Chemical and Sensory Properties of Gas-Purged, Minimum-Refined, Extruded-Expelled Soybean Oil

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ABSTRACT: Developing low-cost oil refining methods is critical to businesses that use low-cost extrusion-expelling (E-E) to crush soybeans so they can capture the full value-added potential by marketing finished oils. Normal commodity (CO) and high-oleic (HO) E-E soybean oils were minimum-refined, gas-purged, and evaluated in frying applications. Degummed commodity oil (DCO) and minimum-refined (degummed and deacidified by Magnesol® adsorption) CO and HO oils were gas-purged with N_2 for 1 h at 150°C. For DCO, gas purging did not affect PV, oxidative stability index (OSI), FFA, color, and total tocopherol content, but *p*-anisidine value (AV) increased. For CO, the minimum-refined, gas-purged oil did not differ from degummed, gas-purged oil in terms of *p*-AV, OSI, tocopherol content, and color. PV and FFA were lower in minimum-refined, gas-purged oil. Minimum-refined, gas-purged HO had much higher OSI, tocopherol, and FFA levels than did minimum-refined, gas-purged CO. The oils were used to fry bread cubes at 185°C. Fried bread cubes were stored under various conditions and evaluated for flavor attributes. These oils were different in toasty/nutty, beany/grassy, and oxidized flavors, as well as overall flavor intensity and desirability. Minimum-refined, gas-purged oils produced fried bread cubes having initial flavor profiles similar to those fried in commercial oil; however, when fresh oils were used they were less stable to oxidation. Longer heating times of the minimum-refined, gas-purged oils produced bread cubes with better oxidative stabilities than those produced with commercial oil.

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KEY WORDS: Deep-fat frying, deodorization, extrusion-expelling, gas purging, minimum refining, natural refining, refining, sensory evaluation, soybean oil.

Extrusion-expelling (E-E) is a mechanical process for extracting oil. The process is simple, has a low initial investment, and eliminates the use of hazardous solvents. Crude soybean oil from E-E processing is low in phosphorus and FFA contents and has a unique toasted flavor (1). This high-quality crude E-E soybean oil is ideal for using "minimum" or "natural" refining technologies. Because of its unique quality and flavor, minimum-refined oil is preferred by a growing population that values natural and functional foods and is willing to pay higher than normal prices for such products. These small E-E plants are also suitable for using identity-preserved processing for specialty soybeans with genetically enhanced FA compositions and other traits. E-E plants are seeking means of adding value to their products and improving profitability by marketing finished oil rather than crude oil, but suitable simple, low-cost refining methods are required to achieve this goal.

Minimum refining is attractive because of its simplicity, low capital cost, minimal environmental impact, and high retention of minor but potentially healthful oil components compared to conventional refining. Conventional refining involves degumming, neutralizing with alkali, bleaching, and high-temperature (230–260°C) and vacuum (3–6 mm Hg) deodorizing (2). The latter process requires considerable energy and capital to generate the necessary steam and vacuum as well as expensive equipment. In minimum refining, phosphatides are removed by water degumming and FFA are removed by physical adsorption using Magnesol® (Dallas Group of America, Jeffersonville, IN), as reported by Wang and Johnson (3). Instead of using traditional steam deodorization to achieve an odorless, bland-tasting, and nearly colorless oil (4), nitrogen (N_2) has been used as a stripping gas for deodorizing vegetable oils such as sunflower, olive, and soybean oils (5–7). N_2 has certain advantages over steam as a stripping gas because it requires less energy to produce and it produces high-quality deodorizer distillates.

In the present study, gas purging at low temperature and vacuum were used to deodorize degummed and/or Magnesol-treated oil in an attempt to demonstrate that minimum refining is suitable for both normal commodity (CO) and high-oleic (HO) oils and that the oils are suitable for frying applications.

