focused on the quality evaluation of the fruits and vegetables and the vibration damage in transit, but researches need to be conducted on the resonant frequency of fruit itself, which would greatly aid in designing the proper packaging system.

The objective of this study was to determine the resonant frequency of the pear and to investigate the relationship between resonant frequency and physical, mechanical properties of the pear such as mass, volume, bioyield deformation, rupture deformation and apparent elastic modulus etc.

MATHERIALS AND METHODS

Materials

The tested pear was Niitaka cultiva. The pears used in this study were harvested in the Youseong pear farm at the October 1998. The fruit was stored approximately three months in the cold storage facility with the condition of an air temperature 1°C and relative humidity 90%. Thirty-six pears were selected to ensure that the various size of the pear was included in this study. The pears were allowed to stabilize at experimental room temperature(15°C, rh 55%) before tests were conducted.

Experimental apparatus and methods

The vibration exciter was a PET-05-A type(IMV Co.) with sine peak force 49N(5kgf) and a frequency range from 2 to 20,000Hz. Two types of vibration detector were used in this study. One was a miniature piezoelectric accelerometer(2G) having a frequency range from 0 to 400Hz, which was attached to the top of the pear with a double-faced adhesive tape. The other one was an accelerometer(20G) having a frequency range from 0 to 650Hz, which was attached to the specimen-mounting device for detecting frequency response characteristics of the vibration exciter. The specimen-mounting device was made of Aluminium with its weight of 152grams. The input acceleration to exciter was fixed at 0.5g-rms for considering transportation environments(Peleg and Hinga, 1986; O'Brien et al. 1965). The intact pear with stem-calyx axis in a horizontal plane was placed on the specimen-mounting device with a double-faced adhesive tape(Finney and Norris, 1968; Finney, 1970). Function generator(HP-33120A) was connected by wire to the vibration exciter for controlling the input acceleration at a preset constant level and the constant sweep rate. Schematic diagram and general view of the vibration test apparatus are shown in Figs.1 and 2. Specification of the vibration test apparatus is shown in Table 1.

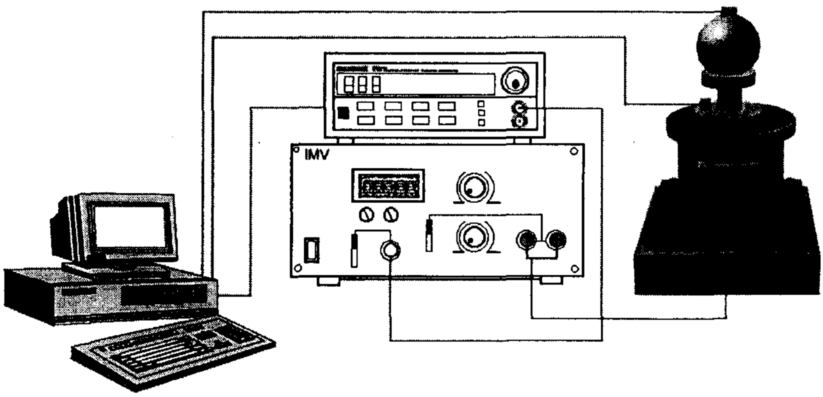


Fig.1. Schematic diagram of the vibration test apparatus.

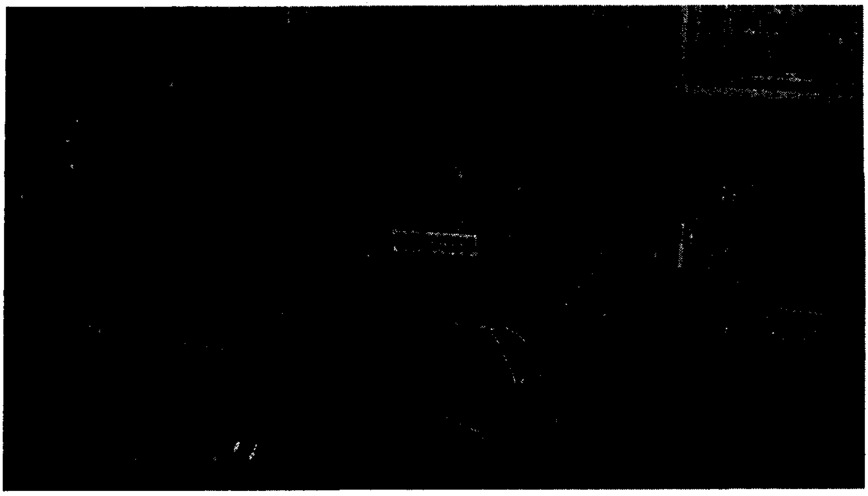


Fig.2. General view of the vibration test apparatus.

