Factors Affecting the Electrical Resistivity of Soybean Oil

Aziz Tekin and Earl G. Hammond*

Department of Food Science and Human Nutrition and Center for Crops Utilization Research,
Iowa State University, Ames, Iowa 50011

ABSTRACT: The electrical resistivity of soybean oil that had been purified to remove polar constituents was determined, and the effect of measuring conditions and the addition of polar constituents (free fatty acids, phospholipids, monoglyceride, α-tocopherol, β-sitosterol, β-carotene, peroxides, and water) on resistivity was investigated. For reproducible resistivity measurements, voltages in excess of 50 volts and charging times greater than 120 s were necessary. As temperature was increased linearly, the resistivity of the oil decreased logarithmically. For making comparisons, a temperature of 24°C, a potential of 50 volts, and 120 s charging times were chosen. All polar constituents decreased the resistivity of the purified soybean oil, but water, phospholipids, and monoglycerides had the greatest effects. Water increased the resistivity-lowering effects of all other constituents except for free fatty acids, which were affected by water only slightly. The synergistic effect of water was much greater for phospholipids and monoglyceride than for other constituents.

JAOCS 75, 737–740 (1998).

KEY WORDS: β-Carotene, charging time, electrical resistivity, free fatty acids, peroxides, polar compounds, soybean oil, temperature, voltage.

The increased price of petroleum has created interest in using fats and oils as alternative materials. Although the prices of triglyceride oils usually are significantly greater than those of most refined petroleum products, vegetable oils are being considered in a number of applications, such as lubricants, hydraulic fluids and printing inks, where their biodegradability is particularly valuable. In some digital ink applications, the printed image is formed by an electrostatic charge, and it is important for the ink base to have a high electrical resistivity to maintain the sharpness of the image.

Vegetable oils are known to be relatively good insulators, but the few studies of their electrical properties have mostly dealt with their dielectric values. Dielectric values depend on the fatty acid profile, are correlated with refractive index and iodine value, and are affected by oxidation and crystal structure (1–4). So far, there has been almost no research about the electrical resistivity of vegetable oils.

*To whom correspondence should be addressed at Department of Food Science and Human Nutrition, Food Sciences Building, Iowa State University Ames, IA 50011. E-mail: hammond@iastate.edu

According to Ohm's law, resistance in ohms is the ratio of the applied potential in volts to the current in amperes. The resistivity of a material is the reciprocal of its conductivity and is the resistance to current passing through a 1-cm cube of the material (5). Measurements of the resistivity of insulators have shown that the temperature, applied voltage, and charging time affect the results (6). Higher temperatures generally give lower resistivities. Higher voltages may reduce the apparent resistivity, especially for relatively low-resistance materials. After application of a voltage, resistivity readings reach a steady value after a certain period. The time required for a constant value generally is longer with higher resistivities.

Moisture and other polar solutes reduce the resistivity of mineral oils; so, such compounds are removed from oils used as electrical insulators (7).

This paper reports the resistivity of crude and purified soybean oils and documents the effects of voltage, charging time, temperature, moisture, and minor components on the resistivity.

MATERIALS AND METHODS

Commercial soybean oil was purchased locally. Soybean oil was freed of water and polar constituents by passage through alumina according to Jensen *et al.* (8). Chemicals were reagent-grade and purchased from Fisher Scientific (Pittsburgh, PA), Sigma (St. Louis, MO) and Aldrich (Milwaukee, WI).

Resistivity measurements were carried out with a Hewlett-Packard 4339 B high-resistance direct-current meter (Wilmington, DE), equipped with a conductivity cell (Fisher Scientific # 9,366) with a cell constant of 1.3. The following conditions were used to measure resistivity unless otherwise specified: 24°C, 50 volts, charging time 120 s. Fifty readings were made and averaged automatically by the instrument.

To test their effects on resistivity, various substances were dissolved in alumina-purified soybean oil at 24°C. To test for interaction of each substance with water, after the dry resistivity reading was taken, 1 drop of water (0.05 mL) was mixed with 10 mL of the sample at 24°C for 30 min, the sample was centrifuged for 2 min to remove excess water, and the wet resistivity was measured.

RESULTS AND DISCUSSION

Alumina-purified soybean oil (APSBO) was subjected to various voltages (up to 1000 volts) for various charging times (up to 600 s) to observe the effects on resistivity. Figure 1 indicates that the apparent resistivity increased significantly with voltage up to 50 volts. The apparent resistivity at all voltages became fairly constant after charging times of 120 s, so for subsequent readings we used 50 volts with a charging time of 120 s.

