Characteristics of Ultrasonic Propagation of the Fruit and Vegetables

Y. H. Lee, M. S. Kim*, Y. K Cho, D. S. Choi*
National Agricultural Mechanization Institute
RDA, Suweon 441-100, Korea
* Department of Agricultural Machinery Engineering
Chungnam National University
Daejeon 305-764, Korea

ABSTRACT

A fundamental study was conducted to obtain the basic data involved in nondestructive quality evaluation of the fruit and vegetables. An experimental equipment for ultrasonic propagation characteristics of the fruit and vegetables such as radish, carrot, potato, and apple was set up and also power spectrum analysis system of an ultrasonic wave through the fruit and vegetables was set up. The velocity and attenuation of ultrasonic wave through the tissue specimens from the fruit and vegetables were measured and analyzed. The elastic modulus and density by the mechanical method currently used were compared with those using by ultrasonic method.

The ultrasonic transit time was almost linearly increased with the length of the specimens and attenuation of ultrasonic was mainly affected by the internal fibrous structure of the products. The regression equation was derived from the highly correlated experimental variables.

Key Words : Ultrasonic velocity, Attenuation, Fruit, Vegetables

Introduction

Recently nondestructive quality evaluation techniques of the fruit and vegetables are growing up with concern about the evaluation of the agricultural products because destructive methods need a lot of time and which have difficulty of sampling, also we are not able to sale which were destructed. In order to develop the techniques for nondestructive quality evaluation of the fruit and vegetables using ultrasonic method, the characteristic of ultrasonic propagation of these products has to be discovered.

The velocity and attenuation of ultrasonic propagation are most important factors among acoustic parameters to evaluate the products quality using ultrasonics. Because there is a great difference in the velocity and attenuation through the internal mediums of the products, many researchers investigated the relationship between ultrasonic velocity and attenuation and physical property of agricultural products.

Garret and Furry(1972) measured the Young's ratio, density, Poisson's ratio of apple to use the acoustic velocity. Clark(1975) tried to investigate the relationship between the hardness of watermelon and velocity which have close relation.

Mizarch(1989) tested ultrasonic propagation velocity and attenuation of the apple, potato and cucumber using ultrasonic frequency of 50kHz. He reported that propagation velocity of apple was slower than potato because the tissue of apple has less fibrous materials than potato.

The physical properties of agricultural products were changed according to cultivation condition and environment of storage. Therefore, the short time analysis of ultrasonic signal is important to find the characteristics of reaction in the internal property of the fruit and vegetables.

The objectives of this study were to measure and analyze the characteristics of ultrasonic propagation for the fruit and vegetables, and to investigate the relationships among the experimental variables such as ultrasonic velocity through the products, peak frequency and magnitude of ultrasonic wave, moisture and desity of the products, and elastic modulus of the products by ultrasonic method and by mechanical method.

Material and Methods

Material

Sample fruit and vegetables were selected from cultivar of apple, radish, carrot and potato. These products have homogeneous internal tissue to take specimens without difficulty and which were not exceed three or four days after harvest. The physical characteristics of products are shown in Table 1.

Cylindrical specimens of diameter 17.6mm and length from 5mm to 40mm, at regular 5mm interval, were removed from the location perpendicular to the core using a standard cork bore. The grease was applied for close adhesion between sensor and specimens.

Experimental apparatus and method

A schematics and block diagram of ultrasonic test apparatus and measuring systems are show in Fig. 1. This testing apparatus consisted of ultrasonic sensor driver, digital oscilloscope and computer which equipped with DSP board for analyzing the frequency and ultrasonic spectrum. The specifications of the experimental equipment are tabulated in Table 2.