Table 1. Specification of the vibration test apparatus

Items	Specification	Remarks
Vibration shaker	49N(5kg), 326m/s^2 (33G)	IMV (PET-05-A)
Oscillator-Amplifier	2~20000Hz	IMV (PET-05-A)
Function Generator	10mHz~15MHz(Frequency sweep)	HP-33120A
Accelerometer	0~400Hz, 0~600Hz	KYOWA
Strain gage measurement board	12bits, 7kHz	ADAC 5508BG
HP-IB card	355KB/s	HP

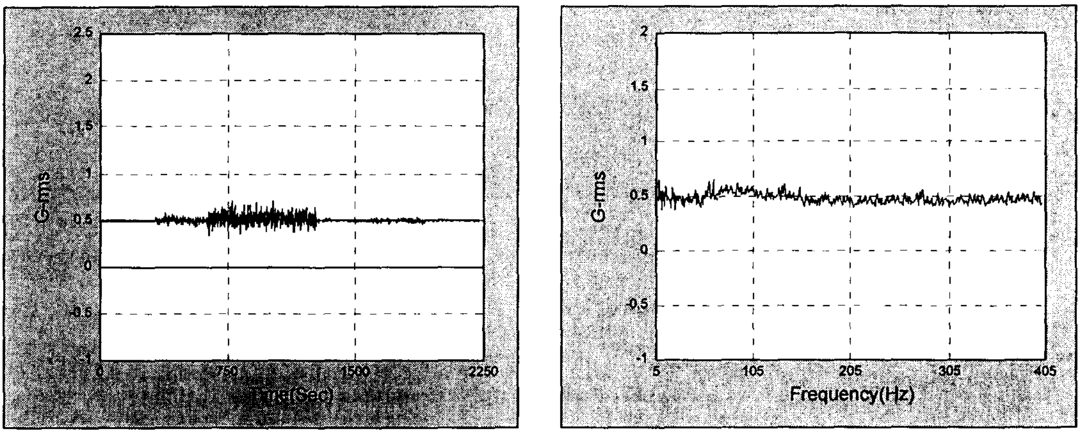
Sinusoidal vibration sweep tests of pears were conducted with the frequency range 5 to 320Hz, and at the logarithmic sweep rate of 0.2 octaves/min. The computer program for controlling the vibration exciter and the function generator and for measuring the vibration response characteristics of the pear was developed with Microsoft Visual Basic(5.0) programming language. The vibration response signals were passed through the low pass filter, and sampled by the A/D converter, and processed by the FFT algorithm, which was implemented on the microcomputer. The resonant frequencies and the corresponding amplitudes(g-rms) of the pear analyzed form the graphical display processed by the FFT algorithm and graphic program. In order to investigate the relationship between vibration and physical, mechanical properties of the pear, such as bioyield deformation, rupture deformation, and apparent elastic modulus etc were measured by the same method reported by Kim et al (1999).

RESULTS AND DISCUSSION

Vibration response characteristics of the vibration exciter and resonant frequency

