Dielectric Spectroscopy of Melons for Potential Quality Sensing

S. O. Nelson, S. Trabelsi, S. J. Kays

Abstract. *Several cultivars of cantaloupe, honeydew melons, and watermelons were planted and harvested with a range of maturities for dielectric properties measurements and moisture and soluble solids content (SSC) determination. Permittivities (dielectric constants and dielectric loss factors) were determined over the frequency range from 200 MHz to 20 GHz with an open-ended coaxial-line probe and network analyzer for both interior tissue and surface measurements. Permittivity data are presented graphically for all three types of melons. High correlations were noted between SSC and moisture content in the tissues of all three kinds of melons, with SSC increasing linearly with decreasing moisture content of the edible tissues. Dielectric properties determined by measurements on the external surface of the melons had lower values than those of the internal tissues. Dielectric properties were similar for all three melon types, and they reflect the influence of the dielectric behavior of free water. No obvious correlations were noted between the dielectric properties and the SSC (sweetness) for sensing the quality of the melons.*

Keywords. *Cantaloupe, Dielectric properties, Honeydew melons, Melons, Permittivity, Quality sensing, Soluble solids, Sweetness, Watermelons.*

Nondestructive techniques for sensing quality of agricultural products are useful for growers, handlers and packers, marketers, and consumers of these products. For melons in general, there are no reliable methods for nondestructive determination of quality, the main attribute being the sweetness of the internal edible tissue. For watermelon, correlations have been reported between melon density and soluble solids content (SSC), which were used in the sorting process (Kato, 1997), but other techniques, including near-infrared reflectance for SSC determination, are destructive. Sweetness can be rapidly assessed by taking a plug from a melon and measuring SSC with calibrated refractometers, but this leaves the melon vulnerable to rapid deterioration. Radio-frequency electric fields can penetrate melons well. Therefore, if the dielectric properties of the internal tissue of melons could be correlated with the SSC of those internal tissues, it might be possible to develop inexpensive instruments to sense those dielectric properties with electric fields and, thus, determine sweetness nondestructively.

Dielectric properties of materials are those electrical properties that determine the interaction of the material with electric fields. For example, the dielectric properties determine how rapidly materials absorb energy from the electric fields in microwave heating. These properties can be defined in terms of the complex relative permittivity, $\varepsilon = \varepsilon' - j\varepsilon''$, where the real part ε' is called the dielectric constant and the imaginary part ε'' is the dielectric loss factor; ε' is associated with energy storage in the electric field in the material, and ε'' is associated with the energy lost or converted to heat in the material.

The dielectric properties of cantaloupe were measured in the frequency range from 200 MHz to 20 GHz along with many other fruits and vegetables to provide some background data on those properties (Nelson et al., 1994). Cantaloupe was also included in dielectric spectroscopy studies on several fruits and vegetables in the 10 MHz to 1.8 GHz range (Nelson, 2005). Efforts to find correlations between SSC and dielectric properties from 10 MHz to 1.8 GHz have been published for honeydew melons (Nelson et al., 2006b) and watermelons (Nelson et al., 2007). An interesting correlation between the dielectric properties and SSC was reported for honeydew melons (Nelson et al., 2006a), but attempts to use that correlation for predicting SSC were not successful (Guo et al., 2007). The work reported here was conducted to determine whether useful correlations might be obtained between SSC and dielectric properties of cantaloupe, honeydew melons, and watermelons in the frequency range from 200 MHz to 20 GHz.

Materials and Methods

Melons

Four cultivars of cantaloupe (*Cucumis melo* L. Cantalupensis group), 'Ambrosia', 'Athena', 'Carousel', and 'Gourmet', three cultivars of honeydew melons, (*Cucumis melo* L. Inodorus group), 'Earli Dew', 'Honey Brew', and

Submitted for review in July 2008 as manuscript number IET 7598; approved for publication by the Information & Electrical Technologies Division of ASABE in October 2008. Presented at the 2008 ASABE Annual Meeting as Paper No. 083627.

Mention of company or trade names is for purpose of description only and does not imply endorsement by the USDA.

The authors are **Stuart O. Nelson, ASABE Fellow,** Collaborator (Research Agricultural Engineer), and **Samir Trabelsi, ASABE Member Engineer,** Research Electronics Engineer, USDA Agricultural Research Service, Athens, Georgia; and **Stanley J. Kays,** Professor, Department of Horticulture, The University of Georgia, Athens. **Corresponding author:** Stuart O. Nelson, USDA-ARS Russell Research Center, P.O. Box 5677, Athens. GA 30604-5677; phone: 706-546-3101; fax: 706-546-3607; e-mail: stuart.nelson@ars.usda.gov.

