Sensory and Chemical Stability of Tortilla Chips Fried in Canola Oil, Corn Oil, and Partially Hydrogenated Soybean Oil

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ABSTRACT: The effects of canola, corn, partially hydrogenated soy (PHS), partially hydrogenated canola (PHC), and low-linolenate canola (LLC) oils on sensory and chemical attributes of tortilla chips were determined initially, after Schaal storage for 8 and 16 d (S8 and S16), and after practical storage for 16 and 24 wk (P16 and P24). Fresh chips were similar to each other in characteristic and off-odors/flavors, except that PHC chips had the lowest characteristic and highest off-odor/flavor. All S8 chips had similar lower ($P < 0.001$) characteristic and greater off-odor/flavor scores than hidden reference chips, but PHC chips had a more intense off-odor than did LLC chips. After S16, canola chips had the lowest ($P < 0.001$) characteristic and highest off-odor/flavor; all other chips were similar. At P16, canola, PHC, and LLC chips had slightly higher ($P <$ 0.001) characteristic odor/flavor scores than other chips. After P16 and P24, all stored tortilla chips had lower characteristic odor/flavor scores than hidden reference chips. Rancid, painty, buttery odor/flavor, and bitter flavor notes were detected in Schaal and practically stored chips. Stored chips from all oils were similar in color and crispness. The peroxide value and the *p*-anisidine value for oils extracted from Schaal-stored chips tended to support panelist data; results from similar analyses of practically stored chips did not. Peroxide values and *p*-anisidine values for stored used frying oils and the corresponding sensory data for stored chips generally did not agree. Results indicate considerable potential for increasing use of canola oil products for frying tortilla chips.

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KEY WORDS: Canola, corn and soybean oils, sensory/chemical storage stability, tortilla chips.

Current consumer preference for foods low in saturated fats has increased the use of polyunsaturated fats and oils for fried snack foods (1). Because canola oil (C) is high in polyunsaturated fatty acids, especially linolenic acid (18:3n-3), it is prone to oxidation, hydrolysis, and thermal degradation during heating. Thus more saturated oils, such as cottonseed (2), corn, and sunflower (3), are used more frequently than canola and soybean in snack-food manufacture. Partial hydrogenation of oils, such as canola, should improve thermal stability due to decreased amounts of linolenic acid (4,5). Recently Canadian researchers (6) have genetically altered the fatty acid composition, especially the 18:3n-3 content, of canola seed, and a low-linolenate canola oil (LLC) has been produced. Improvement in stability and heated room odor development for low $C_{18:3}$ canola oil has been reported (7).

Studies (8–12) have evaluated the flavor of potato chips fried in various oils such as canola, partially hydrogenated canola (PHC), and cottonseed. Reports of the quality of chips fried in LLC are lacking. Melton *et al.* (11) recently concluded that research on the effects of polyunsaturated oils on the stability and quality of other fried snack foods was needed. Others (13) have recommended that more information on the stability of foods fried in canola and other oils is needed. In addition, workers (13) have suggested that assessments of stored oil used for frying snack foods may provide a prediction of the stability of fried food, but that research in this area is needed. Although tortilla chips are a popular fried snack, no published reports have compared the sensory attributes of tortilla chips fried in C, PHC, and LLC with other commonly used frying oils. Moreover, information on the odor/flavor of tortilla chips fried in C, PHC and LLC, particularly upon storage, is lacking. Thus the objective of this study was to evaluate the quality and storage stability of tortilla chips fried in C, PHC, LLC, partially hydrogenated soybean oil (PHS), and corn oil (CO) after accelerated and practical storage using sensory, chemical, and instrumental methods.

MATERIALS AND METHODS

Materials. The fully refined and deodorized oils used for frying were: C and PHC, both from Prairie Margarine (Edmonton, Alberta, Canada); CO and PHS, both from Canada Packers (Edmonton, Alberta, Canada); and LLC from CSP Foods (Saskatoon, Saskatchewan, Canada). Dimethylpolysiloxane (2 ppm) was present or added to all oils. Raw tortilla chips, obtained from Condillo Foods (Calgary, Alberta, Canada) were packaged (200 g) in plastic bags and held frozen (–25°C) until they were fried.

Frying procedure. For each oil treatment, 48 L of oil was heated to 185°C for frying. Within each replication, assignment of oils to two institutional deep-fat fryers (Model 10-701; Garland Commercial Range, Ltd., Mississuaga, Ontario, Canada) and to treatment frying order was randomized. Tor-

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tilla chips were thawed (4°C) overnight and held at room temperature 1 h prior to frying. Cooking of tortilla chips was standardized. Two baskets of evenly distributed raw chips (200-g batch per basket) were fried simultaneously in each fryer at 185 ± 5°C for 1 min. Ten fries (20 batches) of chips were fried. All tortilla chips for sensory and instrumental/chemical analyses were cooked within 1.5 h. Following frying, chips were drained (1 min), blotted with paper towels to remove excess oil, cooled at 22°C for 15 min, double-bagged in plastic and stored at 5°C. Fryers were thoroughly cleaned and dried between oil treatments. Additional chips, fried in fresh C and stored frozen (–25°C) in sealed foil potato chip bags, served as reference and hidden reference (HR) samples for sensory evaluation. Four replications of the experiment (frying and storage in each of the oils) were completed.

