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STUDY OF ELECTRICAL RESISTANCE ON APPLES

C. Puchalski

Faculty of Production Technology, University of Agriculture Cracow,
Ćwiklińskiej 2, 35-959 Rzeszów, Poland

A b s t r a c t. The objectives of this study were to investigate the relationship between electrical resistance and various parameters and to quantify the changes in this relationship for several varieties of apples. The objects of testing were apples of three varieties, i.e., McIntosh, Spartan and Starkrimson. The universal bridge was used for the resistance measurements. The tests were carried out on both specially prepared samples and on whole apples. Apple resistance varied from 2.1 to 6.4 % and sample resistance was higher, i.e., 7.9-16.5 %. Compared to the green sides, the resistance of on red sides was 0.7-2.2 % higher for apples and 4.2-8.3 % higher for samples. Resistance increased with measurement time. The slope of the line was computed for each variety tested at its harvest time. The change in resistance per unit of time was significantly different and declined with harvest time. The resistance, averaged for 20 apples increased progressively during harvest time by as much as 20 %. The change in resistance during harvest time for tested varieties differed significantly. This is contrary to the normal pattern of a gradual softening of the flesh as fruit matures on the tree. Spartan and Starkrimson had lower resistance than McIntosh which corresponds inversely to firmness. Correlations of electrical resistance with pressure test values were highly significant for all cultivars.

K e y w o r d s: apples, electrical resistance, firmness

INTRODUCTION

Product quality and quality evaluation are important in the production and marketing of fruits. One of the key physical attributes indicative of fruit maturity and product quality is flesh texture, commonly referred to as firmness [6]. Firmness is usually measured by hand-held penetrometer as the force required to puncture the exposed flesh with a blunt cylindrical tip, and is influenced by shear and compressive strengths of the tissue. Many problems have been reported with the consistency of penetrometer firmness measurements and their relationship to consumer perceptions of texture [1]. Researchers have tried various techniques, such as mechanical, optical, sonic and X-ray transmission [5]. Each of these techniques is based on the detection of certain physical properties of the material and therefore, is only suitable for evaluating certain specific quality factors. Electrical methods can detect quality factors and are sensitive to variations in the concentration and state of water [3,4]. Therefore, it can be associated with maturity, damage, overripe condition, decay or other quality factors. The objectives of this study were to investigate the relationships between electrical resistance and various parameters and to quantify the changes in those relationships for several varieties of apples.

MATERIALS AND METHODS

The objects of testing were apples of three varieties, i.e. McIntosh, Spartan and Starkrimson, prepared according to principles developed by Blanpied *et al.* [2], so as to constitute a uniform testing material. Apples picked manually from trees at a strictly de-fined altitude on the south-western side of a tree, every five days throughout the harvesting season.

The fruits were kept in cold storage at a temperature of 276 K and humidity of about 93 %. The samples for measurement were harvested from trees or removed from storage and allowed to equi-librate at room temperature (293 K). Resistance measurements were carried out with universal bridge, which had a working range of 11 MΩ. The accuracy of the bridge was ±0.1 % of full scale. This device was equipped with two probe sensors for measurements in whole apples (Fig. 1) and samples (Fig. 2), which were chosen on the base of preliminary tests. The probe sensor (Fig. 1) was pushed into the intact fruit to a 12 mm depth, so that the distance from the plastic base to the fruit surface was 2 mm. These movements were in a direction perpendicular to the stem-calyx axis of apples. The resistance measurements of the samples (Fig. 2) were conducted at a 50 g load on the electrodes. The values of resistance were read in kΩ at various times after application (0, 15, 30, 45, 60 s). The tests were carried out at direct current on both specially prepared samples (dimensions of 15x14x3 mm), cut out from apple flesh, and on whole apples.

Firmness was measured by hand penetrometer with a 11.1 mm tip according to standard procedures developed by Blanpied *et al.* [1]. To minimize variability among apples, each of the three testes was run on the green (unblemished) and red (blemished)

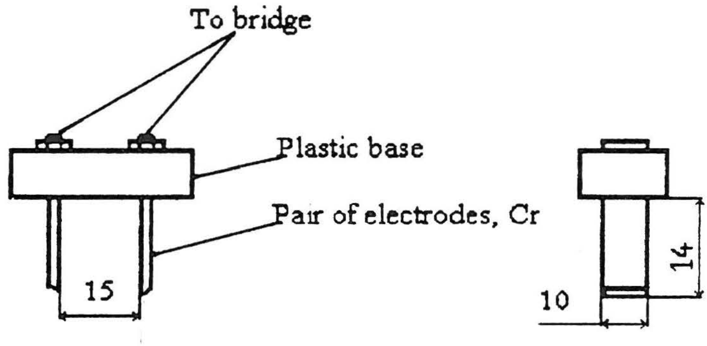

Fig. 1. Experimental probe sensor for measurements in whole apples.