Sample weight in this study was measured by electronic scale with 0.01g accuracy. Moisture content of samples was measured after samples were dried for 35 hours at 80℃. The elastic modulus was calculated by measuring compression load and deformation length using UTM(Universal Testing Machine) at loading rate of 25mm/min(ASAE standard s368.1). The ultrasonic propagation time and attenuation measurement carried out using two sensors of 54kHz which one was transmitter and the other receiver. The elastic modulus by ultrasonic was calculated by Equation(1)

$$E = \frac{\rho C^2 (1 + \mu)(1 - 2\mu)}{(1 - \mu)} \quad \text{------------------------} \quad (1)$$

where, C = ultrasonic velocity, m/s

E = elastic modulus by ultrasonic, MPa

μ = Poisson's ratio

ρ = density of specimens, kg/m^3

The ultrasonic attenuations(Eq. 2) were determined from the difference between input voltage of transmitter and output voltage of receiver by acoustic energy which transit through the specimens.

$$a * d = 20 \log\left(\frac{A_0}{A_d}\right) \quad \text{--------------------------} \quad (2)$$

where, A_d = output voltage at thickness d, mV

A_o = input voltage, mV

a = attenuation coefficient, Np/m

d = thickness of specimens, m

Result and Discussion

Propagation time of ultrasonic

The results of ultrasonic transit time with the length of the specimens were shown Fig. 2, and ultrasonic velocity through the fruit and vegetables is given in Table 3. In this results we can find that ultrasonic velocity at any length may not be different because ultrasonic transit time was almost linearly increased as shown Fig. 2. Ultrasonic velocity of products except the potato was slower than acoustic velocity in the air at normal temperature. Ultrasonic velocity of apple was the slowest among the samples. Ultrasonic velocity of the potato was faster than other products. The reason was considered to be the internal space of cell tissue of potato is very small comparing with the other products.

Characteristic of ultrasonic attenuation

Ultrasonic attenuation through the fruit and vegetable samples at different sample length was shown Fig. 3. The attenuation coefficients for the tested samples were 0.92dB/mm for the radish, 0.93dB/mm for the carrot, 0.28dB/mm for the potato and 0.43dB/mm for the apple.

Specially attenuation coefficient of potato which density was the highest among the samples was low to compare with others. In this results we can estimate that attenuation coefficient of products which have a lot of fabric tissue was comparatively high because the ultrasonic wave was absorbed or scattered by fibrous tissue of products when ultrasonic transit through these products.

Correlation coefficients among the experimental variables

The correlation coefficients among the experimental variables of the fruit and vegetables were given in Table 4. Correlation among the experimental variables of radish except the magnitude was high when the correlation coefficient of the experimental variables more than 0.6 were considered. Magnitude, ultrasonic velocity and elastic modulus by ultrasonic method of potato were highly correlated. But, apple's correlations among the experimental variables except the magnitude and peak frequency were not high.

Spectrum analysis of samples

In the analysis of correlation coefficient among the experimental variables, to compare the relatively higher correlated variables, peak frequency of radish increased as density increased and at higher density part of the sample, the first, second, and third peak frequency could be clearly founded respectively. Fig. 5 showed the comparison of the ultrasonic spectrum analysis according to lower and upper parts of the radish. Peak frequency location was taken place at any where at almost the same frequency range. The shape of spectrum, however, was different and the magnitude has a big difference. This result estimated from density variation resulted from different part of the sample.

Conclusion

1. The ultrasonic transit time was almost linearly increased with the length of the specimens, and the ultrasonic velocities through the fruit and vegetables were 599.4m/s for the potato, 290m/s for the carrot, 220.6m/s for the radish and 145.2m/s for the apple.

2. Attenuation of ultrasonic waves through the fruit and vegetables were mainly affected by the fibrous structure of the samples, the attenuation coefficients for the tested samples were 0.92dB/mm for the radish, 0.93dB/mm for the carrot, 0.28dB/mm for the potato and 0.43dB/mm for the apple.

3. The correlation coefficient among the experimental variables such as moisture content, density, ultrasonic velocity, elastic modulus measured by UTM, elastic modulus using ultrasonic method, and peak frequency and magnitude from ultrasonic wave spectrum analysis were calculated, and the regression equations among the variables highly

correlated were derived.

4. The peak frequency and the magnitude from ultrasonic wave spectrum analysis showed a difference along density variation of the fruit and vegetables.