To monitor frying oil quality, samples were taken from the fresh oil and immediately after the last batch of raw chips was fried (for used stored Time 0 oil and for storage). Samples were nitrogen flushed and held at –25°C until portioning and storage tests could be completed.

Storage tests. After overnight storage (5°C), tortilla chips from designated fries in each oil treatment were mixed to form composite samples for sensory and chemical analyses, respectively. Tortilla chips from each frying treatment were subjected to the following conditions: (i) Schaal storage: Time 0, flushed with nitrogen and stored in sealed commercial foil potato chip bags at –25°C; Schaal 8 (S8), stored at 60°C for 8 d; Schaal 16 (S16), stored at 60°C for 16 d; and (ii) practical storage: Time 0, as for Time 0 Schaal storage; practical 16 (P16), stored in the dark for 16 wk at ambient temperature (23°C); and practical 24 (P24), stored in the dark for 24 wk at 23°C. For Schaal (accelerated) storage, 60 chips were placed in 1000-mL beakers, loosely covered with aluminum foil and stored in a forced air oven (60°C) for the appropriate length of time. For practical storage, 60 chips were placed in commercial cellophane tortilla chip bags, heat-sealed, and held at ambient temperature (23°C) for 16 and 24 wk.

Prior to portioning and conducting the storage tests, oil samples were thawed overnight at 5°C. Because fresh and fresh heated oil samples were not subjected to storage tests, they were portioned into glass vials and bottles, nitrogen flushed, and frozen (–25°C) for later chemical/instrumental analyses. Used oils from each treatment were exposed to the same storage conditions as outlined for tortilla chips. For Schaal storage, oil samples (68 g) were placed in 100-mL glass beakers, covered loosely with aluminum foil, and held in a forced air oven at 60°C for the appropriate time. For practical storage, oils (68 g) were stored in capped, 100-mL amber glass bottles at ambient temperature, in the dark, for 16 and 24 wk.

Immediately after Schaal and practical storage tests were complete, oils and chips were packaged in glass vials and foil potato chip bags, respectively, nitrogen flushed, sealed, and frozen (–25°C) for later sensory (chips only) and chemical testing.

Sensory evaluation. Sensory data were obtained from nine trained panelists who had been screened on the basis of 16 triangle tests. Selected panel members were intensively trained for seven weeks according to the procedures of Cross *et al.* (14). Canola oil standards with specific notes and tortilla chip samples, prepared by exposing the chips to tainted oils, were prepared to familiarize panelists with specific odor/flavor notes, such as buttery, painty, etc. Throughout training, panelists were given tortilla chips fried in fresh C as a reference and an HR, as canola oil is commonly used in Canada.

During each of the twenty-four daily experimental sessions, panelists evaluated six randomly presented tortilla chip samples (one from each oil treatment and an HR) in comparison to an identified reference chip (chip fried in fresh C, frozen at Time 0). Chips were presented at 22°C in plastic souffle cups with lids. Fifteen quality attributes, including five for odor (characteristic tortilla/corn chip, off, rancid, painty, and buttery), seven for flavor (characteristic tortilla/corn chip, off, rancid, painty, buttery, bitter, and aftertaste), hardness, crispness, and color intensity were evaluated by panelists using 15-cm unstructured line scales where 0 = absent and 15 = extreme. In judging chips, panelists placed a vertical line across a 15-cm horizontal line at a point which best described their impression of each chip attribute. Panelists rinsed with water, evaluated the chips for odor/flavor/texture, rinsed with lemon water to clear the palate, rinsed with plain water, and then proceeded to the next sample. Evaluations for odor, flavor, and texture were conducted in individual booths, equipped with a computerized sensory evaluation network work station, under white fluorescent lighting in an atmospherically controlled panel room. Panelists also assessed tortilla chip color intensity under the Macbeth Skylight (northern daylight, 7500 K). Sensory evaluations of chips from Schaal and practical storage were conducted separately. Oil samples were not subjected to sensory evaluation.

Chemical analyses. Initial (fresh) frying oil quality was defined chemically *via* iodine values (Method Cd 1-25) (15), peroxide values (Method 2.501) (16), and % free fatty acids (Method Ca 5a-40) (15). To monitor chip stability, oil was extracted (17) from chips representing each oil treatment and storage condition. Extracted oils and stored used frying oils were analyzed for peroxide value (PV) (Method 2.501) and *p*-anisidine value (AV) (Method 2.504) (16). Moisture (5) and fat (17) contents of the tortilla chips were determined before and after frying, as well as after storage.

Instrumental evaluations. Fresh oil was evaluated for fatty acid composition (18) and color (19). Tortilla chip color (L, a, and b values) was determined on a Hunter Lab Color Difference Meter (Model 25-D2; Hunter Associates Laboratory Inc., Fairfax, VA). Chips (approximately 40 g) were crushed with a mortar and pestle (40 strokes), ground in a coffee grinder (20 s), sieved to remove particles >2 mm, and placed in two plastic petri dishes (5-cm in diameter). Readings from four different positions were taken on each of the two samples (eight measurements/treatment). The mean value of each of the 8 L, a, and b readings was used for chip overall L, a, and b values.

Tortilla chip texture was measured using an Instron Food Testing Machine (Model 4201; Instron Corp., Canton, MA) to record the peakload force (g) to puncture measurements with a 50-kg load cell and a crosshead speed of 100 mm/min. Chip thickness was determined with a micrometer (Model IDU25E; Mitutoyo, Tokyo, Japan). The chip was placed on a hollow cylindrical fixture with three raised areas which produced a flat surface through which a 7.5-mm cylindrical plunger was lowered until it punctured the chip. The mean value of four thickness and force-to-puncture readings was taken per treatment.

