Storage Stability of Potato Chips Fried in Genetically Modified Canola Oils

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ABSTRACT: The storage stability of potato chips fried in regular (RCO), hydrogenated (HYCO), low-linolenic (LLCO), and high-oleic (HOCO) canola oils was compared. Potato chips were fried in each oil over a 5-d period for a total of 40 h of frying. Chips from frying day 1 and 5 were packaged and stored at 60°C for 0, 1, 2, 4, 8, and 16 d. Lipids were extracted from the stored chips and analyzed for peroxide values, free fatty acids (FFA), conjugated dienoic acids (CDA), and polar components. A trained sensory panel evaluated the stored chips for odors characteristic of oxidation. Chips were also analyzed for volatile components. Potato chips fried in RCO, LLCO and HOCO developed an intense painty odor, whereas chips fried in HYCO developed an intense stale/musty odor by the end of the 16 d of storage. Chips fried in RCO had greater rates of accumulation of peroxides, FFA, CDA, and polar components and developed higher levels of total volatiles over the 16 d of storage than chips fried in the other three oils. Chips fried in HYCO had lower rates of accumulation of peroxides and CDA than chips fried in LLCO and HOCO, and lower rates of FFA accumulation than chips fried in LLCO. Chips fried in HYCO and HOCO had the lowest amounts of total volatiles during storage. The effect of oil degradation products on potato chip storage stability was not shown in this study since only the chips fried in HYCO from frying day 5 exhibited a significantly greater rate of off-odor development than chips from frying day 1, and only the chips fried in LLCO from frying day 5 had a greater rate of accumulation of volatiles than chips from frying day 1.

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Frying fats and oils with a high proportion of unsaturated fatty acids are more prone to oxidative rancidity than fats with high levels of saturated fatty acids. Thus, the high level (9–12%) of linolenic acid (18:3) in canola oil has limited the storage stability of snack foods fried in canola oil. Decreasing the 18:3 content of canola oil by hydrogenation has been shown to reduce the accumulation of peroxide values (PV), conjugated dienoic acids (CDA), and total volatiles and the development of rancid and painty odors and flavors in potato chips during accelerated storage over a 12-d period (1). Melton *et al.* (2) found that potato chips fried in hydrogenated canola oil (HYCO) and in blends of HYCO and cottonseed oil had similar storage stability to potato chips fried in 100% cottonseed oil as measured by PV.

Reduction of 18:3 levels through genetic modification has also been shown to extend the shelf life of fried foods. Improved storage stability of bread cubes fried in modified soybean oil has been reported (3,4) and tortilla chips fried in low-linolenic canola oil (LLCO) were found to have a higher intensity of characteristic odor and lower intensities of off, rancid and painty odors after 16 d of storage at 60°C compared to chips fried in regular canola oil (RCO) (5,6). Initial values for PV, CDA, free fatty acids (FFA), and total volatiles were similar for chips fried in LLCO and RCO, but after 16 d of storage the chips fried in RCO had significantly higher values compared to LLCO chips (5). Warner *et al.* (6) found potato chips fried in RCO had the lowest flavor quality scores (10 = excellent quality, 1 = bad quality) after 4 mon of storage at 25°C compared to chips fried in HYCO, LLCO, and high-oleic canola oils (HOCO). Chips fried in HOCO and LLCO had higher flavor quality scores compared to HYCO chips. Similarly, RCO chips had significantly higher amounts of total volatiles than chips fried in the other three oils, and HOCO and LLCO chips had lower amounts of total volatiles than HYCO chips.

The presence of frying oil degradation products in fried foods has been demonstrated by some workers to have a prooxidative effect on the storage stability of snack foods (7,8). Few reports exist on the effect of frying oil degradation products on storage stability of foods fried in genetically modified oils.

The objectives of this study were to compare the storage stability of potato chips fried in genetically modified canola oils with chips fried in regular and hydrogenated canola oils and to determine if the level of oil degradation products caused by prolonged frying influences the storage stability of potato chips.

EXPERIMENTAL PROCEDURES

Materials. Commercially refined, bleached and deodorized RCO and LLCO were obtained from CanAmera Foods Ltd.

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(Altona, Manitoba, Canada). Citric acid was added to these oils during processing. Commercially processed HYCO was obtained from CanAmera Foods Ltd. (Nipawin, Saskatchewan, Canada). Laboratory refined, bleached, and deodorized HOCO was obtained from Anderson Clayton/Humko (Memphis, TN). Norchip variety potatoes were obtained from Southern Potato Company (Winkler, Manitoba, Canada).

Fatty acid composition of the initial oils was determined by gas chromatographic (GC) analysis of methylated samples using a Hewlett-Packard 5890A GC equipped with a fused-silica capillary column 30 m × i.d. 0.25 mm coated with polar phase Supelcowax 10 (Supelco Inc., Bellefonte, PA), autosampler, 3392A integrator, and flame-ionization detector. Column temperature was programmed from 195 to 235°C at a rate 2°C/min with lower and upper temperatures being held for 3 and 4 min, respectively. Detector and injection port temperatures were both 250°C.