'Rocio', and three cultivars of miniature ("icebox", "pocket") watermelons (*Citrullus lanatus* (Thunb.) Matsum. & Nakai), 'Smile', 'Sugar Baby' and 'Yellow Doll' were grown at the University of Georgia Horticulture farm, Watkinsville, Georgia, in a Cecil clay loam soil using standard melon culture methods (Boyham et al., 2006). Plantings at 1 × 4 m were made on June 1, 7, and 14, 2007. Bravo and Pristine fungicide were applied alternately at two-week intervals. Fertilization was based upon soil analysis and culture recommendations (Boyham et al., 2006). Fruit of varying stages of maturity were harvested on August 7 and 21 for analysis. They were stored at 4°C from time of harvest until time for measurements, which was not more than a few days. Measurements were taken on twelve each of the 'Ambrosia', 'Athena' and 'Carousel' and seven of the 'Gourmet' cantaloupe cultivars; on sixteen 'Earli Dew', nine 'Honey Brew', and eighteen 'Rocio' honeydew cultivars; and on four 'Smile', fifteen 'Sugar Baby', and nine 'Yellow Doll' watermelon cultivars, respectively.

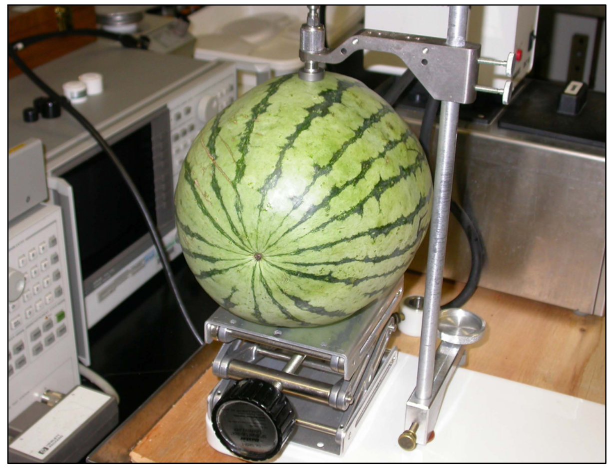

Figure 1. Surface measurement of watermelon dielectric properties with open-ended coaxial-line probe.

Dielectric Properties Measurements

The electrical measurements necessary for dielectric properties determination were obtained with a Hewlett-Packard 85070B open-ended coaxial-line probe and a Hewlett-Packard 8510C network analyzer (Nelson et al., 2006b). Permittivities (dielectric constants and loss factors) were calculated with Agilent Technologies 85070D dielectric probe kit software, which provided permittivity values from the reflection coefficients of the material in contact with the active tip of the probe (Blackham and Pollard, 1997). Settings were made to provide measurements at 51 frequencies on a logarithmic scale from 200 MHz to 20 GHz. The 85070B probe and 8510C analyzer were calibrated with measurements on air, a short-circuit block, and glass-distilled water at 25°C. A personal computer was used to control the system and record resulting data.

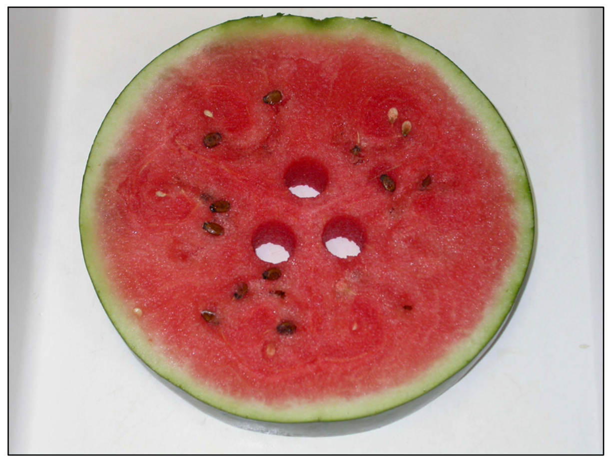

Figure 2. Equatorial slice of watermelon and location from which cylindrical tissue samples were cut.

Procedures

Melons were removed from 4°C storage the night before measurements were scheduled, washed with tap water to remove any dust or soil material, and permitted to equilibrate to 24°C for the measurements. Initial permittivity measurements on the honeydew and watermelons were made with the probe in firm contact with the surface of the melon in the equatorial region at four points about 90° apart around the perimeter of the melon. No surface measurements were made on the cantaloupe because of their rough exterior surface. Melons were supported and maintained in firm contact with the probe with a laboratory jack, as shown in figure 1. Samples for measurements of the internal melon tissue were all taken from an equatorial slice, about 4 cm thick, cut with a sharp knife from the center of the melon perpendicular to the proximal-to-distal axis. From this slice, three cylindrical core samples were cut for the dielectric properties measurements near the center of the slice for watermelons, avoiding the seed bearing regions as shown in figure 2, and at three locations for the cantaloupe and honeydew melons as shown in figure 3. Three more samples adjacent to the first samples were taken for moisture content determination. Moisture contents were determined by drying the triplicate samples in disposable 57-mm aluminum weighing dishes that were placed in a forced-air drying oven for 24 h at 70°C. Upon removal from the oven, weighing dishes with samples were cooled in a des–

Figure 3. Equatorial slice of honeydew melon and location from which cylindrical tissue samples were cut.