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Table 1. Physical characteristics of materials used in this study

Produces	Volume (m^3)	Weight (kg)	Dia(m)		Length (m)	True density(kg/m^3)
			Major	Minor		
Radish	0.04426 (0.0052)	0.3878 (0.054)	0.074 (0.005)	0.0508 (0.0038)	0.1407 (0.0065)	85.96 (6.4)
Carrot	0.0236 (0.00413)	0.2049 (0.037)	0.052 (0.0036)	0.033 (0.0082)	0.15 (0.022)	85.06 (10.22)
Potato	0.0145 (0.0019)	0.1414 (0.0174)	0.063 (0.0026)	0.048 (0.0034)	-	97.25 (7.4)
Apple	0.0514 (0.0062)	0.4 (0.03)	0.1 (0.0037)	0.084 (0.0046)	-	77.157 (8.58)

※Note: ( ) STD

Table 2. Specifications of ultrasonic test apparatus and measuring system

Items	Specifications	Remarks
Ultrasonic generator	· Transits time range : 0.1~9999 μ sec · Accuracy : ±0.1 μ sec	Model : PUNDIT C.N.S(LTD)
DSP board	· 50MHz AT&T DSP32C · Sample rate : 12-bit, 400Khz	Ariel(co)
Computer	· IBM 486-66MHz · Hard disk : 540Mb · ROM : 8Mb	
Digital oscilloscope	· 40MHz · Sensitivity:5mV/DIV~5V/DIV	Hueng hang Model :5804

Table 3. Ultrasonic velocity of the fruit and vegetables

Produces	Density(kg/m^3)	Velocity(m/sec)	STD(m/sec)
Radish	85.96	220.6	12.9
Carrot	85.06	290.1	12.5
Potato	97.25	599.4	41.6
Apple	77.16	145.2	7.24

Table 4. Correlation coefficients among the experimental variables of the fruit and vegetables

Products		Experimental variables						
		DY	VE	MC	EM	PF	MG	EU
Radish	DY	1.0000						
	VE	0.8927	1.0000					
	MC	0.9742	0.8406	1.0000				
	EM	0.7583	0.7668	0.6988	1.0000			
	PF	0.7317	0.7689	0.7231	0.3877	1.0000		
	MG	0.5816	0.4472	0.4934	0.2394	0.5227	1.0000	
	EU	0.8905	0.9918	0.8314	0.7690	0.7256	0.4223	1.0000
Carrot	DY	1.0000						
	VE	0.5908	1.0000					
	MC	0.1492	0.4248	1.0000				
	EM	0.6676	0.7848	0.1754	1.0000			
	PF	0.1417	0.3188	0.3183	0.1844	1.0000		
	MG	0.2133	0.2142	-.2616	0.0637	0.6455	1.0000	
	EU	0.7627	0.9713	0.3872	0.7763	0.2933	0.2319	1.0000
Potato	DY	1.0000						
	VE	-.0499	1.0000					
	MC	-.2656	0.3268	1.0000				
	EM	0.1378	-.0278	-.1698	1.0000			
	PF	-1920	0.4027	0.2356	0.1140	1.0000		
	MG	-.0609	-.6207	-.3552	0.3481	0.1380	1.0000	
	EU	0.0718	0.9826	0 .3514	-.0089	0.3780	-.6119	1.0000
Apple	DY	1.0000						
	VE	-0.6748	1.0000					
	MC	0.3999	-.2616	1.0000				
	EM	0.5540	0.4544	0.3080	1.0000			
	PF	0.2590	0.1758	0.1422	0.5028	1.0000		
	MG	0.1235	0.1621	-.1058	-0.6210	0.9086	1.0000	
	EU	0.2308	0.6855	-.5102	0.0545	0.0395	0.0870	1.0000

Note : DY = density(kg/m³)
VE = ultrasonic velocity(m/s)
MC = moisture content(%, w.b)
EM = modulus of elesticity by UTM(MPa)
PF = peak frequency of spectra analysis(kHz)
MG = magnitude of spectra analysis(dimensionless)
EU = elastic modulus by ultrasonic velocity(MPa)

