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APPLE BRUISE RESISTANCE DETERMINATION USING AN ELECTRICAL UNIVERSAL BRIDGE

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A b s t r a c t. Electrical resistance measurements were correlated with bruises in apples generated by an impact load. Bruises were induced on all the apples by swinging a steel plunger to produce 0.3-0.9 J energy. Electrical resistance parameters and bruise parameters varied over four harvest dates and five storage periods. Two parameters, unit electrical resistance and electrical resistance difference appeared to be good indicators of apple bruise resistance. Gloster had smaller bruises and higher electrical resistance than Jonagold and Melrose.

K e y w o r d s: apple, bruise, method, parameter

INTRODUCTION

Apples are commercially used for both fresh market and processing. Fresh market apples usually require harvest by hand. Apples for processing can be harvested by hand or more commonly mechanically. Wider acceptance of mechanical harvesting systems for apples is limited by the possibility of extensive bruising. Bruise resistance is an important attribute of fruit such as apples to insure a high quality of product. Bruise resistance is both a qualitative and quantitative characteristics [2]. The ability to measure bruise resistance would be of great value in evaluating readiness to harvest, effect of storage methods, selecting fruit varieties for planting and studying means of reducing fruit bruising during harvest and handling. Presently, there is no established, universally recognized standard technique for measuring bruise resistance. Holt and Schoorl [5] and Schoorl and Holt [9] reported a linear relationship between the energy absorbed and bruise volume produced in apples. Srivastava *et al*. [10] developed a model to predict apple bruising during harvest, storage and transport. Brown and Perry [1] investigated resistivity of cylindrical specimens of apple tissue using two copper disks of the sample holder and a General Radio Impedance Bridge. Resistance was measured at 1 kHz. Rotz and Mohsenin [8] measured electrical resistance of bruised and unbruised tissues in apples. They used two needles inserted into the apple skin and a General Radio Impedance Bridge at 1 kHz. Cox *et al*. [3] stated that a bruise index based on the impedance measurements at 1 kHz was well correlated with the degree of bruise damage. Thompson and Zachariah [11] revealed a number of problems associated with electrical measurements of biomaterial. The specific objective of this study was to determine, if bruise resistance can be determined by electrical resistance measurements.

MATERIALS AND METHODS

Three varieties of apples were picked from the selected trees in the orchards of commercial growers and placed into refrigerated storage at the temperature at 3 ^{o}C and RH-93 %. Any undersized, oversized and unusually shaped apples from the lot were discarded. Before testing, samples were moved to room conditions (20 ^{o}C and 65 % RH) for a sufficient time to equilibrate. The varieties of Gloster, Jonagold and Melrose were tested during harvest on 28 Sep., 4 Oct., 11 Oct. and 15 Oct (test dates Nos 1, 2, 3 and 4), and during storage on 8 Nov., 29 Nov., 20 Dec., 10 Jan. and 31 Jan. (test dates Nos 1, 2, 3, 4 and 5). Bruises were induced on all the apples by swinging a steel plunger of 11.1 mm in diameter into each individual fruit with the aid of a pendulum. The pendulum produced a controlled impact of 0.3, 0.6, and 0.9 J and assured proper orientation of the apple with the plunger at impact. After impact loading treatment, apples were held at 20 ^{o}C for up to 5 h for bruise development.

Electrical resistance measurements of the bruised and unbruised tissue were performed at the frequency of 1 kHz using a universal impedance bridge. The electrical sensor [7] consisted of two electrodes of 10-14 mm dimension (width-length) which were set at a distance of 12 mm on a Teflon probe. This sensor was pushed into the fruit to a fixed depth of 12 mm to measure electrical resistance of the sample between two electrodes in kΩ.

From the measurement of electrical resistance three parameters were derived:
- electrical resistance of bruised tissue measured (kΩ),
- difference in electrical resistance between the bruised and unbruised tissues (kΩ),
- unit electrical resistance as the slope of regression equation of electrical resistance vs. energy absorbed (kΩ J^{-1}).

After the measurements of electrical resistance, bruise size was measured. The apples were cut through the center of the contact area, and the bruised diameter and bruised depth was measured. Bruise volume was calculated using the formula reported by Holt and Schoorl [5]. Energy absorbed was determined on the basis of the drop and rebound heights using a pendulum apparatus [6]. The unit bruise volume was calculated as the bruise volume divided by the energy absorbed (ml J^{-1}).Ten replications were conducted for each combination of variables.

