Effects of Microwave Heating on Changes in Chemical and Thermal Properties of Vegetable Oils

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ABSTRACT: The effects of microwave heating on the cooling profiles of two vegetable oils (corn oil and soybean oil) were studied using differential scanning calorimetry (DSC) and compared to changes in chemical parameters. These oils were exposed for several periods of time to three controlled treatments: low-, medium-, and high-power settings, respectively. The DSC results were derived from the cooling curve of oils at a scanning rate of 5°C/min. The chemical analyses of the oils included peroxide value, anisidine value, free fatty acid content, iodine value, and C18:2/C16:0 peak area ratio. A statistical comparison was carried out between DSC and the chemical parameters. In general, correlations were good between these parameters. Likewise, the experimental data showed that, for a given microwave power setting, a good correlation existed between DSC curve parameters and heating periods. These results indicate that DSC can be used as an objective nonchemical, instrumental technique to monitor lipid oxidation in both traditionally heated and microwave-heated oils.

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KEY WORDS: Chemical analyses, DSC, microwave heating, oxidation, quality characteristics, vegetable oils.

Microwave heating is one of the most commonly used methods of food preparation today because of its convenience, rapidity, and economy (1). Advances in equipment design, trends in electrical energy costs, and research on food properties have provided a basis for modeling microwave heating patterns that should stimulate the development of new and improved commercial food processes. In the food industry, microwave heating operations have been used with increasing success in baking, blanching, cooking, drying, pasteurization, sterilization, and thawing of various food products (2,3). George (4) reviewed the application of microwave heating in food processing with reference to the advantages and limitations for a range of food processing operations.

Microwave penetration depths within a product are determined by the electrical and physical properties, heating patterns, microbial inactivation, and safety (5) and can vary significantly with chemical composition, product temperature, and the frequency at which the microwave operates. Industrial microwave systems are available in both batch and continuous design configurations and use magnetrons that develop either 915 or 2450 MHz (6). Lassen and Ovesen (7) reviewed the effects of microwave heating on the nutritional constituents of foods and concluded it does not change the nutrient content of food to any greater extent than conventional cooking.

The chemical constituents of oils that degrade during microwave heating do so at rates that vary with heating temperature and time, as with other domestic processing methods (e.g., frying, steaming, and roasting). Suitable quality parameters therefore can be used as time–temperature integrators of quality deterioration of oils during microwave heating. Monitoring of many of these parameters makes extensive use of chemicals. Also, the methods for measuring such components can be relatively complex and time-consuming, which can be a major drawback in industrial applications. Instrumental methods involving simpler and faster techniques for determining changes in oil are desired.

Differential scanning calorimetry (DSC) is an instrumental method available to the oils and fats researcher (8). This technique is used for studying various heat-related phenomena in materials by monitoring associated changes in enthalpy. It offers a sensitive and reproducible fingerprint method for identification of vegetable oils and fats. DSC has been used to describe and interpret thermal properties and chemical composition of 17 vegetable oil samples in terms of melting and crystallization behaviors (9), to monitor oxidation processes (10), and to determine total polar compounds in heated oils (11).

Yoshida *et al.* (12–14) studied the composition and oxidative stability of edible oils during microwave heating. However, little has been reported on how microwave heating affects thermal properties of vegetable oils. The primary purpose of this research was to examine the influence of time–microwave power interactions on the thermal properties and quality characteristics of vegetable oils. A secondary objective was to investigate the correlation between DSC curve parameters and other standard chemical methods in microwave-heated oils.

MATERIALS AND METHODS

Materials. Two different edible oils were used in this study. Commercial corn oil (CO) and soybean oil (SO) were purchased from a local grocery store and were used in all of the experiments. All chemicals and solvents used were of analytical grade unless otherwise specified.