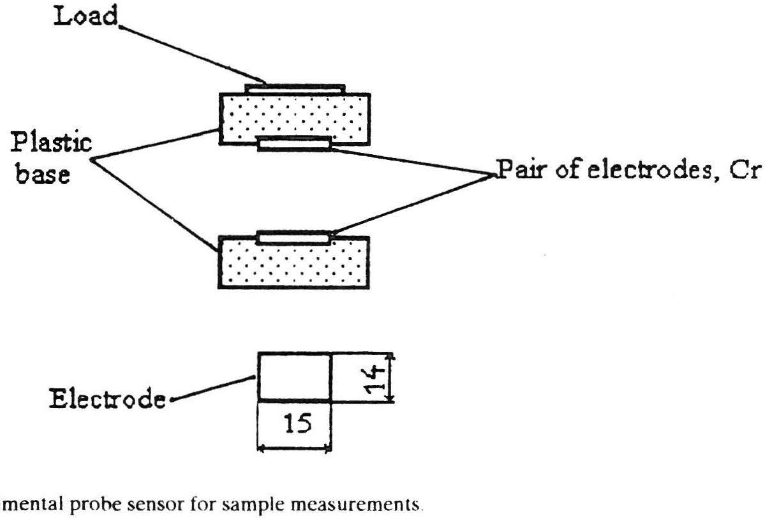

Fig. 2. Experimental probe sensor for sample measurements.

sides of apples. Twenty apples were tested for each run.

The measurements were taken at four dates during harvest (I, II, III, IV every 5 days) and at four date during storage time (every 21 days). The first (I) measurements during harvest had been carried out on following days for respective varieties: Sept. 13 (126 DAFB) for McIntosh, Sept. 19 (131 DAFB) - Spartan and Oct. 8 (156 DAFB) - Starkrimson.

Differences between means for varieties were compared with Duncan's new multiple range test and all results from harvest and storage times with the analysis of variance. Correlation coefficients between fruit characteristics at harvest and storage were calculated.

RESULTS AND DISCUSSION

Measurement system variability

After calibration of the universal bridge, repeatability was determined 20 times. As shown in Table 1, apple resistance varied by 1.5-4.3 % and sample resistances were higher and ranged from 5.5 to 15.7 %. Slight differences in dimension of the samples might be the reason for that large variation in sample resistance. Those parameters varied with the variety of the apple (Table 1). For McIntosh, which is characterized by a least compact texture, the apple resistance had larger variations in comparison with Starkrimson and Spartan varieties.

Variation around an apple

Previous researchers noted property variations between the green and red sides of an apple. Blanpied *et al.* [2] reported that for certain varieties, Magness-Taylor firmness readings were 0.5 kg greater on the red side than on the green side. Compared to the green sides, the resistance of on red sides was 0.7-2.2 % higher for whole apples and 4.2-8.3 % higher for samples. On the green side, the tissue is less mature and this presumably produces smaller resistances. The measurement side location on an apple is a source of variation which needs to be taken into account if the experimental design has only one measurement per fruit.

Table 1. Electrical resistance measurement test repeatability and effect of location on apple at commercial harvest date

Parameter	Variety	Mean (kΩ)	C.V. (%)	% Difference from green side
Apple resistance after 0 s	McIntosh	26.9	3.9	+1.1
	Spartan	23.9	2.6	+2.2
	Starkrimson	22.8	2.0	+1.8
Apple resistance after 30 s	McIntosh	27.9	4.0	+1.0
	Spartan	24.5	2.2	+1.7
	Starkrimson	23.6	1.8	+1.6
Apple resistance after 60 s	McIntosh	28.6	4.3	+0.7
	Spartan	25.0	2.3	+1.6
	Starkrimson	24.1	1.5	+1.6
Sample resistance after 0 s	McIntosh	6.8	7.2	+5.5
	Spartan	6.1	5.8	+4.6
	Starkrimson	4.2	15.7	+6.4
Sample resistance after 30 s	McIntosh	7.1	7.5	+5.2
	Spartan	6.2	5.7	+4.3
	Starkrimson	4.3	14.4	+8.3
Sample resistance after 60 s	McIntosh	7.3	8.5	+5.5
	Spartan	6.3	5.5	+4.2
	Starkrimson	4.5	13.1	+7.3

Electrical resistance versus measurement time

Resistance increased with measurement time as shown in Fig. 3 obtained from 100 apples measured for each characteristic. It was affected by a loss caused by a polarization.