RESULTS AND DISCUSSION

Figures 1a and b show the relationship between electrical resistance of bruised tissue and energy absorbed by apples. This relationship was linear both during harvest and storage. An increase in the energy absorbed to bruise samples produces a decrease of electrical resistance of the bruised tissue. Rotz and Mohsenin [8] observed also a decrease in the bruised compared to unbruised apple tissue. They claimed over 60 % change in the resistance.

In this study, the sensor geometry was the same, therefore the parameters identified were related to the measured value of electrical resistance. It agreed with the observations by Holcomb *et al*. [4].

Equations describing the relationship between the above varieties and measurement data for each harvest and storage date are given in Table 1. The coefficient determining the slope of the line is the measure of apple resistance to bruising. The higher this coefficient

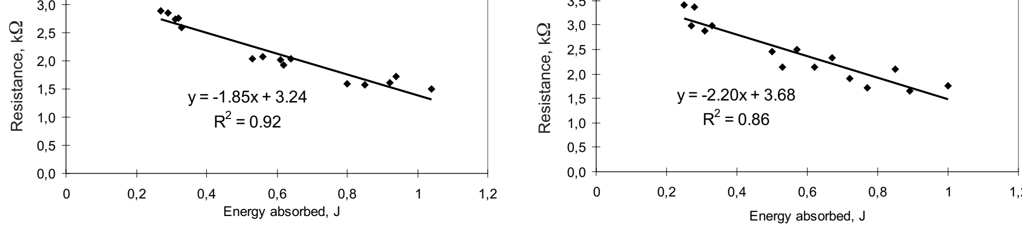

Fig. 1. Electrical resistance of the bruised tissue versus energy absorbed for all the a) harvest dates and b) storage times (each point represents the average of ten readings).

T a b l e 1. Relationship between electrical resistance of the bruised tissue and energy absorbed for three varieties, four harvest dates, and five storage dates

Variety	Period	Measurement date	Equation	R^2
Gloster	Harvest	1	4.24-2.89 x	0.90
		2	4.22-3.42 x	0.97
		3	4.34-3.35 x	0.95
		4	4.06-2.93 x	0.96
	Storage	1	4.35-3.25 x	0.85
		2	4.72-3.15 x	0.83
		3	-	
		4	5.32-3.86x	0.87
		5	5.83-4.17 x	0.90
Jonagold	Harvest	1	4.76-4.07 x	0.95
		2	4.80-4.30 x	0.96
		3	4.86-4.65 x	0.93
		4	4.75-4.16 x	0.95
	Storage	1	5.38-5.56 x	0.90
		2	5.56-5.60 x	0.86
		3	-	
		4	6.02-5.91 x	0.87
		5	5.87-6.28 x	0.86
Melrose	Harvest	1	4.87-3.68 x	0.97
		2	4.75-3.86 x	0.96
		3	5.08-3.98 x	0.96
		4	5.06-4.07 x	0.96
	Storage	1	5.14-4.56 x	0.84
		2	5.22-4.68 x	0.84
		3	5.39-4.97 x	0.88
		4	5.86-5.48 x	0.90
		5	5.88-5.18 x	0.84

expressed in $k\Omega\ J^{-1}$, the more prone the apple flesh to bruising. Low values indicate high resistance to bruising. The slope of regression equation determined as the unit electrical resistance, significantly changed with time, i.e.: from 2.89 to 4.17 , 4.07 to 6.28 and 3.68 to 5.18 for Gloster, Jonagold and Melrose, respectively. Differences in this parameter between varieties were also significant. Gloster, with lower coefficient, had highest resistance to bruising. This agrees with the higher unit bruise volume shown in Table 2. Other resistance parameters were worked out. Differences in electrical resistance showing the difference between undamaged and damaged tissue, becomes high for the apple varieties with small resistance to bruising (Table 2). Bruises were smaller in diameter and depth for Gloster than Jonagold and Melrose (Table 2). The measured bruise parameters, unit electrical resistance and electrical resistance difference, had coefficients of variation in the 11 to 25, 13.9 to 17,4 and 8.9 to 17.1% range, respectively. The bruise dimensions had lower variations than electrical measurements.