The resistivity of APSBO increased logarithmically from 0.251 to 100 Tohm·cm as the temperature decreased from 100 to −5°C (Fig. 2). Similar logarithmic relations with temperature have been observed for viscosity (9) and may be related to the heat of vaporization—the energy required to pull two molecules apart. Resistivities were not recorded below −5°C, the cloud point of the oil, because the resistivity values became irregular below this temperature. These results show the importance of holding the temperature constant in comparing resistivities. In these studies 24°C, which was ambient temperature, was used.

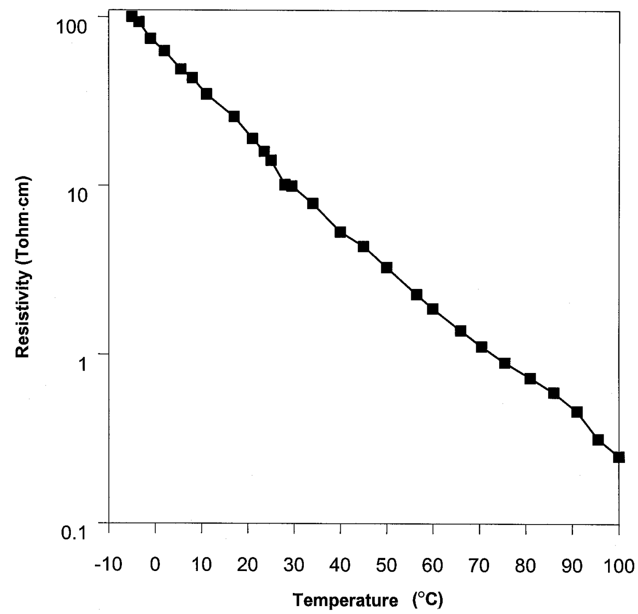

FIG. 2. The effect of temperature on the resistivity of alumina-purified soybean oil.

The effect of free fatty acids (FFA) on the resistivity of oil was determined by adding oleic acid to APSBO, and the results are shown in Figure 3. FFA reduced the resistivity from 23.7 to 1.99 Tohm·cm at 0.3% FFA, but the resistivity increased slightly with additional FFA. Probably, this is caused by hydrogen-bond dimerization of the FFA as their concentration is increased. Water addition had little or no additive effect over that observed for FFA.

The resistivity of commercial soybean oil (SBO) increased from 3.39 to 23.7 Tohm·cm after alumina treatment to remove water and polar constituents. Treatment with water reduced the resistivity of APSBO from 23.7 to 7.25 Tohm·cm, and that of SBO from 3.39 to 0.05 Tohm·cm. These results show that water has a great effect on the resistivity of soybean oil although it is not very soluble in oil.

The reduced resistivity of commercial soybean oil, especially in the presence of water, suggests that it contains components that affect its resistivity. The alumina treatment removes polar compounds, such as phospholipids, monoglycerides, sterols, and tocopherol; so these compounds were added singly to APSBO, and the resistivity was determined both dry and in the presence of water.

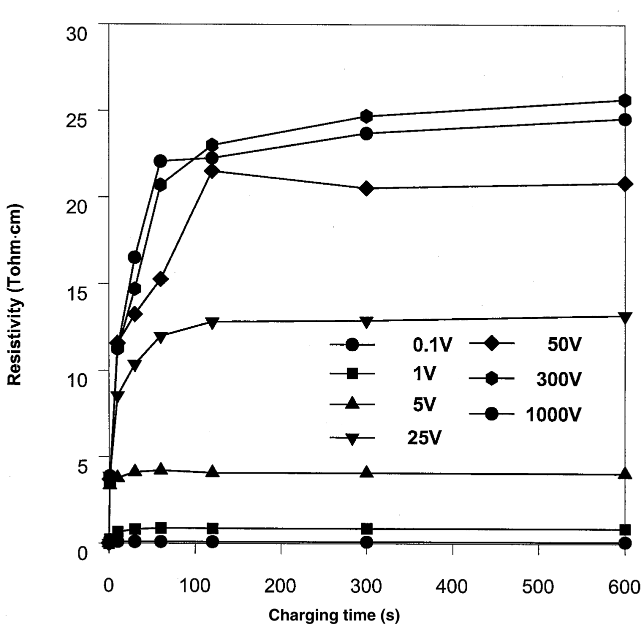

FIG. 1. The effects of voltage and charging time on the resistivity of alumina-purified soybean oil.