Microwave treatments. A domestic microwave oven (National, Model NN-5656F; Matsushita Electric Industrial Co.,

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Ltd., Osaka, Japan) was used in this study. To standardize the operation of the microwave oven for each heating test, we took additional steps between tests. Between tests, the oven door was opened and an electrical fan was used to blow ambient air into the oven cavity (max. 23 L) for 5 min to facilitate the cooling process. Thus, the temperature of the oven was reduced to approximately 30 ± 2°C between tests. All oil samples were simultaneously exposed at a frequency of 2450 Hz. There were three settings of heating corresponding to low, medium, and high power, and when operated at high power the oven provided *ca.* 900 W. Eighty grams of oil were divided into two 40-mL amber bottles (40 g each; 4 cm i.d.), which were placed at equal distances on the rotary turntable plate of the microwave oven. The oil samples were heated for various periods (4, 8, 12, 16, and 20 min) at each power setting. The two samples were combined after microwave treatment and before analysis. The temperatures of the heated oils immediately after exposure for each time period were determined with a calibrated chromel-alumel thermocouple. These temperature data are shown in Figure 1. All oil samples were stored under nitrogen at −18°C for further analyses. Analysis of oil was carried out immediately after the heating experiments and completed within 2 wk.

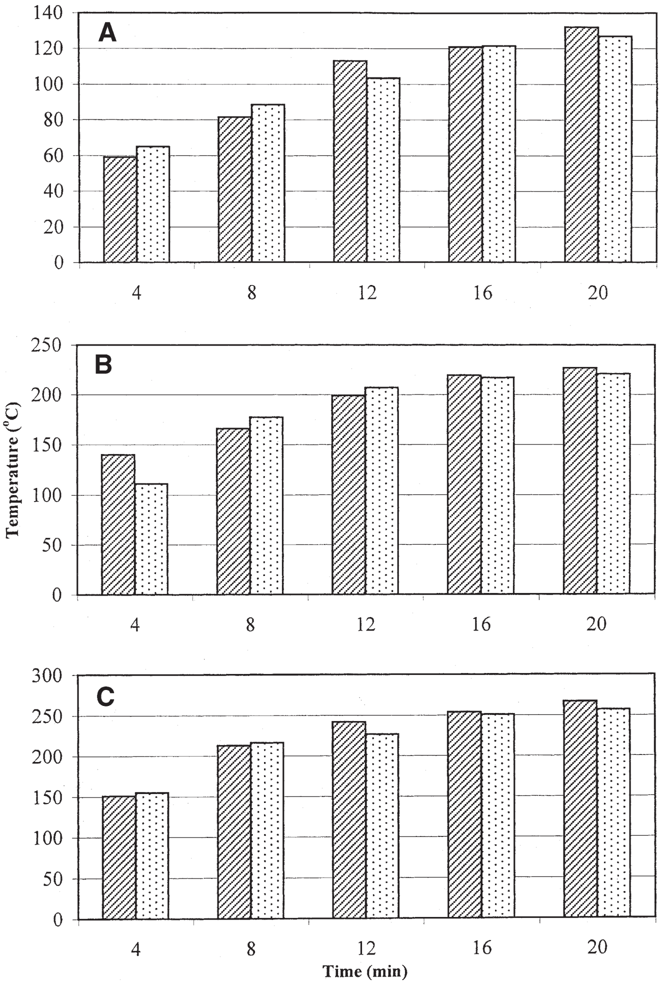

FIG. 1. Temperatures of oils heated in a microwave oven at three different power settings: A, low-power setting; B, medium-power setting; C, high-power setting. Lined bars, corn oil; stippled bars, soybean oil.

Standard chemical analysis. The AOCS Official Methods were employed for determinations of free fatty acid (FFA) content; iodine (IV), anisidine (AnV) and peroxide (PV) values in the oil samples (15). The fatty acid compositions of the microwave-heated oil were analyzed by gas chromatography (GC) after transesterification. GC analysis was performed as described previously for edible oils (9). The peak area ratios of C18:2/C16:0 were then calculated.

DSC analysis. A PerkinElmer differential scanning calorimeter, DSC-7 (PerkinElmer Corp., Norwalk, CT) was used for thermal analysis of oil samples. Purified nitrogen (99.999% purity) was the purge gas for the dry box and flowed at *ca.* 20 mL/min. The DSC instrument was calibrated with indium and *n*-dodecane. Samples of *ca.* 6–12 mg were weighed into aluminum pans to the nearest of 0.1 mg, and covers were hermetically sealed into place. An empty, hermetically sealed aluminum pan was used as reference. Prior to analysis of samples, the baseline was obtained with an empty, hermetically sealed aluminum pan. Samples were subjected to the following temperature program: Sample was melted at 50°C and held for 5 min before cooling to −100°C at the rate of 5°C/min. The cooling curves of the samples showed three distinct crystallization peaks (A: high-temperature, B: medium-temperature, C: low-temperature peaks). The percentage areas of these three peaks were calculated with the 7 Series/UNIX DSC software library (16). The construction and designation of these parameters are shown in Figure 2.

