Effects of Sugar, Salt and Water on Soybean Oil Quality During Deep-Frying

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The effects of flour dough components (water, sugar and salt) on soybean oil deterioration during deep-fat frying have been investigated. Flour dough sheets made from flour and water were used as the carrier of salt and sugar. Several analyses, including acid value, carbonyl value, *p*-anisidine value, color, dielectric constant, Fritest, total polar compounds and polymer content, were used to evaluate deterioration of oil quality during deep-fat frying. The relationship between frying time and analytical data was analyzed by Duncan's multiple range test. Oil quality after frying simple flour dough sheets without additives was inferior to that after frying dough sheets with added sugar or salt. The sugar and salt in the flour dough sheets may play a role as water-binding substances during frying. Among the effects of water, salt and sugar, the rate of oil deterioration was found to be highest for water, followed by salt and sugar. The combined addition of salt and sugar had no enhancing effect on the oil deterioration during deep-fat frying.

KEY WORDS: Flour dough, frying, oil deterioration, salt, soybean oil, sugar, water.

Deep-fat frying is widely used by both the food industry and by consumers. Various chemical reactions, such as oxidation, hydrolysis, polymerization and scission, occur during frying (1). The extent of these reactions depends on the frying temperature, duration, aeration, frequency that the fat is changed, frying equipment, cleaning of the fryer, type of frying oil or fat, and the food that is being fried (2,3). Although several methods have been used to evaluate deterioration of frying oils (4), no single method is satisfactory. A previous study suggested that heat abuse accentuates the normal deterioration of oils and fats (5). A myriad of (volatile and nonvolatile) decomposition products accumulate with increased use, in a frying oil to some extent. Soybean oil heated under static conditions for 80 h contained 29% total polar (TP) compounds (6), which exceeds the acceptable limit (27% TP compounds) proposed by the German Society for Fat Research (4,7). During frying, equipment design, control of operating conditions, the type of food being fried and oil type all affect end-product quality as well as the life of the oil (8). The type of food being fried and its interaction with oil have been reported to contribute to the deterioration of frying oil (8,9). Stevenson *et al.* (9) indicated that, when the food being fried contains a large amount of water, it increases the rate of oil breakdown. In this study, attempts were made to characterize the extent of frying oil deterioration by using a food system containing various levels of water, sugar and salt.

MATERIALS AND METHODS

Materials. Refined, bleached and deodorized soybean oil, flour with low protein content (7.5%), sugar and salt were purchased from a local market. Potassium hydroxide, trichloroacetic acid, 2,4-dinitrophenyl hydrazine, absolute ethyl alcohol, benzyl alcohol, ethyl ether and petroleum ether were purchased from E. Merck (Darmstadt, Germany); benzene and isooctane were purchased from Fisher Scientific Co. (Fairlawn, NJ); and *p*-anisidine (*p*-AnV) was purchased from Sigma Chemical Co. (St. Louis, MO).

Methods. Soybean oil (4.5 L), contained in a 6-L fryer, was heated to 185–190°C. The compositions of samples used for frying were as follows: (a) control, oil was heated without sample; (b) water, 18 g of cotton balls saturated with 225 mL water; (c) flour–water, a flour dough made from 450 g flour and 225 mL water; (d) flour–water–sugar, dough (c) with 75 g sugar added; (e) flour–water–salt, dough (c) with 30 g salt added; (f) flour–water–sugar–salt, dough (c) with 75 g sugar and 30 g salt added. Samples (c)–(f) were prepared by proper mixing and kneading and then divided into six lots for one-hour frying tests. Each lot was again divided into ten portions, and each portion was flattened into a sheet with a diameter of 5–6 cm. The total time needed for frying each lot of ten dough sheets was 10 min, which included 5 min for temperature rise and 5 min for frying. These frying processes were conducted continuously for six hours a day on four consecutive days, and the oil after each six-hour frying period was allowed to cool to ambient temperature for 18 h before resuming frying. Oil samples (100 mL) from each frying test were taken after the 18-h cooling cycle.