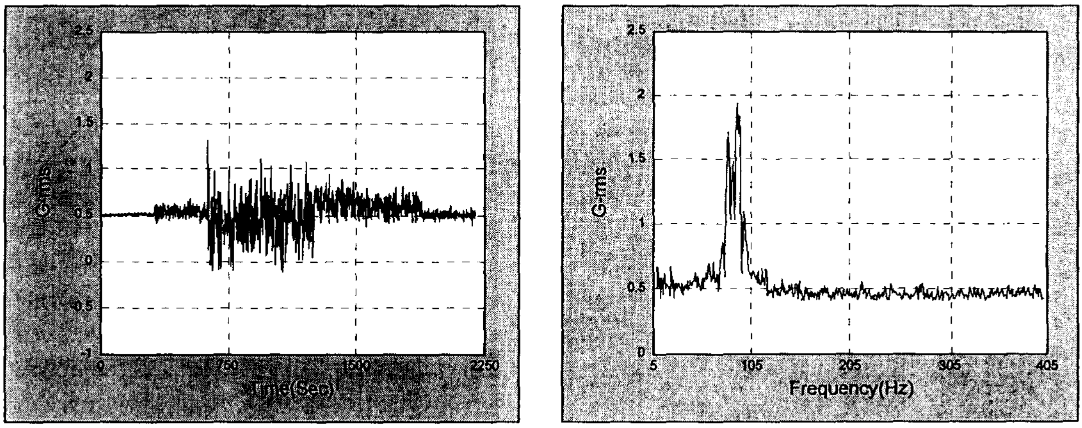
During vibration tests, a vibration response characteristics of the vibration exciter are important. Fig.3 shows the vibration response characteristics of the vibration exciter when the pear was not placed on the vibration exciter. It was found that the input acceleration(0.5g-rms) was nearly constant during 35min(2100sec) as shown in Fig.3.(a), and the frequency response of the exciter had not major resonance as shown in Fig.3(b) within the frequency range that was swept at a continuous logarithmic rate of 0.2 octaves/min from 5 to 320 Hz.

The resonant frequencies and amplitudes for each sample were detected from the miniature accelerometer was attached to the top of the pear with the double-faced adhesive tape while the input acceleration of 0.5g-rms was applied to the exciter, and the frequencies were swept logarithmically from 5 to 320Hz. The typical vibration response curve for 0.5499kg of the pear is shown in Fig.4.



(a) Time domain (b) Frequency domain

Fig.3. Vibration response characteristics of the vibration exciter without the pear.



(a) Time domain (b) Frequency domain

Fig.4. Typical vibration response curve for 0.5499 kg of the pear.

The average resonant frequencies and amplitudes of vibration for the samples at different mass are shown in Table 2. It was observed that resonant frequencies and amplitude at resonance decreased with the increase of the sample mass. This agrees well with the results of Finney(1970) that resonant frequencies of fruits were highly correlated with mass of the fruit. As shown in Table 2, the resonant frequency of the pear varied from 64.50 to 72.17Hz and the amplitude varied from 1.78 to 2.21g-rms by the sample mass.

Table 2. Average resonant frequency and g-rms for different mass of the pear

Mass of pear(kg)	g-rms	Resonant frequency(Hz)
0.35 ~ 0.44	2.21	72.17
0.45 ~ 0.53	2.05	71.08
0.54 ~ 0.70	1.78	64.50

Correlation between vibration response characteristics and mechanical properties

Correlation coefficients between the vibration response characteristics and physical, mechanical properties of the pear are shown in Table 3. Pear size, expressed as either pear mass or pear volume was highly correlated to the amplitude at resonance, and also correlated fairly well to the resonant frequency. Correlation coefficients for bioyield deformation(BD) vs. g-rms and rupture deformation(RD) vs. g-rms were 0.6025, 0.6927, respectively. It was found that the bioyield and rupture deformation also correlated with the resonant frequency of the pears and the correlation coefficients were shown a little lower than with g-rms. The other parameters such as the bioyield point, rupture point, and the apparent elastic modulus were not correlated well to the resonant frequency and g-rms

Table 3. Correlation coefficients of selected parameters for vibration and mechanical test of the pear

	MA	VO	G-rms	RF	BP	BD	RP	RD	E
MA	1.0000								
VO	0.9662	1.0000							
G-rms	[redacted]	[redacted]	1.0000						
RF	[redacted]	[redacted]	0.6394	1.0000					
BP	-0.2514	-0.3096	0.2480	0.1766	1.0000				
BD	-0.6667	-0.6676	[redacted]	[redacted]	0.6187	1.0000			
RP	-0.1791	-0.2535	0.1520	0.1035	0.7283	0.4084	1.0000		
RD	-0.6748	-0.7021	[redacted]	[redacted]	0.3243	0.7597	0.1789	1.0000	
E	0.1561	0.1256	0.0903	0.0674	0.1620	-0.3386	0.0784	-0.2620	1.0000

Note : MA = Mass of the pear(kg) VO = Volume of the pear($10^{-4}m^3$) RF = Resonant Frequency(Hz)
BP = Bioyield Point(N) BD = Bioyield Deformation(mm) RP = Rupture Point(N)
RD = Rupture Deformation(mm) E= Apparent Elastic Modulus(kPa)

Relationship between vibration response characteristics and physical and mechanical properties

A regression analysis was performed among the relatively high correlated parameters being studied in order to investigate the relationship among the parameters. Figs. 5 and 6 show the regression between the resonant frequency and the mass and volume of the pear, respectively. It was observed that the resonant frequencies of the pear were decreased curvilinearly with the increase of mass and volume of the fruit, indicating that resonant frequency occurred at a low frequency band for the higher mass of fruits.