Statistical analyses. A strip-plot experimental design (20) involving frying oil treatments (t = 5) and storage time (s = 3) for both Schaal and practical storage was used for the experiment. Four replications (blocks) of the frying oil × storage time combinations were completed. Sensory data were determined by using nine panelists (p = 9). Chemical data were determined using either duplicate (s = 2) or triplicate (s = 3) subsamples. All data were subjected to analyses of variance computed (21) within each of the three storage times. Sensory data sources of variation were block, frying oil, block × frying oil, panelist, and panelist × frying oil. Chemical data sources of variation were block, frying oil, and block × frying oil. For both sensory and chemical data, experimental error for frying oil was block × frying oil. Where appropriate, Student–Newman Keul's multiple range test was used to identify significant ($P < 0.05$) differences among treatments.

RESULTS AND DISCUSSION

All fresh oils were of good quality, as indicated by low PV and color values and the low % free fatty acids (Table 1). As expected, there were differences in fatty acid composition among the frying oils. C contained the highest amounts of linolenic acid (18:3n-3), eicosenoic acid (20:1n-9), and erucic acid (22:1n-9), a high level of oleic (18:1n-9) acid and a low level of palmitic (16:0) acid. CO had the highest amount of linoleic acid (18:2n-6), the lowest 18:1n-9 content and a high 16:0 content. PHS contained high levels of 18:1n-9 and 18:2n-6, a low 18:3n-3 content and high levels of saturated fatty acids 16:0 and 18:0. PHC had the highest 18:1n-9 content, and high levels of 20:1n-9 and 22:1n-9, but the lowest 18:2n-6 and 18:3n-3 levels. LLC contained high levels of 18:1n-9, 18:2n-6, and 20:1n-9, but a lower 18:3n-3 content than C. These data are similar to data published by other investigators (5,7,22).

TABLE 1
Characteristics of Fresh Oils

Characteristic	Frying oil treatment[a]				
	C	CO	PHS	PHC	LLC
Peroxide value (meq/kg)	0.20	0.28	0.25	0.17	0.22
Iodine value[b] (Wijs)	125.96	133.56	104.26	97.50	119.04
Color ($E^{1\%}_{363\ nm}$)	0.10	0.08	0.04	0.07	0.12
% Free fatty acids	0.00	0.01	0.00	0.01	0.00
Fatty acid composition (%)					
$C_{14:0}$ (myristic)			0.1		
$C_{16:0}$ (palmitic)	4.0	9.7	9.6	3.7	4.6
$C_{16:1}$ (palmitoleic)	0.2	0.2	0.1	0.3	0.2
$C_{18:0}$ (stearic)	1.9	2.2	5.4	5.6	2.4
$C_{18:1}$ (oleic)	58.5	30.7	56.4	76.3	56.3
$C_{18:2}$ (linoleic)	21.3	53.9	25.2	9.4	29.9
$C_{18:3}$ (linolenic)	9.9	1.4	1.5	1.2	3.4
$C_{20:0}$ (eicosanoic)	0.6	0.6	0.3	0.6	0.8
$C_{20:1}$ (eicosenoic)	1.6	0.3	0.3	1.5	1.3
$C_{22:0}$ (docosanoic)	0.3	0.2	0.3	0.3	0.4
$C_{22:1}$ (erucic)	0.6			0.5	0.2
$C_{24:0}$ (lignoseric)	0.2	0.2	0.1	0.2	0.3
$C_{24:1}$ (nervonic)	0.2			0.2	0.2
Others			0.7		

[a]C, canola oil; CO, corn oil; PHS, partially hydrogenated soybean oil; PHC, partially hydrogenated canola oil; LLC, low-linolenate canola oil.
[b]Unit of measure = g iodine absorbed by 100 g oil.

Sensory analyses of Schaal-stored tortilla chips. All fresh (Time 0) chips had high characteristic tortilla chip odor/flavor (Fig. 1); however, PHC chips had the lowest score and differed significantly from C, LLC, and HR chips for odor, and from C, LLC, PHS, and HR for flavor. Trained panelists detected a few differences in off-odor/flavor and related notes in Time 0 chips. Fresh PHC chips were highest in off-odor/flavor intensity; C chips had the lowest off-odor/flavor, but did not differ significantly from LLC chips. All fresh chips had very low rancid and painty odors/flavors; although PHC and CO chips were more rancid/painty in flavor than other chip treatments, the differences were very small. Buttery odor/flavor were higher in fresh PHC tortilla chips than in other chips, which were similar to each other. Fresh PHC and CO chips had a slightly higher aftertaste than the HR; other chips were similar to each other and to the HR.

After 8 d of Schaal storage (S8), all chips had similar, lower ($P < 0.001$) characteristic odor/flavor and higher off-flavor scores than the HR. Rancid odor/flavor and aftertaste increased slightly in all S8 chips; all chips were similar but different ($P < 0.01$) from the HR. Except for C chips, which differed ($P < 0.05$) from the HR, all chips were alike in painty odor/flavor at S8. After S8, PHC and PHS tortilla chips had higher buttery odor/flavor than the other chip treatments. Bitterness scores of all S8 chips were similar and low; C and PHC chips were slightly more ($P < 0.01$) bitter than the HR. All S8 chips were similar and low in aftertaste, but higher ($P < 0.01$) than the HR.