EXPERIMENTAL PROCEDURES

Refining. CO and HO soybean oils extracted by E-E were obtained from Nutriant (Vinton, IA). Crushing methods were previously reported by Wang and Johnson (3). The crude oil was filtered to remove meal fines and then degummed by mixing with 3% (oil basis) distilled water at 60°C for 1 h. The gums were removed by centrifugation. The degummed oil was treated with 3% (oil basis) Magnesol by using a rotary evaporator at 95°C, 150 rpm, and 23 mm Hg vacuum for 20 min (3). The mixture was filtered with Whatman filter paper to remove the adsorbent.

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The degummed commodity oil (DCO), Magnesol-treated commodity oil (MCO), and Magnesol-treated HO (MHO) oil were purged using N_2 gas at 150°C for 1 h in a round-bottomed flask as described by Wang *et al*. (8). About 250 g of each oil was introduced into the round-bottomed, three-necked flask. N_2 gas was introduced at a 1.5 mL/min flow rate, and the flask was connected to a vacuum pump generating 1–6 mm Hg vacuum. The oil flask was immersed in a glycerin heating bath at 150 ± 5°C. The oil flask was then cooled to room temperature, and samples were taken and stored in a refrigerator until removed for chemical analyses and sensory evaluation. Two replications of gas purging were performed for each type of oil.

Chemical analyses. The oils produced with or without gas purging (DCO, DCO/N_2, MCO/N_2, and MHO/N_2) were analyzed using standard AOCS methods (9): PV (AOCS Cd 8-53), anisidine value (p-AV, AOCS Cd 18-90), FFA (AOCS Ca 5a-40), phospholipid content (AOCS Ca 12-55), oxidative stability index (OSI, AOCS Cd 12b-92), color (AOCS Cc 13b-45), and tocopherol content (AOCS Ce 8-89).

Sensory evaluation of oils. Each oil was randomly chosen from the duplicates of all treatments, and a sensory evaluation was conducted by using a panel of nine trained panelists. A commercial soybean oil (Com; Flavorite Vegetable Oil, Preferred Products, Inc., Eden Prairie, MN) was used as a reference. The oil samples were evaluated for their toasty/nutty flavor, buttery flavor, beany/grassy flavor, desirability, and overall flavor intensity. A line scale was used to provide the panelists with an infinite number of positions at which to indicate the relative intensity of each attribute (10). The line was 15 cm long, and the scale was directed from left to right with increasing intensity ("bland" to "extreme" for various flavors, and "like extremely" to "dislike very much" for desirability (lower scores for all traits were better). This graphic rating scale was modified based on AOCS Official Method Cg 2-83 (8).

Deep-fat frying of bread cubes. One pound (0.45 kg) of each oil (DCO, DCO/N_2, MCO/N_2, MHO/N_2, and the Com oil mentioned above) was placed into a Teflon-coated 1-L minifryer (Presto Fry Baby Electric Fryer; National Presto Industries, Inc., Eau Claire, WI). Oil was heated to 185°C within 10 min. Two 30-g batches of 2.54-cm^3 crust-free bread cubes were fried for 1 min each using the method of Liu and White (11). After draining the fried bread cubes on paper napkins and mixing gently, one-half of the cubes were stored in a 60°C oven for 9 d, and the remaining half were kept frozen (−10°C) in double-guard Ziploc® plastic bags with the air pressed out. The five frying oils were heated at 185 ± 5°C for 10 h/d for 3 d, then two 30-g batches of bread cubes were fried in this 30-h heated oil for 1 min as described above. One portion of the bread cubes was stored at 60°C for 4 d, and the other batch was stored in the freezer until the sensory evaluation was conducted.

Sensory evaluations of deep-fat fried bread cubes. The same trained panel used for oil evaluation was used plus one additional trained panelist. Panelists evaluated the fried bread cubes for toasty/nutty, beany/grassy, and oxidized flavors; overall flavor intensity; and desirability using the 15-cm line scale described above. The samples were served at room temperature. Panelists first smelled the cubes and ranked them in order of increasing odor intensity, then chewed and evaluated each sample for flavor (11).