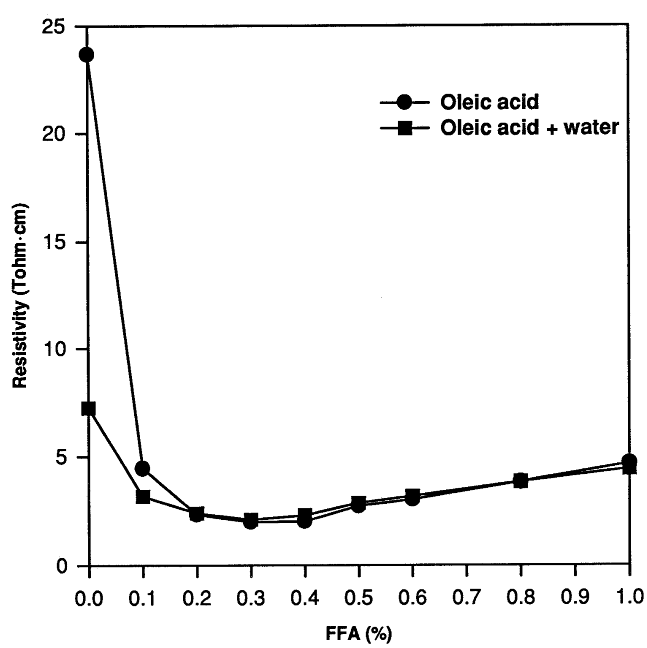

FIG. 3. The effect of oleic acid [free fatty acid (FFA)] on the resistivity of alumina-purified soybean oil.

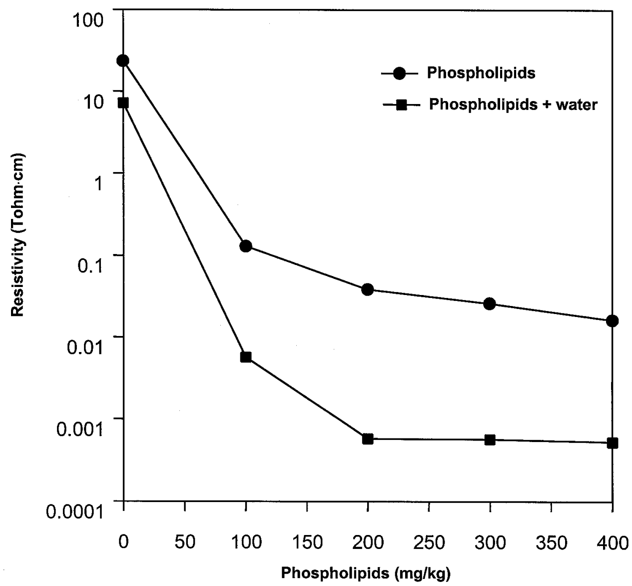

FIG. 4. The effect of phospholipids on the resistivity of alumina-purified soybean oil.

As shown in Figure 4, purified soybean phospholipid lowered the resistivity of APSBO from 23.7 to 0.016 Tohm·cm when added at 400 mg/kg. This effect probably is caused by the polarity of phospholipids. The effect of 1-monoolein, α-tocopherol, and β-sitosterol on the resistivity of dry oils was much less than that of phospholipids (Table 1), but of these three compounds, monoglycerides had the greatest effect. Water augmented the resistivity-lowering effects of phospholipids and monoglycerides by factors between 23- and 335-fold, depending on concentration of the additive. Both of these substances are effective emulsifying agents, and the synergistic effect of water on resistivity may possibly result from the emulsification of water so that it is difficult to remove from the APSBO by centrifugation. Water also augmented the resistivity-lowering effect of α-tocopherol and β-sitosterol, but in these instances, the effect was less than 40-fold greater than that of the dry additives.