Analyses. American Oil Chemists' Society methods were used for the determination of acid value (AV) (Method Cd 3d-63), TP compounds (Method Cd 20-91) and color (Method Cc 13b-45) (10). Carbonyl value (COV) and *p*-AnV were determined according to Bhalerao *et al.* (11) and Paquot and Hautfenne (12), respectively. The change in dielectric constant (DC) was measured with a Foodoil Sensor Model NI-20 (Northern Instruments Corp., Lino Lakes, MN) (13). The Fritest, based on the reaction of oxidative products, (i.e., aldehyde with alkali solution) was measured with a spectrophotometer at 520 nm (4). Viscosity was determined with a VT-03 portable viscometer (Rion Co., Tokyo, Japan).

Statistical analysis. All the data were analyzed for difference with Duncan's multiple range test on SAS software (14).

RESULTS AND DISCUSSION

Changes in the physicochemical properties of soybean oil during static heating and frying of flour dough sheets with different additives are shown in Figure 1. Control soybean oil during static heating without any frying showed the lowest values in AV, COV, DC, Fritest, oil color, *p*-AnV, TP compounds and polymer content among all the sample groups. However, when soybean oil was used to fry either water absorbed in cotton balls or flour dough sheets containing salt and/or sugar additives, the oil deteriorated more rapidly than the control oil. Water, salt and sugar adversely affected frying oil quality, and their effects were different. Table 1 shows the effects of dough preparations,

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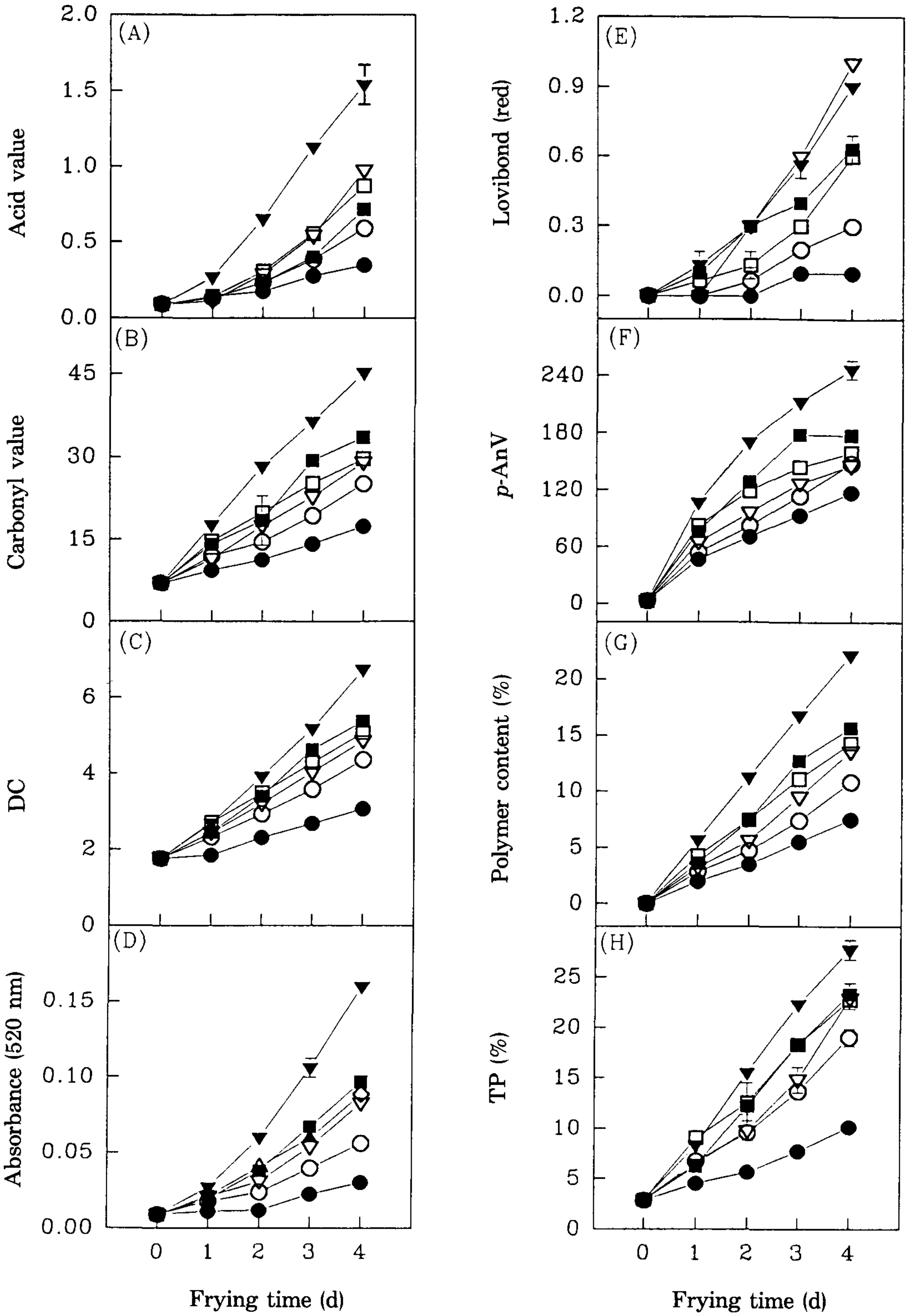