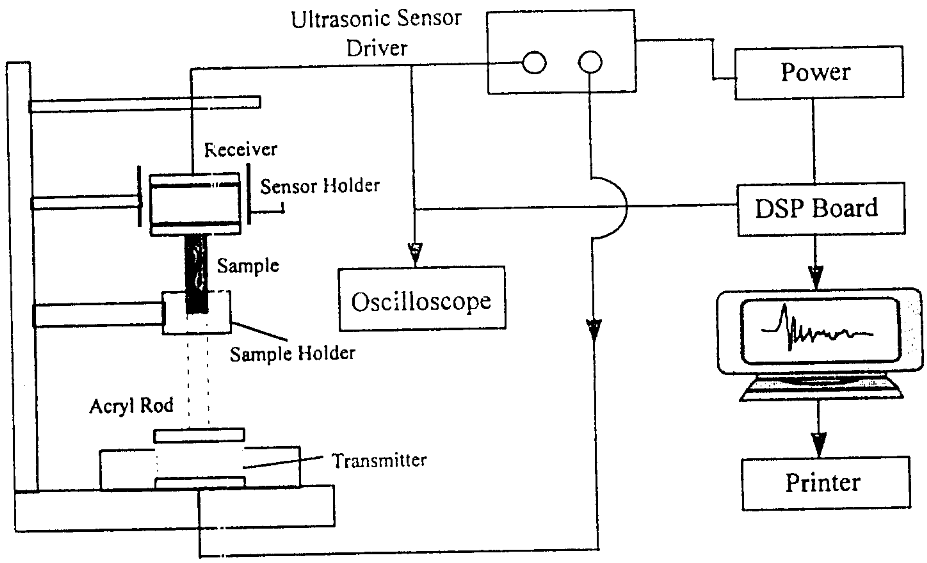

Fig 1. The schematic and block diagram of ultrasonic test apparatus and measuring system