Plots of electrical resistance of bruised tissue versus bruise diameter, depth and volume for different varieties are presented in Figs 2-4. Electrical resistance progressively decreased with higher bruise volumes. A negative relationship between bruise size and electrical resistance was similar for all the three varieties.

T a b l e 2. Mean values of bruise size and electrical resistance (M.) and coefficients of variation (C.V., %) for three varieties

Parameter	Gloster		Jonagold		Melrose	
	M.	C.V.	M.	C.V.	M.	C.V.
Bruise diameter (mm)	22.30	12.2	25.30	6.7	25.70	6.5
Bruise depth (mm)	6.75	9.2	8.60	10.0	8.57	4.9
Unit bruise volume (ml J^{-1})	4.78	21.0	7.66	16.4	7.40	11.0
Unit electrical resistance (kΩ J^{-1})	3.35	14.3	5.56	17.4	4.56	13.9
Electrical resistance difference (kΩ)	3.16	17.1	4.50	8.9	4.11	10.6

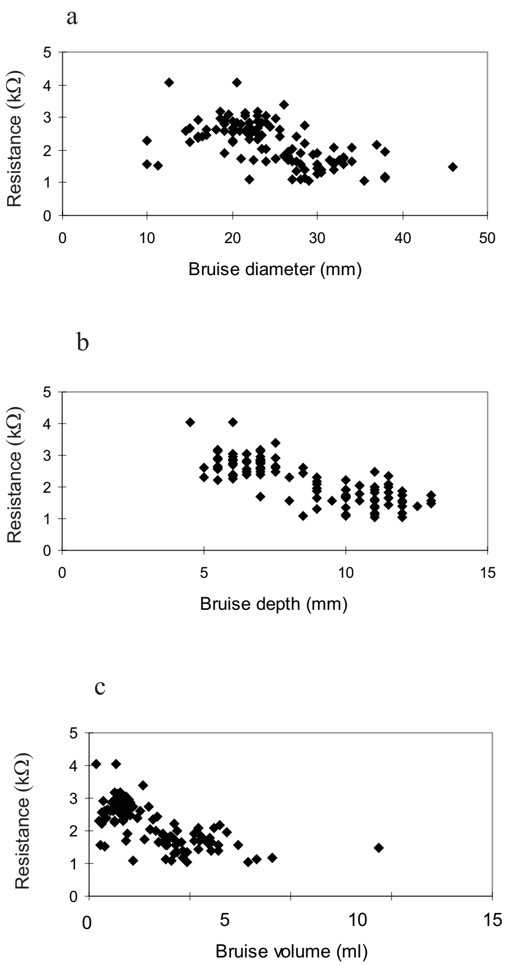

Fig. 2. Scatter plots of electrical resistance versus: a) bruise diameter, b) bruise depth and, c) bruise volume for Gloster for all harvest dates (n=160).

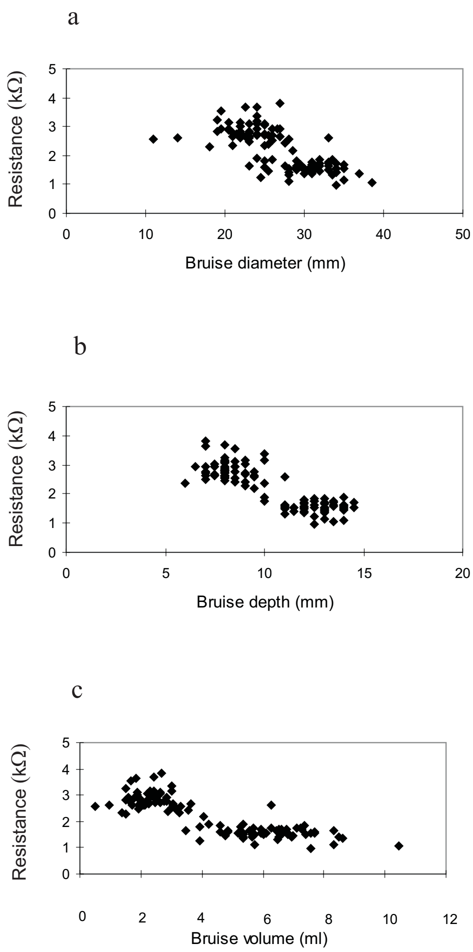

Fig. 3. Scatter plots of electrical resistance versus: a) bruise diameter, b) bruise depth and, c) bruise volume for Jonagold for all harvest dates (n=160).