FIG. 1. Changes in: (A), acid value; (B), carbonyl value; (C), dielectric constant (DC); (D), Fritest; (E), red color; (F), *p*-anisidine value (*p*-AnV); (G), polymer content; (H), total polar (TP) compounds during frying of soybean oil with various preparations of food being fried. ●, Control; ▼, water; ■, dough without additives; ○, dough with added sugar; ▽, dough with added salt; □, dough with added salt and sugar.

TABLE 1

Effects of Different Food Ingredients on the Changes in Parameters of Soybean Oil Quality During Four Days of Frying

	Average change^{a}					
Parameter^{b}	Control	Water	F + W	F + W + Su	F + W + Sa	F + W + Su + Sa
AV	0.0653^{h}	0.3757^{d}	0.1520^{f}	0.1250^{g}	0.2190^{e}	0.1970^{e}
COV	2.511^{h}	9.479^{d}	6.791^{e}	4.291^{g}	5.486^{f}	5.547^{f}
DC	0.34733^{i}	1.24367^{d}	0.93933^{e}	0.64433^{h}	0.77800^{g}	0.81933^{f}
Fritest	0.005400^{i}	0.038033^{d}	0.022333^{e}	0.011600^{h}	0.018000^{g}	0.019767^{f}
Color(R)	0.03000^{i}	0.22333^{e}	0.15667^{f}	0.08000^{h}	0.26000^{d}	0.14333^{g}
p-AnV	27.684^{h}	59.534^{d}	45.319^{e}	35.098^{g}	34.912^{g}	37.640^{f}
TP^{c}	1.773^{g}	6.366^{d}	5.297^{e}	3.919^{f}	4.845^{e}	4.896^{e}
Polymer	1.8489^{i}	5.5285^{d}	4.0359^{e}	2.6076^{h}	3.3278^{g}	3.5319^{f}

[a] The slope of the linear regression equation for each item. The means (n = 3) with the same superscript letter in the same row are not significantly different at 95% level by Duncan's multiple range test.

[b] AV, acid value; COV, carbonyl value; DC, dielectric constant; Color(R), Lovibond (red color); *p*-AnV, *p*-anisidine value; TP, total polar content; Polymer, polymer content.

[c] TP, n = 2.

absorbed water in cotton balls and control oil for each quality parameter. All values were determined from linear regression equations between each analysis and frying time (4-day frying). The correlation coefficients were 0.99 or higher.

Effect of water. When the oil was used to fry moist cotton balls (225 mL water/18 g cotton balls/h), the oil showed significantly higher AV, COV, DC, Fritest, *p*-AnV, TP compounds and polymer content than in other sample groups (Table 1). The water in cotton balls showed the greatest deterioration rate of all the sample groups (4-day frying). Oxidation, hydrolysis and polymerization were greatly accelerated during frying of the moist cotton balls probably resulting from release of free water (e.g., 225 mL water/h) into the oil.