With 16 d of Schaal storage (S16), C chips had significantly lower characteristic odor/flavor and significantly higher off, rancid, and painty odor/flavor scores than all other stored chips, which were rated similar to each other for these attributes. At S16, PHC chips were more intense in buttery odor/flavor than other chip treatments, except that PHS chips had more buttery flavor than C, CO, and LLC chips. After S16, C and CO chips increased in bitter flavor and aftertaste; however, only C chips, which increased most, differed ($P < 0.05$) from other chips and the HR. Compared to similar fresh chips, odor/flavor changes in Schaal-stored LLC, PHS, and PHC chips were minimal. LLC chips tended to resemble PHC and PHS chips, although chips from partially hydrogenated oils possessed slightly higher off and buttery odors/flavors.

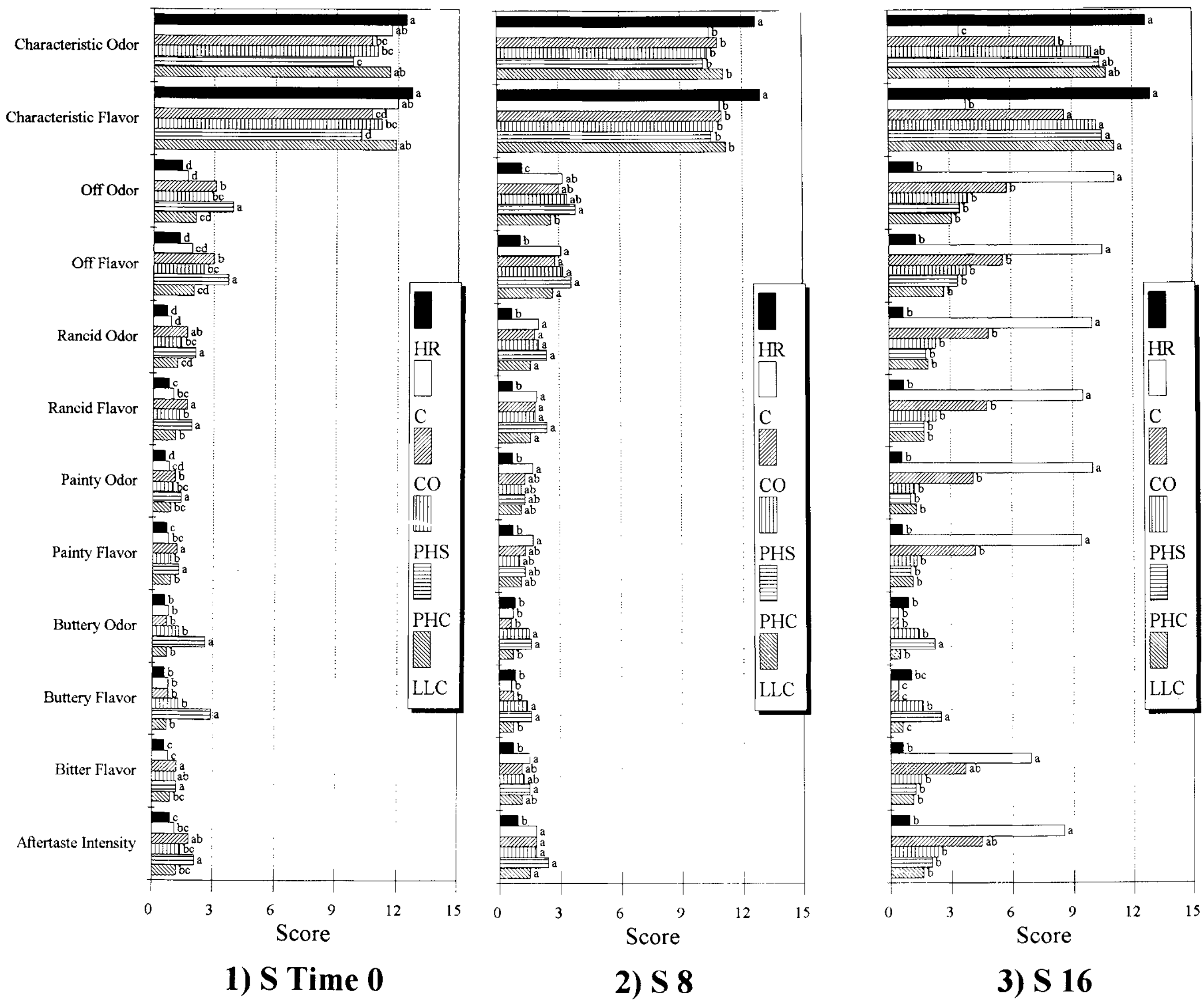

FIG. 1. Mean sensory scores for Schaal-stored tortilla chips at (1) Time 0 (S Time 0) and after (2) 8 d (S8) and (3) 16 d (S16). Frying oil treatments include: canola oil hidden reference (HR); canola oil (C); corn oil (CO); partially hydrogenated soybean oil (PHS); partially hydrogenated canola oil (PHC); and low-linolenate canola oil (LLC). [a–c]Means within the same odor or flavor attribute sharing a common letter are not significantly different at $P < 0.05$.

Sensory data for the HR at each of the storage times illustrate the consistency of the trained panelists.