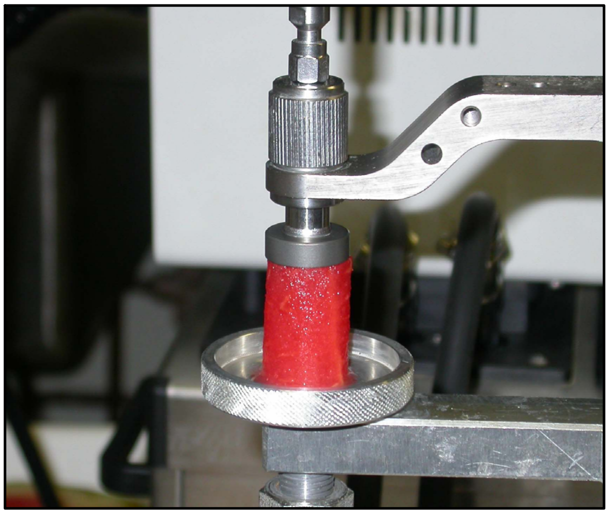

Figure 4. Internal tissue sample measurement with open-ended coaxial-line probe.

iccator over anhydrous $CaSO_4$ prior to reweighing for determination of moisture loss. Tissue moisture contents were calculated as percent weight loss on a wet-weight basis, and mean values of the three replicates were taken to represent each melon.

Samples were cut from the equatorial melon slice with a cylindrical cutter (Nelson, 2003) that provided right circular cylindrical samples of 18.6-mm diameter and 3- to 4-cm length. All permittivity measurements were taken at 24°C. Samples were supported as shown in figure 4 on an aluminum platform that was raised to bring the sample into firm contact with the open-ended coaxial-line probe for the permittivity measurements (Nelson, 2003). When that measurement was completed, the sample was removed, turned end for end, and reinserted for permittivity measurements on the other end of the sample. Thus, six series of permittivity measurements were made for each tissue sample at 51 frequencies from 200 MHz to 20 GHz to be averaged for each melon. The four external surface measurements were also averaged in a similar way for the surface permittivity measurements.

Upon completion of the internal tissue permittivity measurements, each sample was placed in a 30-mL (1-oz.) glass jar with screw-on cap and held from a few minutes to a few hours for soluble solids content determination. The measurements for soluble solids were determined with an Atago Pallete Series model PR101α digital refractometer. Melon tissue samples were placed in a garlic press with cheesecloth patches of several layers to strain the juice expelled for the refractometer measurements. Five readings were taken for each sample, and the composite soluble solids content determination for each melon was a mean of 15 readings.

Results

Soluble Solids Content and Moisture Content

Ranges of soluble solids content (SSC) and moisture content of the three melon types are shown in table 1. The SSC and moisture content of the edible tissue of fresh melons are well correlated. Moisture content decreases as SSC increases. This high correlation has been noted for watermelons (Nelson et al., 2007) and honeydew melons (Guo et al., 2007). Results for the three melon types included in this study

Table 1. Ranges of soluble solids content (SSC) and moisture content measured for different cultivars of cantaloupe, honeydew melons, and watermelons included in the study.

Melon Type	Cultivar	No. of Melons	SSC	Moisture Content
Cantaloupe	Ambrosia	12	8.5 - 12.7	86.6 - 92.9
	Athena	12	6.1 - 9.1	90.0 - 93.4
	Carousel	12	7.1 - 12.1	86.9 - 92.2
	Gourmet	7	9.7 - 11.1	87.6 - 89.4
Honeydew	Earli Dew	16	7.5 - 14.1	85.2 - 91.9
	Honey Brew	9	10.8 - 14.2	85.4 - 88.9
	Rocio	18	7.8 - 11.2	87.4 - 92.2
Watermelon	Smile	4	10.6 - 12.1	87.0 - 88.2
	Sugar Baby	15	7.1 - 11.4	87.6 - 91.0
	Yellow Doll	9	10.1 - 12.0	86.6 - 89.4

are shown in figure 5, where the points for the cantaloupe, honeydew, and watermelons are essentially superimposed. The coefficient of determination for the linear regression of the combined data was 0.92.