Statistical analysis. Data from the two replications were analyzed using the General Linear Model of SAS (12). LSD (at $P = 0.05$) were calculated to compare treatment means.

RESULTS AND DISCUSSION

Changes in the composition and chemical properties of CO and HO oils that occur during degumming and deacidification were reported previously (8). Water degumming removed the phospholipids from the oils without reducing the tocopherol content. Degumming significantly increased PV and decreased p-AV, FFA, and color, because the gums adsorbed some secondary oxidation compounds, FFA, and carotenoid pigments. The oxidative stability of partially refined CO was reduced, possibly due to the removal of phospholipids. Magnesol treatment significantly reduced the PV and color of CO and also reduced the PV, FFA, and color of HO oil.

Qualities of gas-purged oils. DCO, DCO/N_2, MCO/N_2, and MHO/N_2 oils were chosen for frying studies because they had different flavor profiles, as indicated in a preliminary sensory analysis of the oils. The compositional and sensory qualities of these oils are presented in Tables 1 and 2.

For DCO, gas purging did not significantly affect PV, OSI, FFA, color, and total tocopherol content but increased the p-AV significantly. Trace contaminants from the N_2 (99.95% purity) may have promoted peroxide formation at 150°C. At the same time, some peroxides probably broke down into secondary oxidation compounds, resulting in increased p-AV, but this did not affect the PV. The low-M.W. volatile compounds (i.e., the ketones and aldehydes that give off-flavors) were purged under vacuum. However, the relatively large-M.W. and less-volatile compounds that do not significantly contribute to off-flavors may not have been removed, and they were quantified as p-AV. For CO, DCO/N_2 was not significantly different from MCO/N_2 in terms of p-AV, OSI, tocopherol content, and color. PV and FFA were significantly lower in MCO/N_2, primarily because of the adsorption of FFA and peroxides by Magnesol. MCO had PV, p-AV, and FFA levels of 0.22 meq/kg, 0.14, and 0.01%,

TABLE 1
Compositional Quality[a] of Minimum-Refined, Gas-Purged Soybean Oils

Oil type	Processing stage	PV (meq/kg)	p-AV	OSI (h)	Tocopherol (ppm)	FFA (%)	Color (red)
CO	DCO	0.86^{a}	0.14^{b}	14.0^{a}	961.3^{b}	$0.02^{b,c}$	8.3^{a}
	DCO/N_2	0.86^{a}	0.23^{a}	$13.5^{a,b}$	963.3^{b}	0.02^{b}	7.8^{a}
	MCO/N_2	0.37^{b}	0.25^{a}	13.0^{b}	952.9^{b}	0.01^{c}	7.6^{a}
HO	MHO/N_2	0.32^{b}	0.25^{a}	$>60.0^{b}$	1114.7^{a}	0.33^{a}	6.8^{a}
$LSD_{0.05}$		0.20	0.07	0.7	92.9	0.01	1.6

[a] p-AV, p-anisidine value; OSI, oxidative stability index; CO, normal commodity oil; HO, high-oleic oil; DCO, degummed commodity oil; DCO/N_2, degummed commodity oil purged with N_2 gas; MCO/N_2, Magnesol®-treated CO oil purged with N_2 gas; MHO/N_2, Magnesol-treated HO oil purged with N_2 gas.

[b] Values are means of duplicate analyses of duplicate treatments. Values with different superscripts are significantly different at $P = 0.05$.