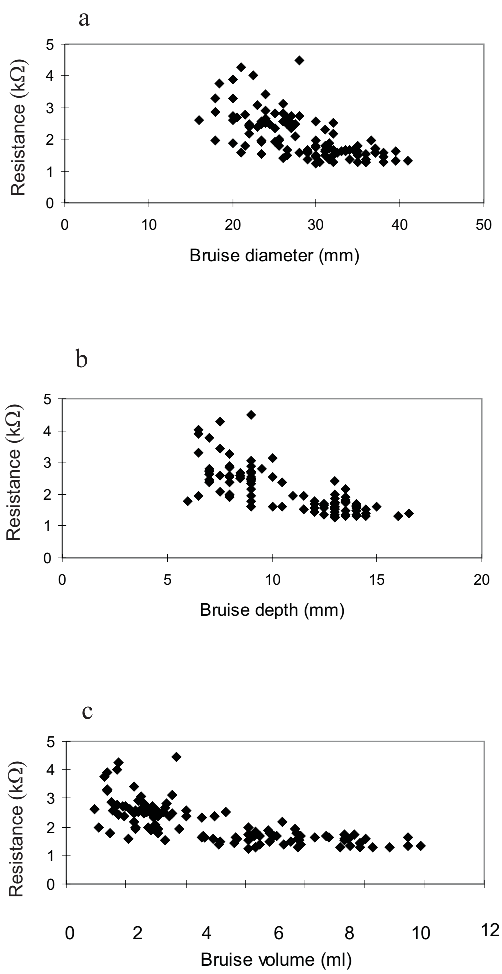

Fig. 4. Scatter plots of electrical resistance versus: a) bruise diameter, b) bruise depth and, c) bruise volume for Melrose for all harvest dates (n=160).

Larger bruises (diameter, depth and volume) had lower electrical resistance. The scatter of the results was very high for small bruise diameters and depths, less than 30 and 10 mm, respectively. As indicated by the scatter of results, variation in the electrical resistance at each depth was very high. Much of this variation can be attributed to non uniform properties of the fruit. Differences in firmness or cell structure may cause comparable apples with the same bruise depth to have different electrical resistance to bruising.

Table 3 shows linear correlation coefficients between electrical resistance parameters and bruise parameters. The best correlation was observed for the unit electrical resistance and difference in electrical resistance difference against unit bruise volume, with the values of the coefficient of 0.83 and 0.91, respectively. The correlation coefficients were similar for all the three levels of absorbed energy (Table 4).

Table 3. Correlation coefficients between electrical resistance parameters and bruise parameters (n=40)

Electrical resistance	Bruise parameter			
	Bruise diameter (mm)	Bruise depth (mm)	Bruise volume (ml)	Unit bruise volume (ml J^{-1})
Resistance of bruise tissue (kΩ)	0.16	0.02	0.10	0.14
Unit electrical resistance (kΩ J^{-1})	0.61	0.80	0.71	0.83
Electrical resistance difference (kΩ)	0.65	0.79	0.77	0.91

Table 4. Correlation coefficients between unit bruise volume and electrical resistance difference with respect to variety and energy absorbed (n=40)

Variety	Energy absorbed (J)		
	0.29 -0.31	0.60 - 0.63	0.89 - 0.93
Gloster	0.81	0.88	0.81
Jonagold	0.93	0.89	0.94
Melrose	0.86	0.94	0.91

CONCLUSIONS

The following conclusions were drawn from the above results:

1. A linear relationship was observed between electrical resistance of the bruised tissue and energy absorbed, with R equal 0.92 and 0.86 for harvest and storage times, respectively. A decrease in the energy absorbed caused an increase in resistance of the bruise tissue.

2. The slope of the relationship between electrical resistance and energy absorbed significantly varied among the varieties and measurement dates.

3. Smaller bruise diameter (less than 30 mm), bruise depth (less than 10 mm) and bruise volume (less than 5 ml) had more electrical resistance.

4. The best correlations was observed between the unit electrical resistance and difference in the electrical resistance with unit bruise volume. Correlation coefficients varied from 0.81 to 0.94.

These parameters may be used to determine apple resistance to bruising.

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