Cantaloupe Permittivities

Typical dielectric constant and loss factor values measured for the internal tissues of Ambrosia cantaloupe are illustrated in figure 6, where the error bars indicate plus and minus one standard deviation. Even though the two graphs represent melons with substantial differences in SSC and moisture content, the values of the dielectric constant and loss factor cannot be considered different for these two melons. Similar values were obtained for other Ambrosia cantaloupe of different soluble solids and moisture contents. One might expect the dielectric constant to be higher for tissues of higher moisture contents, but the order observed did not support this expectation in the range of moisture contents measured in this study.

Results of similar measurements on the other three cantaloupe cultivars are shown in figures 7, 8, and 9 for typical measurements on these melons. Even though SSC and moisture content differed considerably for those curves shown, the dielectric properties are very similar, and in view of the typical standard deviations shown in figure 6, no differences in permittivities among the four cantaloupe cultivars are obvious.

Honeydew Permittivities

Typical results for honeydew melons are illustrated in figures 10 through 13, where the dielectric properties obtained

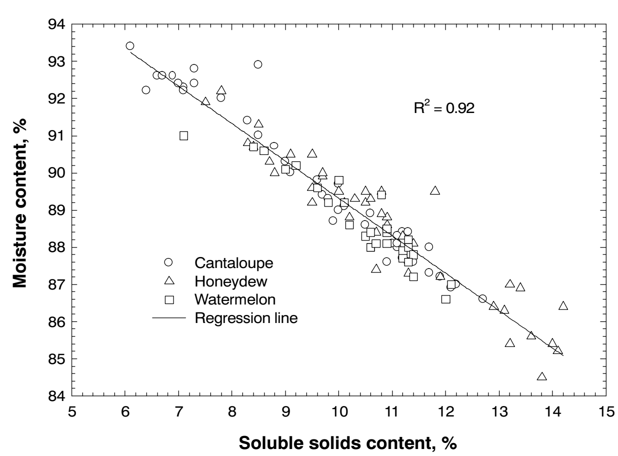

Figure 5. Relationship between soluble solids content and moisture content of fresh melons.

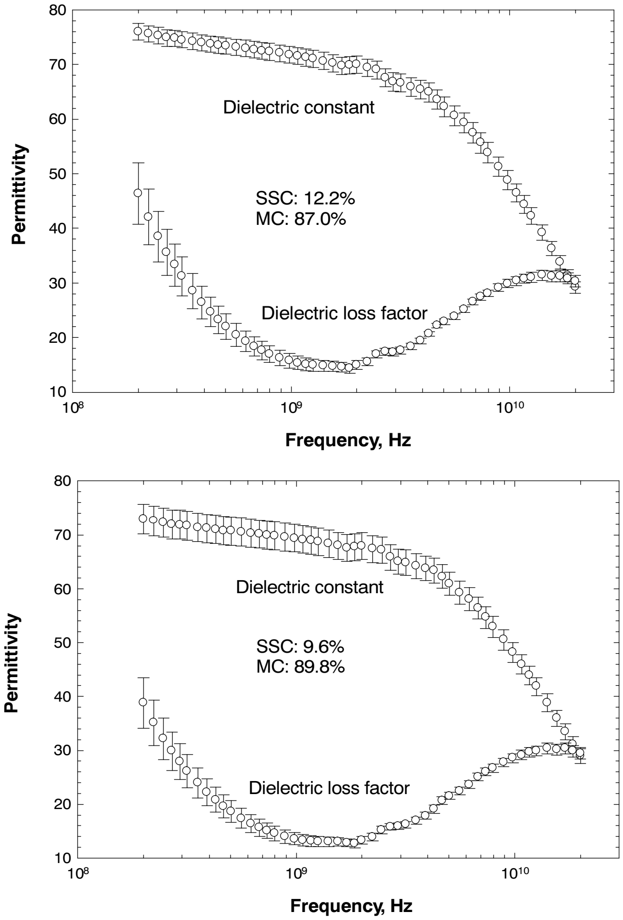

Figure 6. Measured permittivities for internal tissues of two Ambrosia cantaloupe melons of indicated SSC and moisture content. Error bars represent ± one standard deviation for six replicated measurements.