The slope of the line was computed for each variety tested at its harvest date. The change in resistance per unit of time (resist./time) differed significantly and declined with harvest time, evident on Spartan and Starkrimson, as shown in Fig. 4. After 15 days these changes were greatest (51.4 and 50 %) for those varieties, which are characterized by smaller cells and intercellular spaces, in comparison with McIntosh (13.4 %). Based on a 1-year from 1989, the average commercial harvest date for McIntosh and Spartan apples in Albigowa was 23 and 29 Sept. Apples harvested on this date and stored in a refrigerated cold storage retained good poststorage eating quality. The commercial harvest date for these cases was after the instantaneous increase in resist./time (Fig. 4). It suggested a possible use of the detection of the instantaneous increase as a maturity index for two apple cultivars. Starkrimson have a constant rate of decrease of resist./time (Fig. 4). Therefore, it will be difficult to use the unit resistance measurement for commercial maturity evaluation of this apple cultivar.

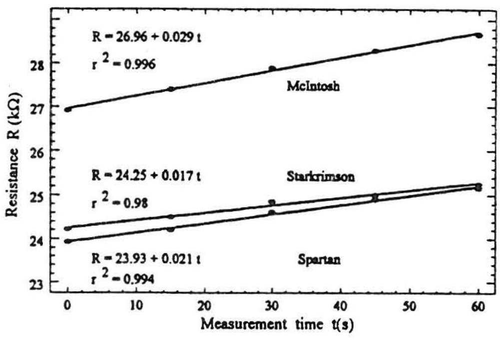

Fig. 3. Apple electrical resistance versus measurement time in commercial harvest date.

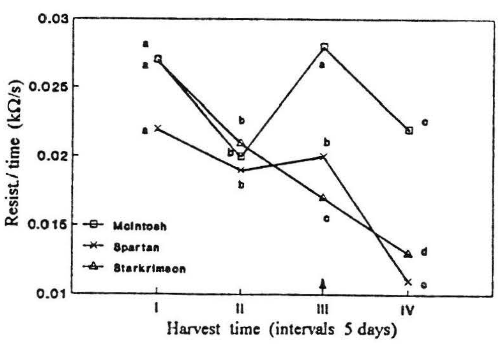

Fig. 4. Change in resistance per unit of time of apples in harvest time. A ↑ symbol on the axis indicates the commercial harvest date. Mean separation within a curve by Duncan's multiple range test, 5 % level.

Electrical resistance versus harvest time

Changes in electrical resistance during harvest time are presented in Fig. 5a. Because early testes showed that apple resistance had less variation than sample resistance

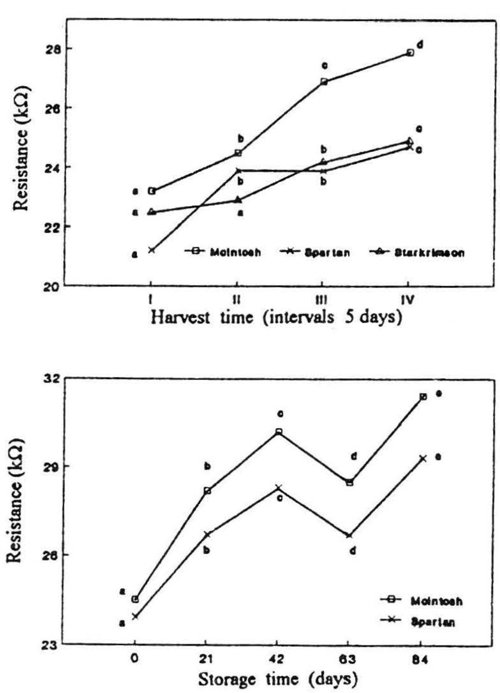

Fig. 5. Change during harvest and storage of apple electrical resistance. Mean separation within a curve by Duncan's multiple range test, 5 % level. Standard errors on the average were 0.2 kΩ and 0.25 kΩ, respectively.

(Table 1), apple resistance should be a more accurate measure of changes in fruit resistance. Average values for apple resistance (from 4 picking) ranged between 25.64 kΩ and 23.63 kΩ and 23.44 kΩ for McIntosh, Starkrimson and Spartan, respectively. Spartan and Starkrimson had smaller resistance than McIntosh, which corresponds inversely to firmness. The resistance, averaged for 20 apples, increased progressively during harvest time by as much as 20 % for McIntosh (which has greatest cells and intercellular space), 16.8 % for Spartan and 10.5 % for Starkrimson (most compact texture). This is contrary to the normal pattern of a gradual softening of the flesh as fruit matures on the tree. Similar observations have been reported for ripe and green tomato [3]. Thus the electrical resistance can be used as an objective criterion for quality classification.