The amplitude at resonance was also decreased almost linearly with the increase of mass and volume of the pear as shown in Figs. 7 and 8. The coefficients of determination(R^2) for these relations were 0.8915 for mass and 0.8604 for volume, relatively higher than for other relationships among parameters. This indicated that the amplitude at resonance for the fruits could be roughly estimated by measuring the mass and volume of the fruits.

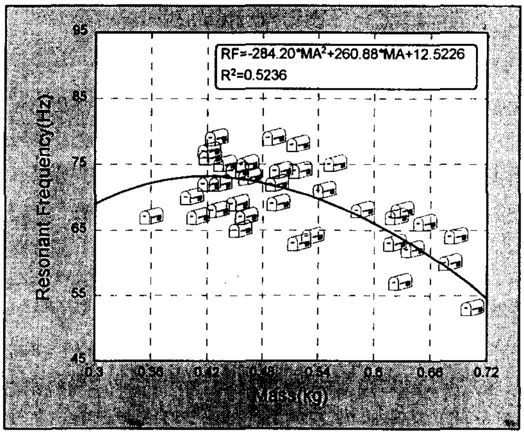


Fig. 5. Resonant frequency versus mass of the pear.

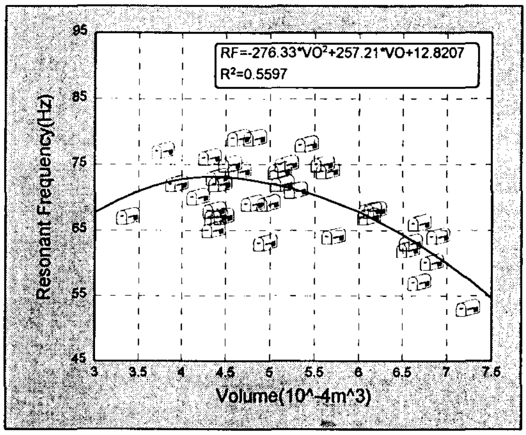


Fig. 6. Resonant frequency versus volume of the pear.

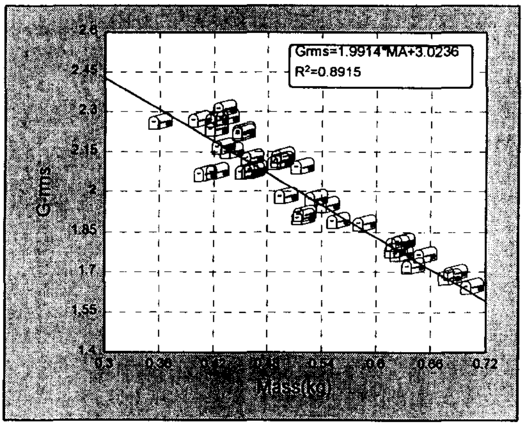


Fig. 7. G-rms versus mass of the pear.

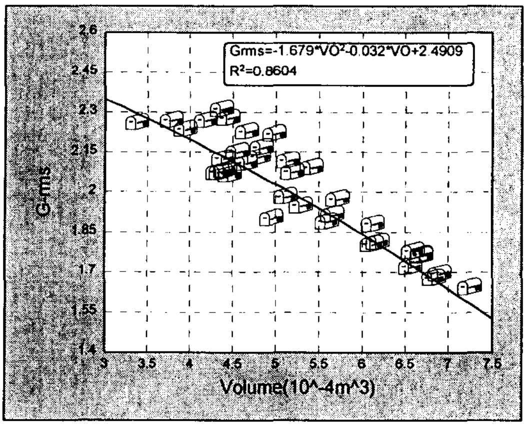


Fig. 8. G-rms versus volume of the pear.

As shown in Table 3, the correlation coefficients between the resonant frequency and its amplitude and the mechanical properties of the pear were shown a relatively very low value except the bioyield deformation and the rupture deformation. A possible explanation is that the frequency range applied to this study was limited below 400Hz in order to determine the resonant frequency of the pear. If the applied frequency range was widen up to several thounsand Hz, a relatively higher value of the correlation coefficient would be obtained.