Statistical analysis. All experiments and/or measurements were duplicated. The data were analyzed using the SAS/STAT release 6.08 program (17). To examine the influence of microwave heating, data from the oils were analyzed as a 3 × 5 factorial arrangement of treatments with microwave power (low, medium, and high) and heating time (4, 8, 12, 16, and 20 min) as

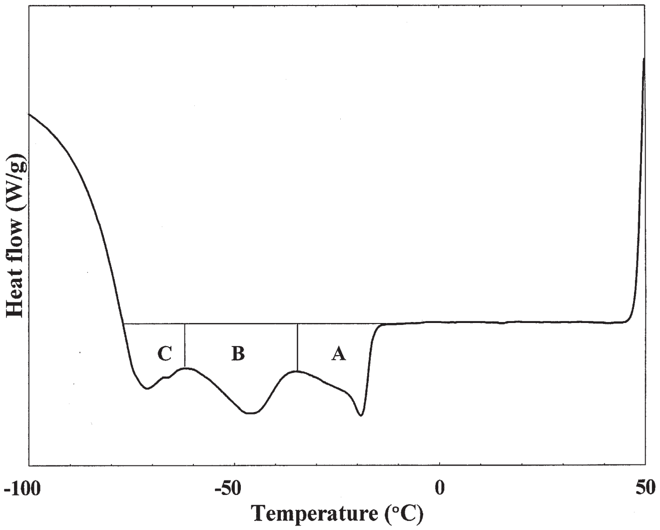

FIG. 2. Differential scanning calorimetry (DSC) cooling curve of unheated corn oil. The techniques used for determination of the DSC peak areas are indicated by the letters A, B, and C. The DSC peak areas are constructed by using 7 series/UNIX software library (16).

main effects using the analysis of variance procedure. Duncan's multiple range test was applied for means with significant ($P < 0.05$) differences. The relationships between each of the DSC curve parameters and standard chemical methods were determined by Pearson's correlation analysis with the SAS program.

RESULTS AND DISCUSSION

The initial characteristics of unheated vegetable oils used in this study are shown in Table 1. Microwave-heated oil samples were analyzed for PV, AnV, FFA, IV, and C18:2/C16:0 ratios. The major chemical and DSC parameter changes affected by microwave heating and heating time are given in Tables 2 and 3 and are in general agreement with those published in the literature (14,18). In general, microwave heating had significant ($P < 0.05$) effects on these quality parameters. As expected, oil samples heated at high-power setting reflected significantly more heat abuse than oil samples heated at medium- and low-power settings. Longer microwave heating times resulted in a greater degree of oil deterioration. There were only minor increases or decreases ($P < 0.05$) in parameters such as AnV, FFA, IV, and C18:2/C16:0 (Table 2), in oil heated at low power. Thereafter, highly significant ($P < 0.05$) increases or decreases for these values were noticed for oil samples heated at higher microwave power settings.

Changes in PV during microwave heating are presented in Table 2. Some investigators (19) consider edible oils with a PV of 7.5 meq/kg to be sensorily unacceptable. At a low-power setting, the PV of CO exceeded this value by 20 min of heating, whereas for SO, the PV surpassed this value at all three power settings at various times. PV for the CO samples heated at medium- and high-power settings exhibited one (at 8 min of heating) and two (at 4 and 20 min of heating) maxima, respectively. The formation of hydroperoxides was more pronounced at the low-power setting than at the medium- and high-power settings. This results from rapid decomposition of hydroperoxides to secondary oxidation products at elevated temperature. They are extremely unstable and decompose *via* fission, dehydration, and formation of free radicals to yield a variety of chemical products, such as alcohols, aldehydes, ketones, acids, dimers, trimers, polymers, and cyclic compounds. Similar changes were noted for microwave-heated SO. In general, PV do not indicate the absolute state of lipid oxidation because hydroperoxides are unstable on heating, resulting in rapid transformation to secondary products (20).