TABLE 2
Sensory Quality[a] of Minimum-Refined, Gas-Purged Soybean Oils

Oil type	Processing stage	Toasty/nutty flavor	Buttery flavor	Beany/grassy flavor	Overall intensity	Desirability
CO	DCO	9.5^a	1.9^a	3.3^a	11.1^a	8.7^a
	DCO/N_2	4.4^b	2.7^a	1.1^c	5.4^b	5.4^b
	MCO/N_2	1.5^c	1.9^a	$1.5^{b,c}$	2.5^c	4.1^b
HO	MHO/N_2	1.8^c	1.9^a	$2.8^{a,b}$	$4.0^{b,c}$	$6.4^{a,b}$
$LSD_{0.05}$		2.1	1.5	1.7	1.6	2.5

[a] Values are means of nine replicates. Values with different superscripts are significantly different at $P = 0.05$. Values are the distances measured from the left end of the line (graphic rating scale) to the vertical line. Lower values indicate higher quality. For abbreviations see Table 1.

respectively (8). The increased PV and *p*-AV of the purged oil were attributed to oxidation during treatment.

MHO/N_2 had much higher OSI, tocopherol, and FFA levels than MCO/N_2. HO oil was much more stable compared with CO (>60 vs. 13.0 h OSI at 100°C) because of composition differences (lower percentages of PUFA and higher tocopherol content). The PV and *p*-AV values of the gas-purged oils were not considerably different from the HO oil without gas-purging treatment. This was attributed to the thermal stability of the HO oil.

Sensory evaluation of gas-purged oils. Sensory evaluation showed that gas purging improved the flavor of DCO (Table 2) by significantly decreasing the toasty/nutty flavor, beany/grassy flavor, and overall flavor intensity. DCO/N_2 had a better desirability score (lower value) than did DCO. MHO/N_2 had a slightly more intense beany/grassy flavor, poorer desirability, and higher overall flavor intensity score than did the similarly treated CO, indicating that HO oil was not deodorized as effectively by gas purging as the CO oil.

These four oils had different flavor profiles (toasty/nutty, beany/grassy, and overall flavor intensity). The desirability scores for DCO/N_2, MCO/N_2, and MHO/N_2 were ≤6.4 on a 15-cm line scale, indicating that all three oils had acceptable flavors. Based on the standard flavor evaluation method of AOCS, a score greater than 7.5 on a 15-cm scale indicates a poor-quality oil. DCO was processed the least and was also the least desirable. However, one limitation of our desirability test must be acknowledged: A quantitative preference or acceptance test would be more robust with a larger group of panelists than was used, and further consumer preference testing with more panelists is warranted.

Deep-fat frying and sensory evaluation of bread cubes. Deep-fat frying with soybean oil is commonly used for food preparation because of its simplicity and the resulting desirable flavors and textures of fried foods. To evaluate frying applications of the minimum-refined soybean oils, white bread cubes were deep-fat fried and a sensory evaluation of the bread cubes was conducted. Com was used as a control. A preliminary test showed that bread cubes fried in fresh oil could be kept in a 60°C oven for 9 d, and bread cubes fried in used oil could be kept in the oven for 4 d without severe lipid oxidation. Therefore, 9 and 4 d were used as time periods in our accelerated lipid oxidation tests. The results are summarized in Table 3.

Oil type, heating time, and oxidation stage did not significantly affect the toasty/nutty flavor of the fried bread cubes (Table 3), and there were no significant interactions for this flavor among these main factors. The strong toasty/nutty flavors produced through the Maillard reaction in the bread cubes may have masked the toasty/nutty flavors from the oils.

Oil type, heating time, and oxidation stage did not significantly affect beany/grassy flavor, and there were no significant interactions for beany/grassy flavor among these main factors. Even though the oils had different degrees of beany/grassy flavor, the fried products did not exhibit this difference. The frying operation itself resembles steam deodorization, although it is not done under high vacuum. Hence, the volatile off-flavor compounds may easily be carried out by vigorous evaporation of the moisture contained in foods.