For both Time 0 and S8 tortilla chips, there were no significant differences in sensory hardness or crispness (not presented). The mean hardness scores of chips ranged from 6.6 to 6.3 at Time 0, 6.5 to 6.1 at S8 and 6.5 to 6.2 at S16. At Time 0 and S8, mean crispness scores ranged from 11.1 to 10.7 and from 10.9 to 10.3, respectively. At S16, very small significant differences indicated that C chips were less crisp than the others, and CO chips were less crisp than the HR. Trained panelists found no significant differences in color intensity (data not given) among fresh chips; color intensity values of fresh samples varied from 9.8 to 9.4. At S8 all chips were similar in color except PHS and PHC chips, which were less intense than the HR. At S16, LLC and PHC chips were most intense and most similar in color to the HR, but not different from PHS chips, which were like CO chips which also did not differ from C chips.

Instrumental analyses of Schaal-stored tortilla chips. Data for chip thickness and peakload force-to-puncture for fresh and Schaal-stored chips (not presented) showed that chips from each oil treatment and storage time were similar in crispness. Mean values for peakload force-to-puncture for chips ranged from 1.36 to 1.57 kg at Time 0 and 1.29 to 1.49 kg at S16. At S8 the force-to-puncture value of PHC chips was significantly lower than that of the LLC chips. Thus these instrumental texture data support corresponding sensory findings, indicating oil treatment and storage had little effect on tortilla chip texture attributes.

Time 0 Hunter L, a, and b values (not shown) of chips from all oils were generally similar. Mean Time 0 L, a, and b values of chips were 53.1, 5.3, and 27.8, respectively. For S8 and S16 chips, no differences in L values as a result of oil treatment were found. In contrast, researchers (10,12) have reported that potato chips darkened on storage. At S8 chips fried in CO, PHS, and PHC had significantly lower a values (were less red) than the HR, but did not differ in redness from other chips which were similar and like the HR. At S16, stored chips had a values that were similar and lower than HR chips. At S8, PHS and PHC chips had significantly lower b values (less yellow) than the HR, but did not differ from the other chips, which were the same and like the HR. At S16, the b values of all chip treatments were similar and lower than the HR. No reasons for the slight but significant differences in a and b values determined in chip treatments are apparent.

Chemical analyses of tortilla chips. Raw and fried chips had an average moisture content of 36 and 0.42%, respectively (data not shown). Except for small, but significant, differences in moisture among chip treatments at S16 and P24, % moisture in fresh (0.42%) and stored (0.44%) chips was not influenced by oil. There were no differences in % fat of fresh or stored chips as a result of frying oil. Fresh and stored chips had an average fat content of 20.89 and 21.22%, respectively.

To chemically monitor the quality and storage stability of tortilla chips, extracted oil from Time 0 and stored chips representing each of the frying oil treatments was analyzed. At Time 0, PV for extracted oils (Table 2) were low and the small, significant differences among treatments are not of practical importance. After S8, PV increased in all samples; C, CO and LLC were alike and significantly higher than PHS, which was higher than PHC. PV for all extracted oils increased markedly at S16. At S16, C and CO had similar and significantly greater values (sevenfold greater than those of other treatments); LLC had the next highest PV, but it did not differ from PHS, which was similar to PHC. AV for extracted oils at Time 0 and S8 (Table 2) showed small, but significant differences among treatments; however, all AV were below 10, the maximum level recommended for fresh frying fats (23). At S16, AV of extracted nonhydrogenated oils rose above 10; C and CO had similar, significantly greater AV than LLC, PHS, and PHC, which did not differ from each other. Thus, these chemical data for extracted oils from S16 chips show trends similar to those of the trained panel, which indicated that S16 C and CO chips deteriorated most rapidly. Miller and White (17) also found that the PV of extracted oils from fried bread cubes and flavor scores for comparable stored fried bread cubes gave similar predictions of soybean oil stability. Robertson *et al.* (10) reported that PV and AV data for oils extracted from stored potato chips indicated no marked deterioration; however, sensory data showed a gradual increase in flavor deterioration, not clearly defined as rancidity, during storage.

Chemical analyses of stored, used frying oils. The small significant differences in PV (Table 3) found among Time 0 stored, used frying oils are not of practical importance as all PV are indicative of good quality oils. At S8, the PV of all used oils increased and differed significantly; LLC had the highest value followed by C, CO, PHS, and PHC. After S16 PV increased; LLC and CO had similar values higher than C and PHS, which were alike and higher than PHC. The higher PV determined for LLC than C were unexpected. Peroxides

TABLE 2
Peroxide Values (PV) and *p*-Anisidine Values (AV) of Oils Extracted From Schaal- and Practically-Stored Tortilla Chips

	Frying oil treatment[a]					
Storage time[b]	C	CO	PHS	PHC	LLC	SEM[c]
PV[d]						
Time 0	0.66[g]	0.70[g]	0.73[g]	0.84[f]	0.87[f]	0.04[k]
S8	31.39[f]	33.38[f]	12.50[g]	5.98[h]	33.44[f]	1.75[l]
S16	235.13[f]	234.08[f]	42.90[g,h]	17.09[h]	100.90[g]	22.09[l]
P16	12.40[g]	13.16[g]	6.26[h]	5.05[h]	20.47[f]	0.49[l]
P24	32.34[g]	28.99[h]	10.78[i]	7.46[j]	44.80[f]	1.08[l]
AV[e]						
Time 0	5.99[g]	7.64[f]	5.72[g]	3.82[h]	6.19[g]	0.14[l]
S8	8.69[f]	7.33[g]	5.11[h]	3.42[i]	7.11[g]	0.32[l]
S16	65.42[f]	62.24[f]	5.97[g]	4.10[g]	11.87[g]	9.46[l]
P16	5.67[g]	6.80[f]	4.66[h]	3.10[i]	5.83[g]	0.11[l]
P24	6.60[g]	7.14[f]	4.99[i]	3.56[j]	6.29[h]	0.10[l]