Electrical resistance versus storage time

Storage period data, showing the effect of time on the apple electrical resistance value are given in Fig. 5b. There were rather large differences in resistance between harvest and storage times. During storage, as apples became less firm, apple resistance increased by as much as 27 %. This result is in agreement with Ezeike's observations [3] that the resistance increases with decreasing moisture content of vegetables. McIntosh had higher resistance value than Spartan (Fig. 6) which corresponds to variety having greater firmness than McIntosh.

The tested apple electrical resistances are probably an accurate index for the assessment of ripening differences, but it is necessary to study other attributes to obtain a clear picture of ripening. Several reports have been published recently showing that same fruit properties measured during storage time can be used to predict an important fruit characteristic after refrigerated or controlled atmosphere storage. It seems that resistance of apples may give an indication of optimum quality.

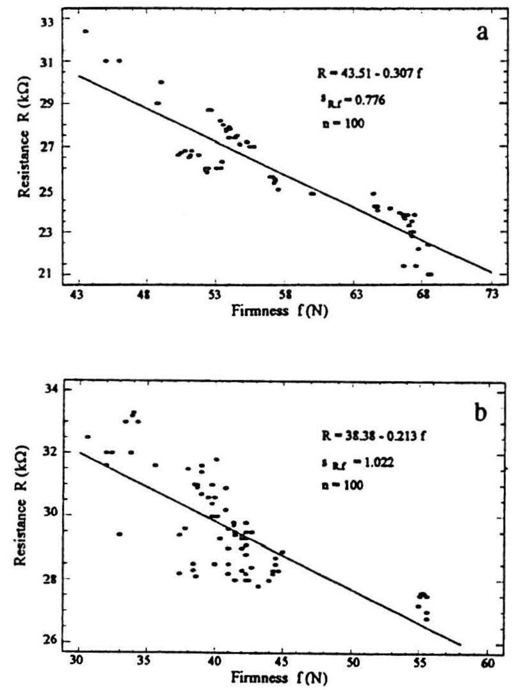

Fig. 6. Scatter plot of resistance versus firmness for McIntosh in harvest (a) and storage time (b).

Correlations of instrument measurements

The pressure tester is widely used to evaluate fruit firmness. Correlations of apple electrical resistance with pressure test values were highly significant for all cultivars (Table 2). Correlation coefficients ranged between 0.58 and 0.998 and were highest for McIntosh and Starkrimson in harvest period. Those two tests differ fundamentally. The pressure test punctures, shears and deforms, it ruptures and destroys cellular tissues. Measurement of electrical resistance involves the conduction of current in the region occupied by the material, an electrode contact with the biological tissue without appearance of damage to cellular structure. The tests evidently measure two different components of attribute. The correlation coefficient reflects the degree of relationship between

Table 2. Correlation coefficients for apple resistance with firmness

Parameter	Correlation coefficients				
	Harvest			Storage	
	McIntosh	Spartan	Starkrimson	McIntosh	Spartan
Resistance after 0 s	-0.997	-0.81	-0.98	-0.72	-0.86
Resistance after 30 s	-0.998	-0.77	-0.96	-0.64	-0.82
Resistance after 60 s	-0.993	-0.74	-0.96	-0.58	-0.80
Resist./time	0.07	0.87	0.95	-0.78	-0.96

these components. The correlations were very high. For McIntosh the relationship between harvest and storage time was less consistent and reliable, despite of this was found higher coefficient in harvest time. The scatter plot of resistance vs. firmness in Fig. 6 confirms this variability. Correlation coefficient between resist./time and firmness for McIntosh in harvest time was very low (Table 2). Unlike the above, resist./time for McIntosh in storage time and for Spartan and Starkrimson were highly correlated to firmness, to 0.96.

CONCLUSIONS

1. Tissue properties around the apple vary sufficiently to influence measured electrical resistance.

2. The change in resistance per unit of measurement time, differed significantly and declined with harvest time, evident on Spartan and Starkrimson.

3. The apple resistance increased progressively during harvest time.

4. During storage, as apples became less firm, apple resistance increased by as much as 27 %.

5. Correlations of apple electrical resistance with pressure test values were highly significant for tested cultivars. Correlation coefficients ranged between 0.58 and 0.998.

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