Effect of additives on flour dough sheets. During frying, the total amount of water supplied by the dough sheets (225 mL water/450 g flour/h) was identical to that from the moist cotton balls. As shown in Table 1, higher values of all quality indicators, other than AV and red color, were observed in the oil from frying flour dough sheets without additives (F + W) in comparison to those with either added salt (F + W + Sa) or sugar (F + W + Su). In comparing the effects of added sugar or salt, the oil from F + W + Sa showed higher AV, COV, DC, Fritest values, higher TP compounds and polymer content and is inferior to the oil from F + W + Su. These results (F + W + Su > F + W + Sa > F + W) indicate that water binding by 75 g sugar in the F + W + Su reduced the release of free water into the frying oil more effectively than did 30 g salt.

Addition of sugar and salt (F + W + Su + Sa) to the flour dough sheets at the level used in F + W + Su and F + W + Sa had no additive or synergistic effect on the deterioration of oil quality. Although the results of some quality analyses, such as DC, Fritest, *p*-AnV and polymer content, showed that the oil from F + W + Su + Sa was significantly different from that of F + W + Sa, other quality indicators (AV, COV and TP) showed no significant differences ($P > 0.05$) between F + W + Su + Sa and F + W + Sa.

For oils from static heating and frying with different flour dough sheets with various additives, the rate of deterioration, determined from DC, Fritest and polymer analyses, declined in the following order: water absorbed in cotton balls, F + W, F + W + Su + Sa, F + W + Sa, F + W + Su and the control oil from static heating ($P < 0.05$). In the TP analysis, frying cotton balls with added water was found to accelerate deterioration most rapidly, and the control group was the slowest. However, there was no significant difference ($P > 0.05$) in the deterioration determined by TP analysis among the oils from F + W, F + W + Sa and F + W + Su + Sa.

Correlation between analytical methods for soybean oils during frying. Table 2 shows correlations between analytical methods for all frying oils used: heating (control), frying cotton balls/water, and frying flour dough sheets with additives (n = 90). The correlation coefficients (r) between each pair of analytical methods, given in Table 2, were obtained by using the SAS method (14). Among these analytical methods, polymer content showed high correlations with COV, DC, Fritest, *p*-AnV and TP analyses, respectively ($r > 0.970$); DC and COV determinations also showed high correlations between each other and with Fritest, TP and polymer analyses ($r > 0.970$). However, red color, *p*-AnV and AV analyses showed no correlations between each other or with other analyses. The correlation coefficients of red color with other analyses, except *p*-AnV, were in the range of 0.880–0.902. The r value between red color and *p*-AnV was even lower (0.803). Color is an important physical property of oil, and the color darkens as heating or frying proceeds. However, the kind of food being fried also affects oil color during frying. Some browning products formed from the interaction of food components, e.g., Maillard reaction products, affect oil color during frying. As a result, the measurement of oil color cannot be used to monitor oil quality due to the possibility of interference of food components with oil during frying.

Although AV is a simple method for oil quality assessment, the correlation coefficients were in the range of 0.859–0.939 between AV and the other analytical methods (except Fritest; r = 0.968), which indicates that AV does not reflect oil quality as well as COV, DC, Fritest, TP or polymer content. These results suggest that COV, DC, Fritest, TP compounds and polymer contents are good

TABLE 2

Correlation Coefficients Between the Results of Analytical Methods for Soybean Oil Quality During Four Days of Frying (n = 90)

	AV	COV	DC	Fritest	Color(R)	*p*-AnV	TP	Polymer
AV	1.000	0.934	0.929	0.968	0.900	0.859	0.918	0.939
COV		1.000	0.982	0.968	0.880	0.964	0.970	0.991
DC			1.000	0.969	0.905	0.951	0.990	0.991
Fritest				1.000	0.902	0.899	0.947	0.970
Color(R)					1.000	0.803	0.903	0.889
p-AnV						1.000	0.938	0.971
TP							1.000	0.980
Polymer								1.000

[a]Abbreviations as in Table 1.

indicators for oil quality assessment while AV, AnV and color analyses require other auxiliary tests for assessing frying oil deterioration.

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