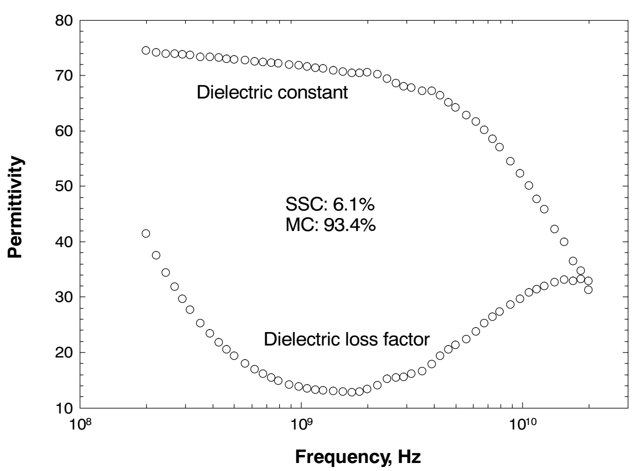

Figure 7. Measured permittivities for internal tissue of an Athena cantaloupe of indicated SSC and moisture content.

for both the surface and internal measurements are shown. Both the dielectric constant and loss factor have lower values for the surface measurements than for those on the internal tissue, but they exhibit similar trends with frequency. Slight differences in some relative values may be evident between the Earli Dew and Rocio cultivars, but taking into account standard deviations for the measurements, as shown in figure 6, and differences among melons of the same cultivar,

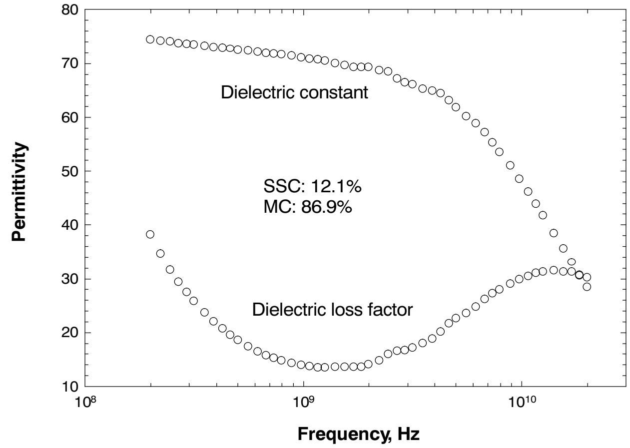

Figure 8. Measured permittivities for internal tissue of a Carousel cantaloupe of indicated SSC and moisture content.

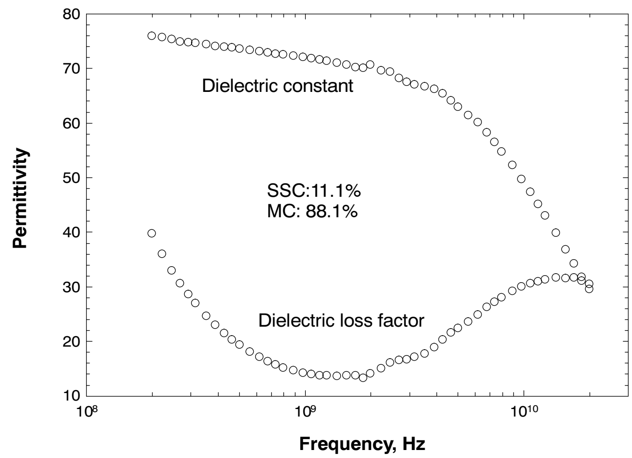

Figure 9. Measured permittivities for internal tissue of a Gourmet cantaloupe of indicated SSC and moisture content.

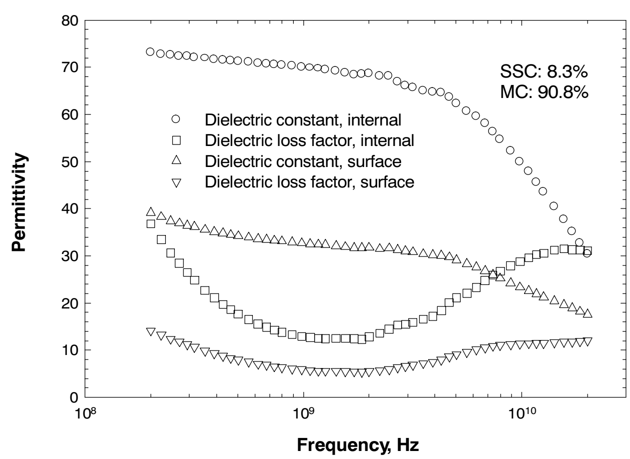

Figure 10. Measured permittivities for an Earli Dew honeydew melon of indicated SSC and moisture content, comparing dielectric properties from surface measurements and internal tissue measurements.

these are not likely real differences. Again, no differences are evident due to differences in soluble solids or moisture content.