TABLE 1
Characteristics of Unheated Vegetable Oils Used in Experiments[a]

Characteristics	Corn oil (CO)	Soybean oil (SO)
Peroxide value (meq/kg oil)	3.7 ± 0.0	4.2 ± 0.3
Anisidine value	2.0 ± 0.1	1.0 ± 0.00
Free fatty acid (%)	0.10 ± 0.00	0.04 ± 0.00
Iodine value (g of I_2/100 g oil)	127.6 ± 0.9	131.1 ± 0.9
C18:2/C16:0 ratio	5.0 ± 0.0	5.9 ± 0.0
DSC peak area (%)		
A	34.7 ± 0.4	33.8 ± 0.6
B	42.6 ± 0.8	49.3 ± 0.8
C	22.7 ± 0.6	16.9 ± 0.1

[a]Each value in the table represents the mean ± standard deviation of four measurements from two replicates. C18:2/C16:0, ratio of linoleic acid/palmitic acid.

The AnV of microwave heated oils are given in Table 2. This oxidation parameter was generally higher in SO samples than in CO. The SO AnV increased slightly more rapidly than the CO, mainly because of its highly unsaturated nature (SO is especially high in linoleic acid content). Generally, the oil AnV increased slowly in the low-power setting and more rapidly in the medium- and high-power settings. As compared to PV, the AnV is a more meaningful test because it measures the accumulation of secondary oxidation products (aldehyde compounds).

Table 2 also shows the effect of microwave heating on changes in FFA for CO and SO at three different microwave power settings. FFA content is an index of hydrolytic rancidity and contributes to the development of off-flavors and off-odors in the oil. Generally, there were no significant differences ($P > 0.05$) in the FFA contents for all oils until 8 min of heating. FFA of the two oils increased slightly with longer heating time owing to significant ($P < 0.05$) production of fatty acids by microwave energy. In general, the FFA content for SO at all power settings and heating duration was much lower than that of CO, mainly as a result of the lower initial FFA content of SO.

IV, a measure of overall unsaturation, gradually decreased with the increased heating power settings and times (Table 2). For CO, the changes in IV from 4 to 20 min of heating were 1.7, 3.6, and 4.0 g I_2/100 g for low-, medium-, and high-power settings, respectively. For SO, these values were 2.8, 5.6, and 8.00 g/100 g, respectively. The reductions in IV were greatest for oil samples heated at the high-power setting. In terms of different types of oils, the reduction was higher for SO than for CO. The reduction in IV during heating is often taken as a measure of oil deterioration (21). The analysis is analogous to that for reduction of unsaturated fatty acids in oil samples.

C18:2/C16:0 ratios in Table 2 reflect a decrease in the relative percentage of unsaturated fatty acids and an increase in the relative percentage of saturated fatty acids when CO and SO are microwave heated (4). Linoleic and palmitic acids are usually used as indicators of the extent of fat deterioration because linoleic acid is more susceptible to oxidation, whereas palmitic acid is more stable toward oxidation. The C18:2/C16:0 for microwave-heated oil decreased with increased heating power settings.

DSC cooling curves for CO and SO samples heated at high-power settings for different durations are affected in a systematic way (Figs. 3,4). Similar changes were noted for CO and SO samples heated at low- and medium-power settings. All curves have three distinct exothermic peaks (A, high-temperature peak; B, medium-temperature peak; and C, low-temperature peak), which may correspond to three triacylglycerol (TAG) groups (monounsaturated TAG, diunsaturated TAG, and triunsaturated TAG) (9). For CO, the original percentage

TABLE 2
Changes in Chemical Characteristics of Edible Oils During Microwave Heating[a]