Oil type, heating time, and oxidation stage significantly affected oxidized flavor. Most interactions among these main factors were significant as well. After 9 d of storage at 60°C, bread cubes fried in fresh DCO/N_2 and MCO/N_2 oils were significantly more oxidized than the others (Table 3). These results correlated with the initial oil OSI values. DCO/N_2 and MCO/N_2 had similar OSI values, which were lower than that of DCO. MHO/N_2 produced fried bread cubes with good oxidative stability because of its FA composition. Bread cubes fried in Com after 30 h of heating and 4 d of storage at 60°C were significantly more oxidized than the others. It is interesting to note that fresh Com produced more stable fried cubes, but the heated Com produced more unstable fried products compared with those fried in minimum-refined E-E oils. The reason may be the much higher total tocopherol content of our minimum-refined oil compared to that of Com (950 vs. 500 ppm). After extended heating at high temperature, the tocopherols in Com may have been largely depleted, but significant tocopherols may have remained in our minimum-refined oils. Therefore, when the bread cubes were oxidized under accelerated conditions, the cubes fried in Com oxidized faster than those fried in the minimum-refined oils.

The effects of oil type, heating time, and oxidation stage, as well as most of the interactions among these factors, were significant for overall flavor intensity. The trend observed for this property was similar to that for oxidized flavor (Table 3). The bread cubes fried in fresh MCO/N_2 had significantly increased overall flavor intensities after 9 d of storage, and bread cubes fried with the 30-h heated Com had significantly higher overall flavor intensities.

TABLE 3
Sensory Qualities of Bread Cubes Fried in Various Oils[a]

Storage temperature (°C)	0 h heating Com	DCO	DCO/N_2	MCO/N_2	MHO/N_2	30 h heating Com	DCO	DCO/N_2	MCO/N_2	MHO/N_2
Toasty/nutty flavor ($LSD_{0.05}$ = 2.9)										
–10	5.8	6.6	5.2	6.4	4.7	5.5	7.4	6.5	6.4	4.8
60	7.0	7.3	6.0	5.0	5.8	5.0	7.2	6.9	7.5	7.3
Beany/grassy flavor ($LSD_{0.05}$ = 3.0)										
–10	3.8	5.3	2.6	2.9	2.4	3.4	2.5	2.9	2.4	3.8
60	1.7	2.3	3.7	3.0	3.9	4.1	2.7	2.4	1.9	2.3
Oxidized flavor ($LSD_{0.05}$ = 3.0)										
–10	4.0	4.3	2.9	3.4	2.6	4.5	3.9	4.6	3.5	5.9
60	2.6	3.0	7.2	11.6	3.3	12.5	4.3	5.3	4.3	5.3
Overall flavor intensity ($LSD_{0.05}$ = 2.7)										
–10	6.9	8.4	5.5	6.0	4.4	6.9	6.6	6.6	6.6	7.1
60	5.6	6.9	8.1	11.5	6.1	11.6	7.3	6.8	6.8	8.4
Desirablity ($LSD_{0.05}$ = 2.4)										
–10	7.0	6.5	5.5	5.4	6.5	7.0	6.3	5.5	4.6	8.7
60	4.1	4.4	8.6	12.8	4.7	13.8	5.8	6.5	5.5	6.0

[a] Values are means of 10 replicates. They represent distances measured from the left end of the line on the graphic rating scale to the vertical line. Lower values indicate higher quality. Com, commercial soybean oil; for other abbreviations see Table 1.

The effects of oil type, heating time, and oxidation stage on the desirability score, as well as most of the interactions among these factors, were significant. The five oils were not significantly different in desirability of the bread cubes fried in fresh oil. However, after 9 d of storage at 60°C, the bread cubes fried in DCO/N_2 and MCO/N_2 became less acceptable because of the oxidized flavor of these oils. These desirability scores exhibited a trend similar to the score for oxidized flavor (Table 3). After 30 h of heating and 4 d of storage at 60°C, there were no significant differences among bread cubes, except for the bread cubes fried in Com.

This study showed that minimum-refined E-E soybean oils can be used to deep-fat fry and to produce freshly fried products that have sensory qualities similar to those fried in traditionally processed Com. But the more highly processed commodity oils, such as the gas-purged oil, produced fried products with lower oxidative stability than those produced with Com. If the gas-purged oil was used repeatedly, the fried products tended to have better sensory qualities and oxidative stabilities than did the products prepared from Com soybean oil.

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