WATERMELON PERMITTIVITIES

Results for measurements on watermelons are illustrated in figures 14 through 17 for the Sugar Baby and Yellow Doll

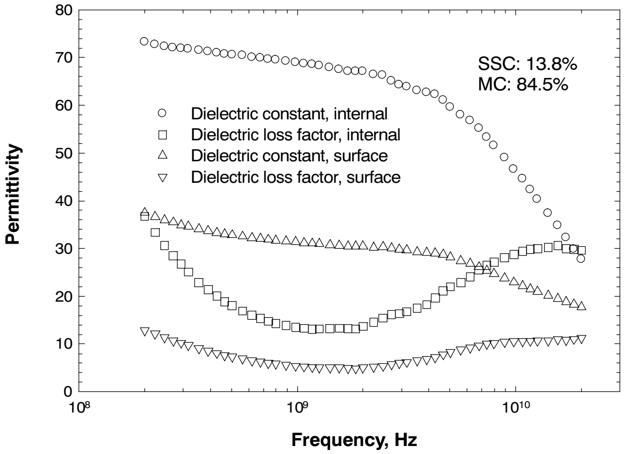

Figure 11. Measured permittivities for an Earli Dew honeydew melon of indicated SSC and moisture content, comparing dielectric properties from surface measurements and internal tissue measurements.

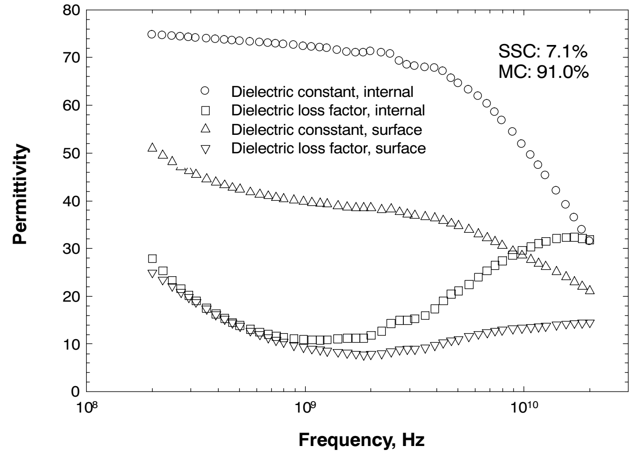

Figure 14. Measured permittivities for a Sugar Baby watermelon of indicated SSC and moisture content, comparing dielectric properties from surface measurements and internal tissue measurements.

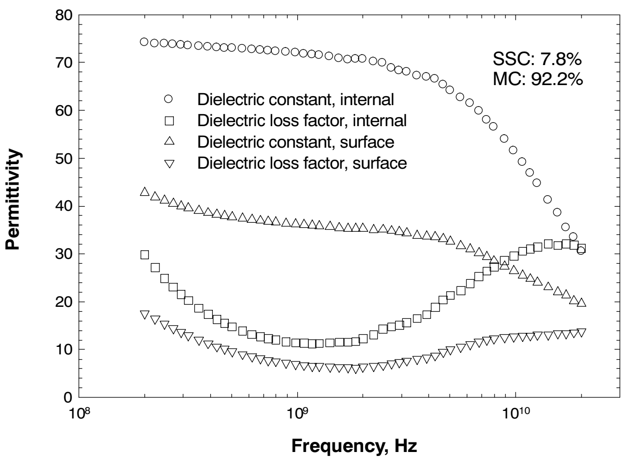

Figure 12. Measured permittivities for a Rocio honeydew melon of indicated SSC and moisture content, comparing dielectric properties from surface measurements and internal tissue measurements.

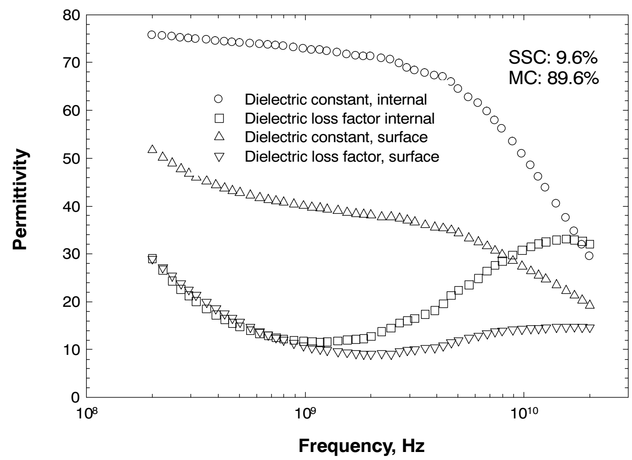

Figure 15. Measured permittivities for a Sugar Baby watermelon of indicated SSC and moisture content, comparing dielectric properties from surface measurements and internal tissue measurements.