Bioyield deformation was increased curvilinearly with the increase of the resonant frequency and its amplitude but their coefficients of determination were very low as shown in Figs. 9 and 10. It was also found that there was almost the same tendency as bioyield deformation at the rupture deformation. In Figs. 9 to 12, it can be seen that the resonant frequency and its amplitude could not provide close predictions of the mechanical properties such as bioyield deformation and rupture deformation by reason of the explanation above.

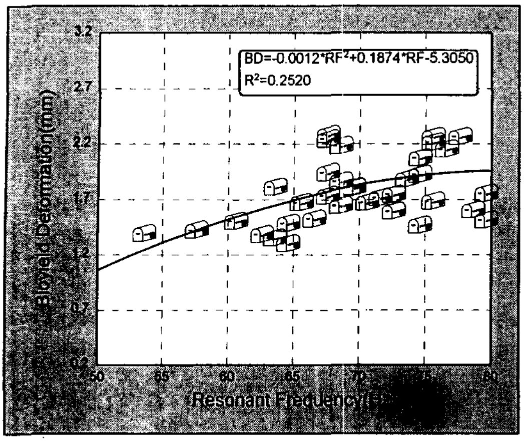


Fig. 9. Bioyield deformation versus resonant frequency for the pear.

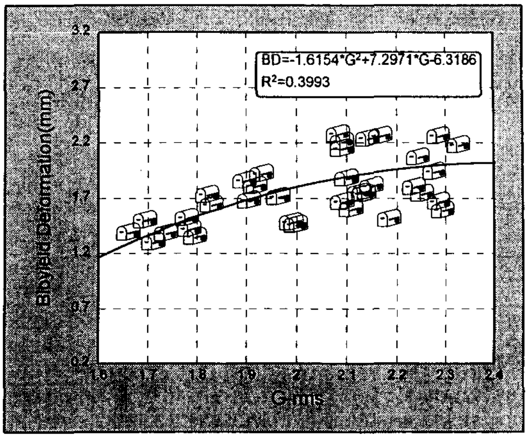


Fig. 10. Bioyield deformation versus G-rms for the pear.

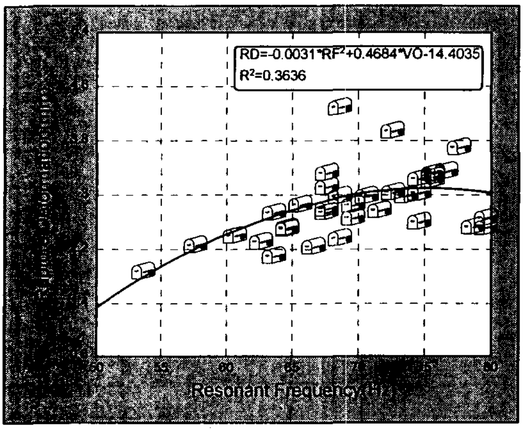


Fig. 11. Rupture deformation versus resonant frequency for the pear.

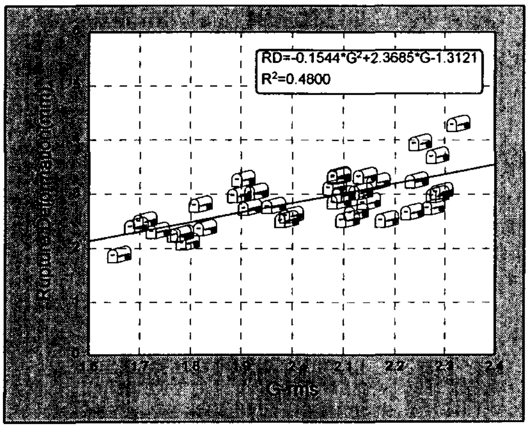


Fig. 12. Rupture deformation versus G-rms for the pear.

It is well known that the average acceleration amplitudes and the vibration frequency which cause significant bruising during transport by trucks are 0.5g-rms and below 40Hz(Peleg, 1985 ; Slaughter etal, 1993). Results obtained in this study revealed that the resonant frequency of the pear were farther away from the frequency range of transport vehicle which was usually encountered over smooth road. However, when transporting fruits over rough road, it is desirable that resonant vibration will not occur between the fruit and the truck bed to reduce vibration damaged fruit.