Oil	Power	Heating time (min)	Peroxide value (meq/kg oil)	Anisidine value	Free fatty acid (%)	Iodine value (g of I_2/100 g oil)	C18:2/16:0
CO	Low	4	3.7 ± 0.2^{e}	2.4 ± 0.0^{e}	0.10 ± 0.01^{d}	127.0 ± 0.4^{a}	5.0 ± 0.0^{a}
		8	4.0 ± 0.0^{d}	2.4 ± 0.1^{d}	0.11 ± 0.00^{c}	$127.0 \pm 0.6^{a,b}$	4.9 ± 0.1^{a}
		12	4.4 ± 0.2^{c}	2.6 ± 0.0^{c}	$0.12 \pm 0.00^{b,c}$	$126.2 \pm 0.5^{b,c}$	4.8 ± 0.1^{b}
		16	5.6 ± 0.0^{b}	2.7 ± 0.0^{b}	$0.12 \pm 0.00^{a,b}$	$125.8 \pm 0.4^{c,d}$	$4.7 \pm 0.0^{b,c}$
		20	8.2 ± 0.2^{a}	3.0 ± 0.0^{a}	0.12 ± 0.00^{a}	125.3 ± 0.2^{d}	4.7 ± 0.0^{c}
	Medium	4	5.4 ± 0.2^{b}	3.1 ± 0.0^{e}	0.11 ± 0.00^{c}	127.1 ± 0.2^{a}	5.0 ± 0.0^{a}
		8	5.7 ± 0.2^{a}	7.2 ± 0.1^{d}	0.11 ± 0.00^{c}	126.0 ± 0.3^{b}	4.8 ± 0.1^{b}
		12	4.0 ± 0.1^{c}	17.4 ± 0.2^{c}	0.12 ± 0.01^{b}	124.9 ± 1.2^{c}	4.7 ± 0.1^{c}
		16	3.5 ± 0.0^{d}	24.0 ± 0.0^{b}	$0.12 \pm 0.00^{a,b}$	$124.2 \pm 0.5^{c,d}$	$4.6 \pm 0.1^{c,d}$
		20	3.3 ± 0.0^{d}	26.0 ± 0.2^{a}	0.13 ± 0.00^{a}	123.5 ± 0.0^{d}	4.5 ± 0.1^{d}
	High	4	5.9 ± 0.6^{a}	4.3 ± 0.0^{e}	0.11 ± 0.00^{c}	127.0 ± 0.2^{a}	4.9 ± 0.0^{a}
		8	4.4 ± 0.0^{b}	16.0 ± 0.1^{d}	0.12 ± 0.00^{c}	126.1 ± 0.1^{a}	4.7 ± 0.0^{b}
		12	3.4 ± 0.2^{c}	21.3 ± 0.0^{c}	0.12 ± 0.00^{c}	$124.8 \pm 2.1^{a,b}$	4.5 ± 0.1^{c}
		16	4.7 ± 0.0^{b}	26.1 ± 0.0^{b}	0.14 ± 0.01^{b}	122.3 ± 1.4^{c}	4.3 ± 0.0^{d}
		20	5.9 ± 0.0^{a}	27.2 ± 0.1^{a}	0.16 ± 0.02^{a}	$123.0 \pm 2.2^{b,c}$	4.3 ± 0.0^{d}
SO	Low	4	4.8 ± 0.1^{e}	1.3 ± 0.0^{e}	0.04 ± 0.00^{c}	131.0 ± 0.1^{a}	5.9 ± 0.1^{a}
		8	5.3 ± 0.1^{d}	1.7 ± 0.0^{d}	0.04 ± 0.00^{c}	131.0 ± 0.4^{a}	5.8 ± 0.1^{a}
		12	5.5 ± 0.1^{c}	2.1 ± 0.0^{c}	0.04 ± 0.00^{c}	129.6 ± 0.7^{b}	5.7 ± 0.1^{b}
		16	6.8 ± 0.1^{b}	2.4 ± 0.1^{b}	0.05 ± 0.01^{b}	129.2 ± 0.7^{b}	5.6 ± 0.1^{c}
		20	11.2 ± 0.1^{a}	2.7 ± 0.0^{a}	0.06 ± 0.00^{a}	128.2 ± 0.7^{c}	5.5 ± 0.0^{c}
	Medium	4	6.7 ± 0.1^{b}	1.5 ± 0.0^{e}	0.04 ± 0.00^{a}	130.8 ± 0.4^{a}	5.8 ± 0.0^{a}
		8	8.7 ± 0.2^{a}	7.2 ± 0.0^{d}	$0.04 \pm 0.01^{a,b}$	130.8 ± 0.2^{a}	5.7 ± 0.0^{a}
		12	2.7 ± 0.0^{c}	20.3 ± 0.0^{c}	$0.05 \pm 0.00^{b,c}$	$129.7 \pm 0.7^{a,b}$	5.6 ± 0.1^{b}
		16	2.8 ± 0.1^{c}	24.7 ± 0.0^{b}	$0.05 \pm 0.01^{c,d}$	$126.9 \pm 0.8^{b,c}$	5.5 ± 0.0^{b}
		20	2.6 ± 0.1^{c}	32.3 ± 0.2^{a}	0.06 ± 0.01^{d}	124.9 ± 4.0^{c}	5.3 ± 0.1^{c}
	High	4	9.4 ± 0.1^{b}	4.1 ± 0.0^{e}	0.04 ± 0.00^{c}	131.1 ± 0.8^{a}	5.8 ± 0.0^{a}
		8	4.2 ± 0.0^{c}	19.3 ± 0.1^{d}	$0.04 \pm 0.00^{b,c}$	130.1 ± 0.1^{a}	$5.7 \pm 0.2^{a,b}$
		12	3.3 ± 0.1^{e}	20.8 ± 0.2^{c}	0.05 ± 0.01^{b}	$128.5 \pm 1.3^{a,b}$	5.5 ± 0.1^{b}
		16	3.8 ± 0.1^{d}	27.8 ± 0.0^{b}	0.08 ± 0.01^{a}	$126.3 \pm 2.1^{b,c}$	5.2 ± 0.3^{c}
		20	9.8 ± 0.4^{a}	34.9 ± 0.5^{a}	0.09 ± 0.00^{a}	123.1 ± 4.2^{c}	4.9 ± 0.1^{d}