[a]See Table 1 for abbreviations.
[b]Time 0 = fresh chips frozen at −25°C, S8 = chips stored at 60°C for 8 d; S16 = chips stored at 60°C for 16 d; P16 = chips stored in the dark for 16 wk at 23°C; P24 = chips stored in the dark for 24 wk at 23°C.
[c]Standard error of the mean.
[d]PV in milliequivalents peroxide/1000 g sample.
[e]AV in absorbance/g sample.
[f–j]Means within the same row sharing a common letter are not significantly different at $P < 0.05$.
[k,l]Significant at $P < 0.01$ and $P < 0.001$, respectively.

TABLE 3
PV and AV of Used Frying Oils Initially and After Schaal and Practical Storage[a]

	Frying oil treatment					
Storage time[b]	C	CO	PHS	PHC	LLC	SEM[c]
PV[d]						
Time 0	1.11[g]	1.29[f]	1.14[g]	1.24[f]	1.07[g]	0.03[k]
S8	20.52[g]	14.39[h]	11.05[i]	4.96[j]	21.39[f]	0.16[k]
S16	42.56[g]	50.30[f]	39.64[g]	12.17[h]	53.03[f]	1.08[k]
P16	1.78[g]	2.04[g]	1.85[g]	1.73[g]	4.52[f]	0.37[k]
P24	8.37[g]	2.63[h]	3.46[h]	2.56[h]	14.86[f]	1.08[k]
AV[e]						
Time 0	9.04[g]	10.90[f]	8.13[h]	4.83[i]	9.03[g]	0.19[k]
S8	13.48[f]	11.31[g]	8.47[h]	4.79[i]	10.94[g]	0.21[k]
S16	21.23[f]	12.87[h]	10.17[i]	5.51[j]	14.86[g]	0.17[k]
P16	8.75[g]	10.79[f]	8.16[h]	4.82[i]	8.93[g]	0.20[k]
P24	8.93[g]	10.73[f]	8.07[h]	4.82[i]	9.10[g]	0.20[k]

[a]See Tables 1 and 2 for abbreviations.
[b]Frying oil storage times are the same as those given in Table 2 for chips.
[c]Standard error of the mean.
[d]See Table 2 for abbreviations and units.
[e]See Table 2 for abbreviations and units.
[f–j]Means within the same row sharing a common letter are not significantly different at $P < 0.05$.
[k]Significant at $P < 0.001$.

decompose readily during heating, thus PV may not indicate the actual extent of oil degradation (24). Significant differences in AV (Table 3) of Time 0 stored, used oils were found. At Time 0, the AV of CO was highest, followed by C and LLC, which were the same and were greater than that of PHS, which also differed from PHC. After S8, the AV of C was higher than those of CO and LLC, which were the same and greater than that of PHS, which also differed from PHC. At S16, AV of all oils differed significantly. C was highest, followed by LLC, CO, PHS, and PHC.

Chemical data for stored, used oils (S8, S16) were compared to sensory results for comparable stored chips to determine whether stored used oils could predict chip quality/stability. The AV of Schaal-stored oils, particularly those of C, PHS and PHC (the least and most stable oils) tended to support corresponding sensory results for chips. However, except for PHC data, PV for the stored, used oil treatments did not agree with findings of the trained panel for stored chips. Thus, stored, used frying oils did not predict tortilla chip quality/stability.

Sensory analyses of practically-stored tortilla chips. Sensory data for fresh (Time 0) practically-stored chips (Fig. 2) resembled those of the comparable Time 0 Schaal-stored chips (Fig. 1) described earlier. All Time 0 chips had high characteristic odor/flavor. However, fresh chips (Fig. 2) fried in C and LLC were similar and significantly greater in characteristic odor/flavor and significantly lower in off-odor/flavor than chips fried in CO, PHS, and PHC, which did not differ from each other. All chips were low in rancid and painty notes, although some significant differences were found. At Time 0, tortilla chip buttery odor/flavor scores were low; however, PHC chips had greater buttery odor/flavor than the PHS chips, which also differed from other chips. At Time 0, C and LLC chips were similar to the HR and lower in bitter flavor intensity and aftertaste than CO, PHS, and PHC chips, which were alike.

At P16, all chips (Fig. 2) were lower in characteristic odor/flavor than the HR, but chips fried in C, PHC, and LLC were similar to each other and greater in characteristic odor than CO and PHS chips, which did not differ from each other. Characteristic flavor scores at P16 were lowest in PHS chips and generally similar among the other chip treatments, except that CO chips had a lower score than C chips. As expected, all stored chips had greater off-odor/flavor intensity than the HR. At P16, CO and PHS chips had similar and higher ($P <$ 0.001) off-odor than C, PHC, and LLC chips, which were alike. Off-flavor intensity at P16 was highest in PHS chips, followed by CO chips, which did not differ from PHC or LLC chips; C chips had the lowest off-flavor but did not differ significantly from PHC and LLC chips. Some small significant ($P < 0.001$) differences in rancid and painty odors/flavors among chip treatments were noted at P16. PHC chips were more buttery in odor/flavor than PHS chips; all other chip treatments resembled the HR in buttery odor/flavor. All P16 chips were slightly higher in bitterness than the HR; C and PHC chips were alike and lowest in bitterness, followed by LLC chips which were similar to both PHC chips and to CO and PHS chips, which were also alike. At 16 wk, all chips had low, but higher aftertaste scores than the HR; PHS chips had the most intense aftertaste followed by CO, PHC, and LLC chips, which were similar, and significantly different than C chips.