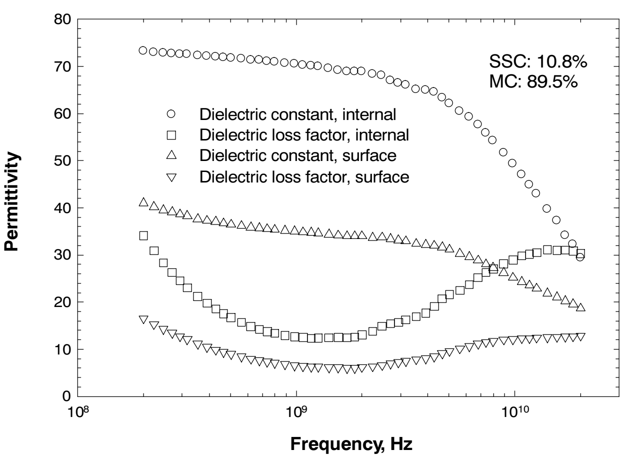

Figure 13. Measured permittivities for a Rocio honeydew melon of indicated SSC and moisture content, comparing dielectric properties from surface measurements and internal tissue measurements.

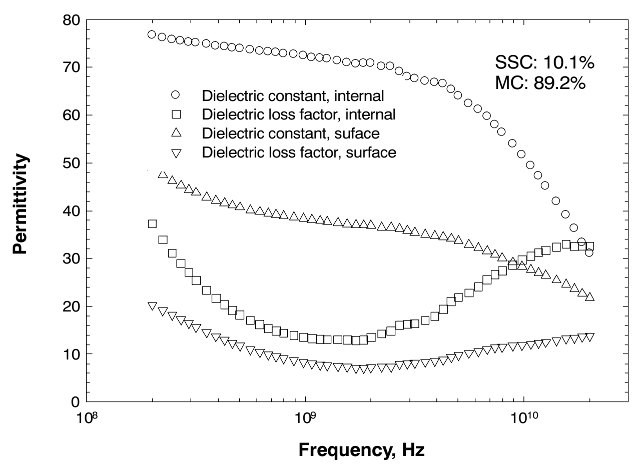

Figure 16. Measured permittivities for a Yellow Doll watermelon of indicated SSC and moisture content, comparing dielectric properties from surface measurements and internal tissue measurements.

cultivars. The only differences evident in these figures are those between the loss factors for the internal and surface measurements on the two cultivars at the lowest frequencies. However, these apparent differences are not likely significant for the reasons already mentioned, and no differences are obvious that might be useful in predicting soluble solids content or moisture content from these kinds of measurements.

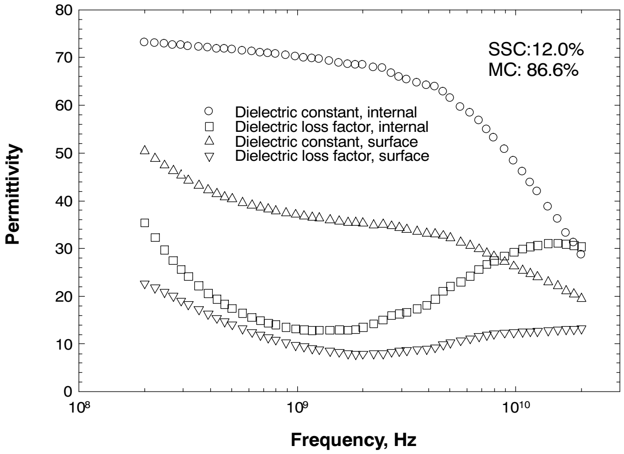

Figure 17. Measured permittivities for a Yellow Doll watermelon of indicated SSC and moisture content, comparing dielectric properties from surface measurements and internal tissue measurements.

Observations

In all of the graphical data for the permittivity measurements on the internal tissue samples, there appears a minor irregularity between 2 and 3 or 4 GHz in the otherwise smooth curves for the dielectric constant and the loss factor. One might suspect some artifact in the measurement system. However, similar measurements on water reveal no such irregularity (fig. 18). When samples are too small, or when the losses are sufficiently low, reflections within the sample can produce perturbations. However, the irregularities noted are of minor significance here and can likely be explained by the presence of a dielectric relaxation that is otherwise masked by ionic conduction and water dipole relaxation.

The relaxation frequency of pure liquid water at 19.3 GHz for water at 25°C is clearly shown in figure 18. The high water content in the melon tissues accounts for the similar dielectric relaxation evident in the loss factor curves for all of the melons shown in the other figures. The influence of dipolar losses is evident in these curves at frequencies above 2 GHz, whereas the influence of ionic conduction is evident at frequencies below about 1 GHz.