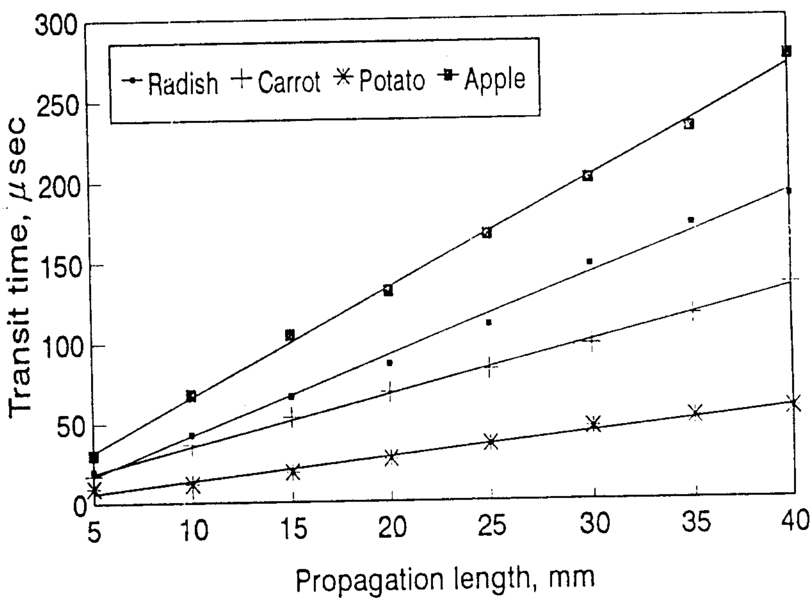

Fig 2. Ultrasonic transit time by the propagation

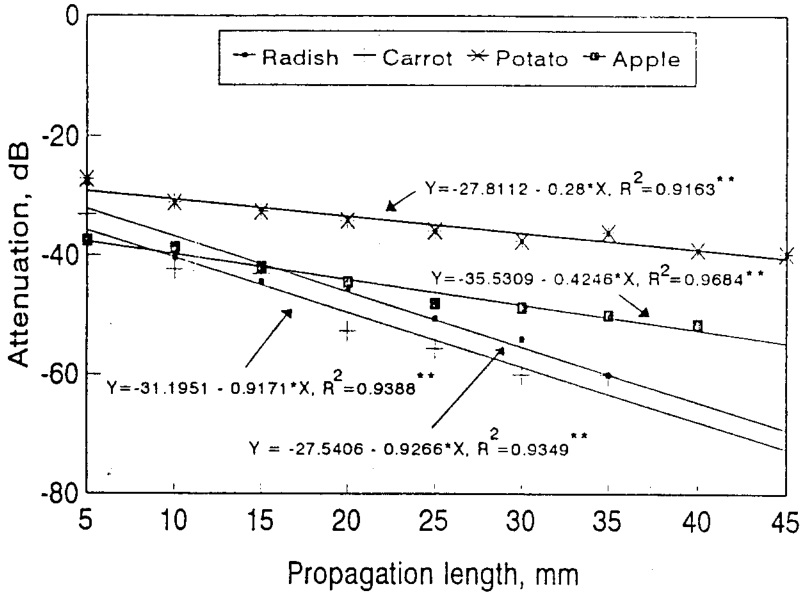

Fig 3. Ultrasonic attenuation through the fruit and vegetable samples at different sample length

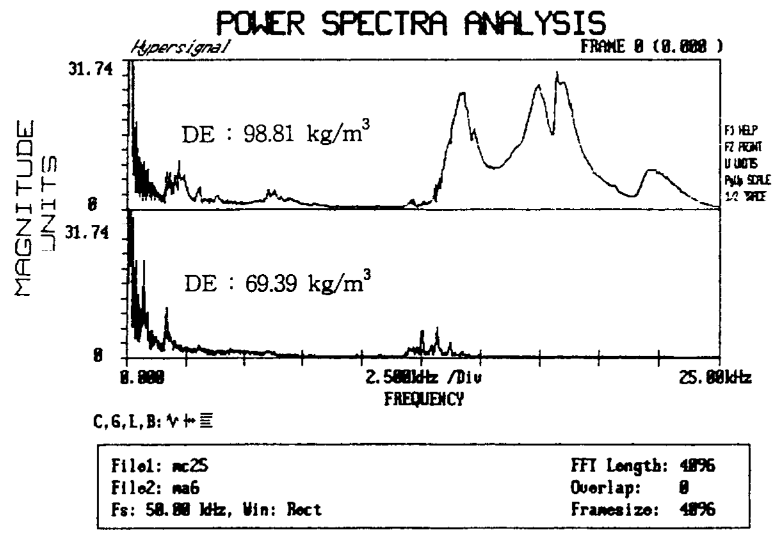

Fig 4. Comparison of power spectra analysis according to difference of density of the radish.

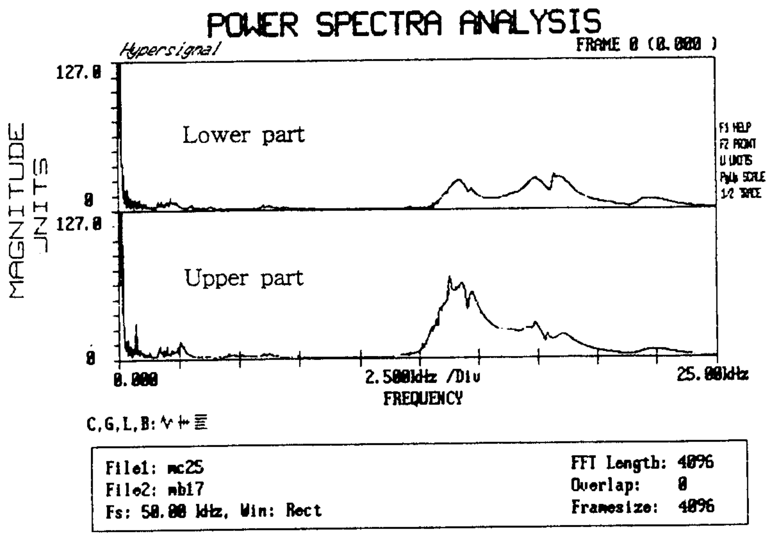

Fig 5. Comparison of power spectra analysis according to lower and upper parts of the radish