[a] Each value in the table represents the mean ± standard deviation of four measurements from two replicates. For each heating power, means within each column with different superscripts are significantly ($P < 0.05$) different. For abbreviations see Table 1.

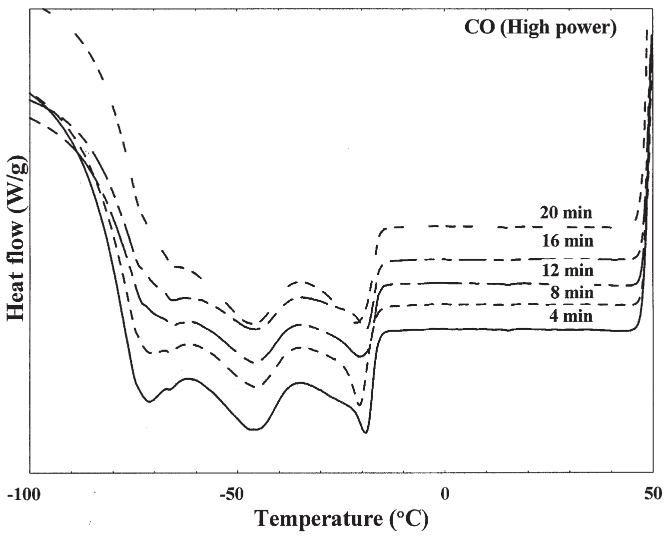

FIG. 3. DSC cooling curves of corn oil (CO) samples heated at the high-power setting for different heating times (4, 8, 12, 16, and 20 min).

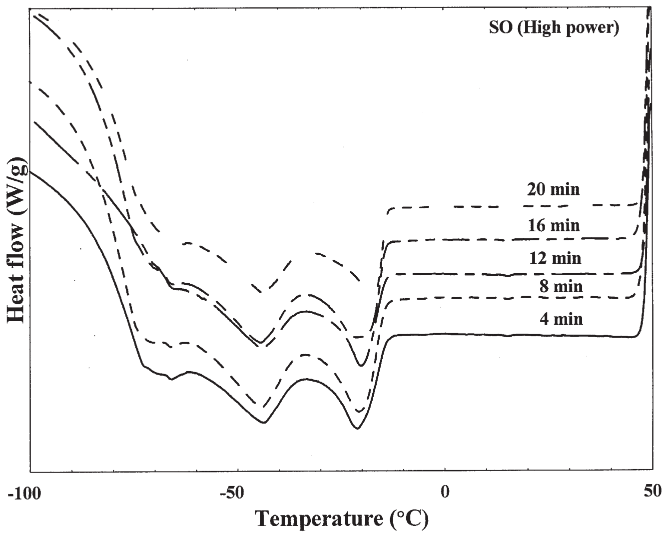

FIG. 4. DSC cooling curves of soybean oil (SO) samples heated at the high-power setting for different heating times (4, 8, 12, 16, and 20 min).