Taking into account the variation in dielectric properties determined by repeated measurements on the same melon (fig. 6) and the minor differences noted for measurements on different melons of the same cultivar with widely differing SSC and moisture content (figs. 10 and 11), no further need for statistical analyses was indicated to discern differences in SSC through measurements of dielectric properties of melons in the frequency range explored. In addition, moisture contents of all of the melons were very high, 85% to 93%, and sensitivity to moisture content through dielectric response is rather low at such high moisture levels.

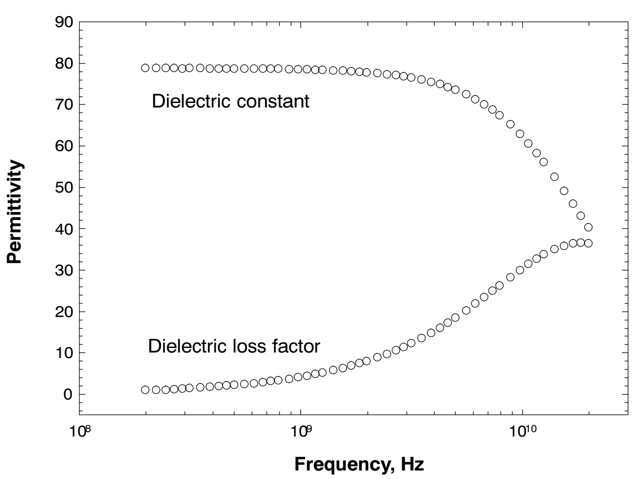

Figure 18. Permittivity measurements on distilled water sample in stainless steel sample cup of 19 mm diameter and 19 mm depth.

Conclusions

New data have been obtained and presented on the dielectric properties of cantaloupe, honeydew melons, and watermelons in the frequency range from 200 MHz to 20 GHz and on the soluble solids content (SSC) and moisture content of these same melons. A high correlation between SSC and moisture content in the tissues of all three kinds of melons was found, with SSC increasing linearly with decreasing moisture content of the edible tissues. Dielectric properties determined by measurements on the external surface of the melons had lower values than those for the internal tissues. Dielectric properties were similar for all three melon types, and real differences were not noted in the values of the dielectric constant or the dielectric loss factor depending on the SSC or moisture content of the internal tissue. Thus, no evidence was noted that dielectric properties in the 200 MHz to 20 GHz frequency range are likely to be useful for predicting the sweetness of the internal edible tissue of these melons. The influence of free water on the dielectric behavior of the melon tissues is obvious when compared to the frequency dependence of the dielectric constant and dielectric loss factor of liquid water.

References

Blackham, D. V., and R. D. Pollard. 1997. An improved technique for permittivity measurements using a coaxial probe. *IEEE Trans. on Instrumentation and Measurement* 46(5): 1093-1099.

Boyham, G. E., D. M. Granberry, and W. T. Kelly. 2006. Commercial watermelon production. Athens, Ga.: University of Georgia, College of Agricultural and Environmental Sciences. Available at: http://pubs.caes.uga.edu/caespubs/pubed/B996-w.htm.

Guo, W.-C., S. O. Nelson, S. Trabelsi, and S. J. Kays. 2007. Dielectric properties of honeydew melons and correlation with quality. *J. Microwave Power and Electromagnetic Energy* 41(2): 44-54.

Kato, K. 1997. Electrical density sorting and estimation of soluble solids content of watermelon. *J. Agric. Eng. Res.* 67(2): 161-170.

Nelson, S. O. 2003. Frequency- and temperature-dependent permittivities of fresh fruits and vegetables from 0.0l to 1.8 GHz. *Trans. ASAE* 46(2): 567-574.

Nelson, S. O. 2005. Dielectric spectroscopy of fresh fruit and vegetable tissues from 10 to 1800 MHz. *J. Microwave Power and Electromagnetic Energy* 40(1): 31-47.

Nelson, S. O., W. R. Forbus, Jr., and K. C. Lawrence. 1994. Permittivities of fresh fruits and vegetables at 0.2 to 20 GHz. *J. Microwave Power and Electromagnetic Energy* 29(2): 81-93.

Nelson, S. O., S. Trabelsi, and S. J. Kays. 2006a. Dielectric spectroscopy of honeydew melons for quality sensing, In *Proc. 23rd IEEE Instrumentation and Measurement Technology Conf.*, 305-307. Piscataway, N.J.: IEEE.

Nelson, S. O., S. Trabelsi, and S. J. Kays. 2006b. Dielectric spectroscopy of honeydew melons from 10 MHz to 1.8 GHz for quality sensing. *Trans. ASABE* 49(6): 1977-1981.

Nelson, S. O., W. Guo, S. Trabelsi, and S. J. Kays. 2007. Dielectric spectroscopy of watermelons for quality sensing. *Measurement Sci. and Tech.* 18(7): 1887-1892.