The odor/flavor scores of P24 chips tended to resemble those of P16 chips. However, at P24, all stored chips had similar, significantly lower characteristic odor/flavor and significantly greater off-odor/flavor than the HR. All P24 chips were greater than the HR, but generally similar to each other in rancid odor/flavor, except for CO chips, which were more rancid in odor than PHC chips, and more rancid in flavor than all other chip treatments. At P24 all chips differed from the HR in paintiness, but all had low painty odor/flavor. PHC chips had greater buttery odor than all other P24 chips and PHC chips had a more intense buttery flavor than PHS chips, which also had greater buttery flavor than all other chips. At P24 all chip treatments scored greater in bitterness than the HR; CO chips were most bitter, although all other stored chips were alike. All P24 stored chips were similar in aftertaste, except that CO chips were more intense than C and LLC chips.

These data from trained panelists showed that the sensory quality of chip treatments was influenced by storage conditions. Under Schaal storage, C chips deteriorated most rapidly, followed by CO chips, whereas LLC, PHC, and PHS chips did not develop the off-odors/flavors noted in C chips. Under practical storage conditions, however, C, PHC, and LLC chips seemed to be the most stable to off-odor/flavor development compared to CO and PHS chips, although all chip treatments had very similar sensory scores. Chips subjected to Schaal storage for 8 d were similar in odor/flavor attributes to comparable P24 chips; 24 wk of practical storage may be longer than the expected tortilla chip shelf-life in the marketplace as manufacturers (Hostess Food Products, Taber, Alberta, Canada, private communication) expect the product to have a shelf-life of about 14 wk. This suggests 16 d of Schaal storage may be too long for practical application and that the sensory quality of tortilla chips at S8 has more relevance to tortilla chip shelf-life predictions. At S8 all stored chips were similar for most of the odor/flavor attributes evaluated. Our previous work (25) has suggested that canola oil subjected to Schaal storage for 2–4 d was similar in flavor to comparable oil stored in the dark at ambient temperatures for 16 wk. In addition, Evans *et al.* (26) showed that the flavor scores of soybean oil stored four days at 60°C and at room temperature for four months were similar.

Sensory evaluation of the texture and color of fresh and practically-stored tortilla chips (not presented) showed very small, significant differences as a result of frying oil. The mean hardness scores of chips varied from 6.6 to 6.1 at Time 0, 7.0 to 6.5 at P16, and 7.0 to 6.4 at P24. Mean crispness scores of chips at Time 0, P16, and P24 ranged from 11.3 to 10.9, from 11.4 to 10.4, and from 11.4 to 10.4, respectively. The mean color intensity values of fresh and practically-stored chips varied from 9.7 to 8.7. Sensory differences of this size are not of practical importance.