TABLE 1
The Effects of Various Constituents on the Resistivity of Alumina-Purified Soybean Oil

	Resistivity in Tohm·cm			Resistivity in Tohm·cm	
	Dry oil	Wet oil[a]		Dry oil	Wet oil[a]
1-Monoolein (mg/kg)			Lauroylperoxide (meq/kg)		
0	23.7	7.25	0	23.7	7.25
100	10.3	0.114	5	15.3	3.11
300	6.27	0.037	10	15.3	2.81
900	4.02	0.012	15	18.3	2.33
			25	18.3	1.42
			50	15.0	1.17
α-Tocopherol (mg/kg)			*t*-Butylhydroperoxide (meq/kg)		
0	23.7	7.25	0	23.7	7.25
250	11.5	3.56	5	10.2	1.33
500	8.43	0.544	10	8.80	0.919
750	6.96	0.309	15	7.94	0.875
1000	6.66	0.179	25	6.93	0.733
			50	5.53	0.290
β-sitosterol (mg/kg)			β-carotene (mg/kg)		
0	23.7	7.25	0	23.7	7.25
250	11.7	4.62	5	16.2	6.28
500	8.98	0.809	10	14.8	5.88
750	8.39	0.670	15	13.1	5.36
1000	7.93	0.408	20	12.7	5.22

[a]Mixed with water for 30 min and centrifuged to remove excess water.

To see the effect of oxidation on resistivity, lauroyl peroxide and *tert*-butyl hydroperoxide were introduced into APSBO. Table 1 shows that the diacylperoxide had only a small effect on resistivity, but hydroperoxides reduced the resistivity from 23.7 to 5.53 Tohm·cm at the level of 50 meq/kg. The effect of hydroperoxides was quite similar to those of β-sitosterol and α-tocopherol, all of which have a polar OH group. When water was introduced, the resistivity of both peroxides decreased less than 20-fold.

β-Carotene is the most common color pigment of SBO. Crude soybean oil contains 40–50 ppm of carotenoids and 1–2 ppm of chlorophyll, but most of these pigments are removed during refining (10). As Table 1 shows, β-carotene reduced the resistivity of APSBO from 23.7 to 12.7 Tohm·cm. When water was introduced, the values were quite similar to those obtained by the addition of water to APSBO alone.

These results suggest that resistivity measurements might be useful in assessing the quality of soybean oil for such traits as the completeness of phospholipid and moisture removal and the level of partial glycerides.

ACKNOWLEDGMENTS

Journal Paper No. J-17641 of the Iowa Agriculture and Home Economics Experiment Station, Ames, Project 3414. The authors thank the Iowa Soybean Promotion Board and The Scientific and Technical Research Council of Turkey for partial financial support.

REFERENCES

1. Lüdde, K.H., Das dielektrische und refraktodensimetrische Verhalten flüssiger Fette beim Altern, *Fette Seifen Anstrich. 61*:1156–1163 (1959).
2. Allen, R.R., Determination of Unsaturation, *J. Am. Oil Chem. Soc. 32*:671–674 (1955).
3. Baker, W.O., and C.P. Smyth, The Possibility of Molecular Rotation in the Solid Forms of Cetyl Alcohol and Their Long-Chain Ethyl Esters, *J. Am. Chem. Soc. 60*:1229–1236 (1938).
4. Shugg, W.T., *Handbook of Electrical and Electronic Insulating Materials,* 2nd edn., IEEE Press, New York, 1995, pp. 18–20.
5. *Lange's Handbook of Chemistry*, edited by J.A. Dean, 13th edn., McGraw-Hill, New York, 1985, pp. 6–44.
6. Tagg, G.F., *The Practical Measurement of Insulation Resistance,* Newnes, Feltham, England, 1968, pp. 17–35.
7. Lipscomb, T.G. II, Mineral Insulating Oil Manufacture and Safekeeping, in *Electrical Insulating Oils. STP 998*, edited by

H.G. Erdman, American Society for Testing and Materials, Philadelphia, 1988, pp. 5–24.
8. Jensen, R.G., T.A. Marks, J. Sampugna, J.G. Quinn, and D.L. Carpenter, Purification of Triglycerides with an Alumina Column, *Lipids 1:*451–452 (1966).
9. Singleton, W.S., Properties of the Liquid State, in *Fatty Acids, Their Chemistry, Properties, Production and Uses,* 2nd edn., Part I, edited by K.S. Markley, Interscience, New York, 1960, pp. 499–607.
10. Taylor, D.R., Adsorptive Purification, in *Proceedings of the World Conference on Oilseed Technology and Utilization,* edited by T.H. Applewhite, American Oil Chemists' Society, Champaign, 1992, pp.152–165.

[Received October 16, 1997; accepted December 19, 1997]