CONCLUSIONS

Vibration tests were performed to determine vibration properties of the pear, and to investigate the relationship between vibration and mechanical properties of the pear. Niitaka pears were used in the experiments.

The vibration exciter was a PET-05-05A type with sine peak force 49N(5kgf) and a frequency range from 2 to 20,000Hz. The vibration detector was a miniature piezoelectric accelerometer having a frequency range from 5 to 400Hz. The input acceleration to exciter was fixed at 0.5g-rms for considering transportation environments. Sinusoidal vibration sweep tests of pears were conducted with the frequency range from 5 to 320Hz, and at the logarithmic sweep rate of 0.2 octave/min. Function generator(HP-33120A) was connected by wire to the exciter for controlling the input acceleration at a preset constant level and the constant sweep rate. The mechanical properties of the specimen removed from each pear were measured by using UTM after vibration tests. The computer program for controlling the vibration exciter and the function generator and for measuring the vibration characteristics of the pear was developed.

The resonant frequency of the pear ranged from 53 to 102Hz and the amplitude at resonance was between 1.08 and 2.48g-rms. G(rms) value was linearly correlated with resonant frequency of the pear. Resonant frequency of the pear decreased curvilinearly with the increase of size of the fruit. There was a tendency that resonant frequency and G value of the pear were slightly affected by mechanical properties such as bioyield deformation and rupture deformation.

The resonant frequencies of the pear from the results of this study were farther away from the frequency range of transport truck, which was usually encountered over smooth road. However, when transporting fruits over rough road, it is desirable that packaging system has to be so designed that resonant frequency will not occur between the fruit and the truck bed to reduce vibration damaged fruit.

REFERENCES

Abbott, J. A. et al. 1968. Sonic techniques for measuring texture of fruits and vegetables. Food Technology: 22(5): 101-112.

Chesson, J. H. and M. O'Brien. 1971. Analysis of mechanical vibration of fruits during transportation. Transactions of the ASAE 14(2): 222-224.

Clark, R. C. and V. N. M. Rao. 1978. Dynamic testing of flesh peach texture. Transactions of the ASAE 21(4): 777-781.

Clark. R. L. and P. S. Shackelford. 1973. Resonance and optical properties of peaches as related to flesh firmness. Transactions of the ASAE 16(6): 1140-1142.

Finney, E. E. 1970. Mechanical resonance within Red Delicious apples and its relation to fruit texture. Transactions of the ASAE 13(2): 177-180.

Finney. E. E. and K. H. Norris. 1968. Instrumentation for investigating dynamic mechanical properties of fruits and vegetables. Transactions of the ASAE 11(1): 94-97.

Hinsch, R. T., D. C. Slaughter, W. L. Craig, and J. F. Thompson. 1993. Vibration of flesh fruits and vegetables during refrigerated truck transport. Transactions of the ASAE 36(4): 1039-1042.

Kim, M. S., H. M. Jung, J. M. Park, and Y. H. Lee. 1999. Mechanical properties of apple and pear. J. of the Korean Society for Agricultural Machinery 24(3): 243-252.

O'Brien, M., J. P. Gentry, and R. C. Gibson. 1965. Vibrating characteristics of fruits as related to in-transit injury. Transactions of the ASAE 8(2): 241-243.

Peleg, K. 1985. Produce handling packaging and distribution(Book). AVI.

Peleg, K. and S. Hinga. 1986. Simulation of vibration damage in produce transportation. Transactions of the ASAE 29(2): 633-641.

Slaughter, D. C., J. F. Thompson. and R. T. Hinsch. 1998. Packaging Bartlett pears in polyethylene film bags to reduce vibration injury in transit. Transactions of the ASAE 41(1): 107-114.

Slaughter, D. C., R. T. Hinsch, and J. F. Thompson. 1993. Assessment of vibration injury to Bartlett pears. Transactions of the ASAE 36(4): 1043-1047

Stephenson, K. G., R. K. Byler, and M. A. Wittman. 1973. Vibrational response properties as sorting criteria for tomatoes. Transactions of the ASAE 16(2): 258-260, 265.

Yong, Y. C. and W. K. Bilanski. 1979. Modes of vibration of spheroids at the first and second resonant frequencies. Transactions of the ASAE 22(6): 1463-1466