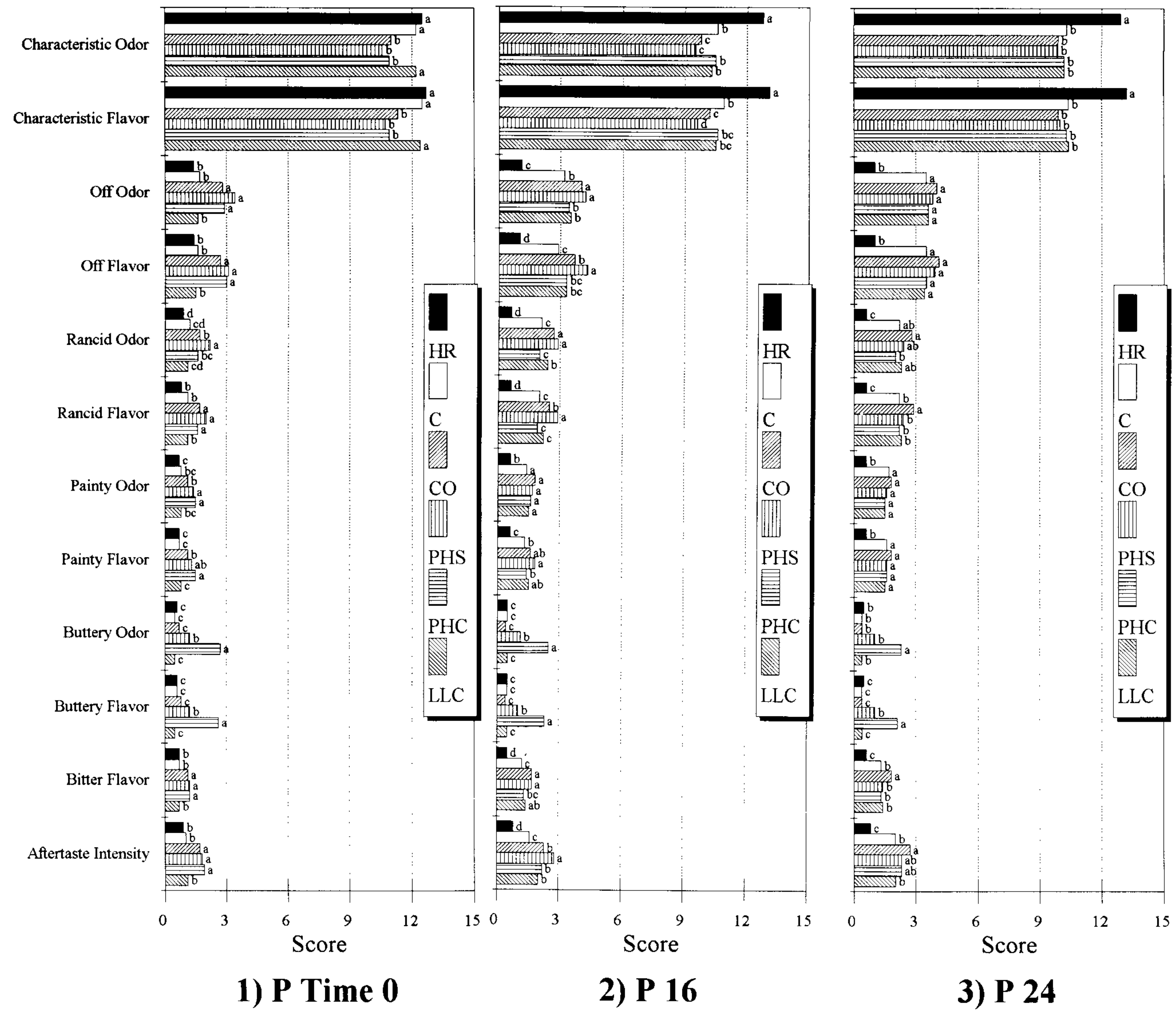

FIG. 2. Mean sensory scores for practically stored tortilla chips at (1) Time 0 (P Time 0) and (2) 16 wk (P16), and (3) 24 wk (P24). See Figure 1 for frying oil abbreviations and superscript letter significance.

Instrumental analyses of practically-stored tortilla chips. For fresh and stored tortilla chips, there were no significant differences in the thickness or peakload force-to-puncture values attributable to oil treatment. Mean force to puncture values for chips ranged from 1.52 to 1.21 kg at Time 0, 1.73 to 1.47 kg at P16, and 1.77 to 1.51 at P24. Thus, these instrumental data (not shown) for chip crispness support sensory results. The Hunter L, a, and b values (not presented) of fresh chips and L and b values of stored chips did not differ as a result of frying oil. Mean Time 0 L, a, and b values of chips were 52.8, 5.5, and 27.8, respectively. For stored chips, the mean L and b values were 53.9 and 27.5, respectively. The a values of all stored chips were similar, but all values (a = 4.7) were significantly lower than the HR (a = 5.4).

Chemical analyses of tortilla chips. The PV of oils extracted from practically-stored chips were generally much lower than for oils from Schaal chips (Table 2). At P16, the PV of extracted LLC was significantly greater than those of CO and C, which were alike and were greater than values for PHS and PHC, which were similar to each other. At P24 the PV of all extracted oil treatments differed significantly; LLC had the greatest PV, followed by C, CO, PHS, and finally PHC. At P16 and P24, AV for extracted oils showed small but significant differences among treatments, however, all AV were low. The AV for extracted oils from practically-stored chips tended to support sensory data which showed that comparable CO chips were most rancid, bitter, and had an intense aftertaste. However, PV do not agree with corresponding sensory findings.

Chemical analyses of stored, used frying oil. At P16, all oils had similar low PV (Table 3), except for LLC which had a significantly higher PV than other oils. At P24, all PV increased; LLC had a higher value than C, which also differed from PHS, CO, and PHC, which were alike. The AV of practically-stored, used frying oils did not differ in magnitude or significance from those of comparable Time 0 used oils. Only the AV of CO was slightly above the recommended level of 10 for fresh frying fats (23).

Results of chemical analyses on stored (P16, P24), used oils and related sensory data for stored chips were evaluated to determine the potential of utilizing stored used oils for predicting chip quality. The AV for practically-stored oils tended to support related sensory findings that show CO chips were most rancid; however, PV did not support trained panelist evaluations of comparable stored chips.

Thus, the results of this study showed that there seems to be considerable potential for increasing the use of canola oil products for frying snack foods, such as tortilla chips. Storage conditions influenced the sensory quality of the tortilla chip treatments. Under prolonged Schaal storage (16 d), C chips deteriorated most rapidly, followed by CO chips, but LLC, PHC, and PHS chips did not develop the off-odors/flavors detected in C chips. However, after S8 all chips were generally similar, except that PHC chips had a slightly more intense off-odor than LLC chips, and PHC and PHS chips had more buttery odor/flavor than other S8 chips. During practical storage for up to 24 wk, all chip treatments had very similar sensory scores; however, C, LLC, and PHC were most stable to off-odor/flavor development. Chemical analyses of oil extracted from Schaal-stored chips tended to support data of trained panelists; results of similar analyses on extracted oils from practically-stored chips did not. Chemical data for stored, used frying oils and corresponding sensory data for stored chips generally did not agree, indicating that stored oils did not predict chip quality/stability. However, panelists did not evaluate stored oils. Further work is required to determine whether storing used oil has potential for predicting fried food stability (13).

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