TABLE 3
Changes in Characteristics of Corn and Soybean Oils During Microwave Heating[a]

Oil	Power	Heating time (min)	Peak area (%) A	Peak area (%) B	Peak area (%) C
CO	Low	4	35.5 ± 0.1^{b}	41.9 ± 1.1^{d}	22.6 ± 1.2^{a}
		8	34.6 ± 0.2^{c}	44.4 ± 0.1^{c}	21.0 ± 0.3^{b}
		12	35.8 ± 0.4^{b}	45.7 ± 0.6^{a,b}	18.5 ± 0.2^{c}
		16	36.8 ± 0.2^{a}	45.0 ± 0.2^{b,c}	18.3 ± 0.4^{c}
		20	37.0 ± 0.3^{a}	46.3 ± 0.2^{a}	16.6 ± 0.2^{d}
	Medium	4	34.9 ± 0.2^{c}	44.6 ± 0.4^{d}	20.6 ± 0.6^{a}
		8	33.3 ± 0.1^{d}	50.2 ± 0.3^{b,c}	16.5 ± 0.2^{b}
		12	35.6 ± 1.2^{c}	49.6 ± 1.2^{c}	14.8 ± 0.0^{c}
		16	36.6 ± 0.4^{b}	51.0 ± 0.1^{a,b}	12.4 ± 0.4^{d}
		20	37.5 ± 0.3^{a}	51.5 ± 0.5^{a}	11.0 ± 0.2^{e}
	High	4	32.5 ± 0.5^{e}	49.0 ± 0.2^{d}	18.4 ± 0.3^{a}
		8	34.2 ± 0.2^{d}	51.4 ± 0.0^{c}	14.4 ± 0.2^{b}
		12	36.9 ± 0.1^{c}	55.4 ± 0.5^{b}	7.7 ± 0.4^{c}
		16	39.0 ± 0.3^{b}	54.1 ± 0.5^{a}	6.9 ± 0.2^{d}
		20	40.8 ± 0.6^{a}	55.6 ± 0.8^{a}	3.6 ± 0.3^{e}
SO	Low	4	33.3 ± 0.5^{b,c}	50.0 ± 0.5^{c}	16.8 ± 0.0^{a}
		8	32.6 ± 1.2^{c}	51.8 ± 0.9^{b}	15.7 ± 0.4^{b}
		12	34.5 ± 1.1^{a,b}	52.0 ± 0.9^{b}	13.5 ± 0.2^{c}
		16	34.8 ± 1.1^{a,b}	52.7 ± 0.8^{b}	12.4 ± 0.3^{d}
		20	35.5 ± 1.1^{a}	54.2 ± 1.2^{a}	10.3 ± 0.1^{e}
	Medium	4	33.8 ± 0.1^{c}	50.0 ± 0.2^{d}	16.3 ± 0.2^{a}
		8	33.8 ± 0.2^{c}	51.8 ± 0.7^{c}	14.4 ± 0.5^{b}
		12	34.5 ± 0.1^{b}	54.0 ± 0.3^{b}	11.6 ± 0.2^{c}
		16	34.7 ± 0.4^{b}	54.8 ± 0.4^{a}	10.5 ± 0.0^{d}
		20	35.6 ± 0.8^{a}	55.4 ± 0.7^{a}	9.0 ± 0.0^{e}
	High	4	33.0 ± 0.1^{d}	53.8 ± 0.5^{d}	13.2 ± 0.4^{a}
		8	34.2 ± 0.9^{c}	55.2 ± 0.7^{b,c}	10.7 ± 0.2^{b}
		12	35.3 ± 0.5^{b}	56.0 ± 0.2^{a}	8.7 ± 0.3^{c}
		16	37.2 ± 0.9^{a}	54.9 ± 0.6^{c}	7.9 ± 0.3^{d}
		20	37.2 ± 0.1^{a}	55.8 ± 0.3^{a,b}	7.0 ± 0.4^{e}

[a] Each value in the table represents the mean ± standard deviation of four measurements from two replicates. For each heating power, means within each column with different superscripts are significantly ($P < 0.05$) different. For abbreviations see Table 1.

areas of these three exotherms before microwave heating were 35.2, 42.2, and 22.6% for A, B, and C, respectively. For SO, these values were 33.5, 49.6, and 17.0, respectively. In general, as the time of heating increased, the area of C decreased dramatically (Table 3). However, the changes in peak area were less pronounced in A and B for both CO and SO during microwave heating. The trends became more pronounced ($P < 0.05$) at higher microwave power settings. This may be attributed to the disappearance of unsaturated TAG and the formation of more saturated TAG (9). Here again, the decrease or increase of each DSC exothermic peak was dependent on microwave power settings, and the decrease and increase were in the order: low power < medium power < high power.

The matrix of correlation coefficients between each of the

TABLE 4
Corn Oil Data—Pearson Correlation Coefficient (*n* = 5) Between DSC Curve Parameters, Heating Time, and Wet Chemical Methods[a]

	DSC peak area A			DSC peak area B			DSC peak area C		
	Low	Medium	High	Low	Medium	High	Low	Medium	High
Heating time	0.8425	0.8349	0.9977**	0.8761	0.8328	0.8864*	–0.9750**	–0.9819**	–0.9728**
PV	0.8295	–0.9394*	0.0333	0.6987	–0.6030	0.3566	–0.8422*	0.8555	0.1483
AnV	0.8401	0.8633	0.9456*	0.8131	0.7928	0.9276**	–0.9287*	–0.9643**	–0.9629**
FFA	0.7123	0.8343	0.9450*	0.9445*	0.8199	0.7337	–0.9706**	–0.9720**	–0.8719
IV	–0.8611	–0.8074	–0.9486*	–0.8701	–0.8588	–0.8027	0.9783**	0.9895**	0.9062*
C18:2/C16:0	–0.8504	–0.7922	–0.9859**	–0.8786*	–0.8643	–0.9196*	0.9800**	0.9869**	0.9817**

[a] Abbreviations: PV, peroxide value; AnV, anisidine value; FFA, free fatty acid; IV, iodine value; C18:2/C16:0, ratio of linoleic acid/ palmitic acid; DSC, differential scanning calorimetry. **Significance at 0.01 level ($P < 0.01$); *significance at 0.05 level ($P < 0.05$).

TABLE 5
Soybean Oil Data—Pearson Correlation Coefficient ($n = 5$) Between DSC Curve Parameters, Heating Time, and Wet Chemical Methods[a]

	DSC peak area A			DSC peak area B			DSC peak area C		
	Low	Medium	High	Low	Medium	High	Low	Medium	High
Heating time	0.8940*	0.9521*	0.9744**	0.8940*	0.9705**	0.6820	–0.9937**	–0.9878**	–0.9687**
PV	0.7796	–0.8157	–0.1150	0.8771	–0.8285	–0.3440	–0.8865*	0.8440	0.2100
AnV	0.8851*	0.9541*	0.9369*	0.9697**	0.9820**	0.7520	–0.9909**	–0.9971**	–0.9664**
FFA	0.9154*	0.9756**	0.9540*	0.9176*	0.9595**	0.3975	–0.9740**	–0.9853**	–0.8503
IV	–0.9645**	–0.9599**	–0.9274*	–0.9081*	–0.8475	–0.5861	0.9913**	0.8951*	0.8992*
C18:2/C16:0	–0.9307*	–0.9672**	–0.9482*	–0.9131*	–0.9633**	–0.5514	0.9785**	0.9861**	0.9019*

[a]For abbreviations: see Table 4. **Significance at 0.01 level ($P < 0.01$); *significance at 0.05 level ($P < 0.05$).

DSC curve parameters and standard chemical methods for CO and SO are shown in Tables 4 and 5, respectively. For CO and SO samples, the DSC peak area of C revealed good correlation with the heating periods and standard chemical methods. For the DSC peak areas of A and B, the results showed good correlations with heating periods and standard chemical methods only at high-power settings. However, correlations were poor between each of the DSC curve parameters and PV. This may be due to the rapid decomposition of hydroperoxides to secondary products during microwave heating. In general, the high correlation found between each of the DSC curve parameters and heating periods suggests that DSC can be recommended as an appropriate objective method for evaluating the extent of oil deterioration during microwave heating. The DSC method can therefore be employed as a time–microwave power indicator during microwave heating.

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