Frying protocol. The antifoaming agent (dimethylpolysiloxane) was added to RCO, LLCO, and HOCO in the amount of 2 ppm (1). To achieve the required concentration, a mixture of silicone in oil was prepared as follows: 0.17 g of silicone was added to 20 g of oil, and 1 g of this mixture was added to 4.25 kg of the oil. Dimethylpolysiloxane was added (2 ppm) to HYCO by the manufacturer.

Unpeeled potatoes were washed and sliced to a thickness of 1.2–1.3 mm (9). The slices were washed under cold running water to remove surface starch and placed in a pan of cold water until required for frying. Potato slices (approximately 60–70 g) were removed from the pan, blotted with paper towels, and spread in a single layer on the wire frying rack. A model 611 mini fryer (Belshaw Bros. Inc., Seattle, WA) with 5-kg capacity was used. The initial amount of oil used was 4.25 kg. On the first day of frying, the oil was conditioned by heating to 185 ± 5°C and holding at this temperature for 30 min. Potato slices were lowered into the oil on the rack and fried until the bubbling of the oil ceased (approximately 2 min). After frying, the chips were allowed to drain for 5 min and were then transferred to paper towels and blotted to remove excess oil. Thirty-two batches of potato chips were fried each day, 15 min apart for a total of 8 h of frying. Chips were fried in each oil for 5 d (40 h of frying).

On the second and consecutive days, the oil was weighed prior to frying to determine the amount of fresh oil needed to replenish the oil in the fryer. The amount of fresh oil added was 10–15% each day for all oils. The antifoaming agent/oil mixture was added to achieve 2 ppm of silicone in the make-up oil. The oil was then heated to 185 ± 5°C before frying the first batch of chips.

Storage protocol. Potato chips from a single day of frying were pooled together, packaged, and stored. Commercial potato chip packaging composed of metallized foil was formed into 10 × 10 cm bags using a heat sealer. The bags were filled with chips (4.5 ± 0.2 g) and heat-sealed. The packaged chips were stored under accelerated conditions (60 ± 2°C). Bags were removed from the storage cabinet at 0, 1, 2, 4, 8, and 16 d and kept at –25°C until analyzed.

Selection and training of odor profile panel. Ten panelists (6 females and 4 males) were selected based on their ability to discriminate between fresh and stored samples of potato chips. Twenty-six, half-hour training sessions were held over a period of 7 wk. During training, each panelist became familiar with the technique for evaluating the samples, the odor attributes to be evaluated, and the scale for rating the samples. They also had an opportunity to practice their judgments so they became consistent with their ratings. Panelists were instructed to cut open the bag just below the seal and push the sides of the bag together at the bottom so that the bag opened at the top. They were then told to take three short sniffs, close the bag by rolling down the top of the bag, and secure it with a paper clip. The purpose of reclosing the bag in this manner was to minimize the loss of odor volatiles should the panelist need to reevaluate the sample. The same odor attributes and reference samples could not be used for rating the chips fried in the four oils since panelists found the odor properties to be different. Painty odor was evaluated for chips fried in RCO, LLCO, and HOCO, whereas stale/musty odor was rated for chips fried in HYCO. Odor attributes were rated on 15-cm unstructured line scales where 0 = none and 15 = intense. Numerical values were assigned by measuring the distance in centimeters to the panelist's marking on the line scale. Reference samples were provided to panelists to calibrate their ratings on the line scales (Table 1).

Sensory test sessions. Only potato chips from frying day 1 and day 5 were evaluated by the sensory panel. Test sessions were held in the computerized sensory facility of the Department of Foods and Nutrition, University of Manitoba. Evaluations were made in individual booths under red lights to mask any possible color differences among the samples. The CSA software (Compusense Inc., Guelph, Ontario, Canada) was used to record the panelists' ratings of the samples directly on the computer screen.

On each day of testing, panelists evaluated all storage intervals for one frying day and one oil (session 1), followed by a 5 min break after which a second set of samples representing the other frying day for the same oil (session 2) was evaluated. Panelists rated the samples within each set in random

TABLE 1
References Used in Sensory Evaluation[a]

Oil	Odor attribute	Reference	Scale value
Regular	Painty	Chips fried in RCO and stored for 16 d	15
Hydrogenated	Stale/musty	Chips fried in HYCO and stored for 20 d	13
Low linolenic	Painty	Chips fried in LLCO and stored for 20 d	13
High oleic	Painty	Chips fried in HOCO and stored for 20 d	13

[a]RCO, regular canola oil; HYCO, hydrogenated canola oil; LLCO, low-linolenic canola oil; HOCO, high-oleic canola oil.

order. Two replications were completed for each oil and frying day. Thus, 16 sessions were required to complete the sensory testing of the chips (4 frying oils × 2 frying days × 2 replications) over an 8-d period.

Volatile component analysis. A purge-and-trap method was used to assess volatile components based on the procedure by Przybylski (10). A Perkin-Elmer 8500 gas chromatograph (Norwalk, CT) with a built-in integrator was used. The column consisted of two parts: a packed pre-column to trap the volatiles, which was connected to the capillary column to separate the volatile components. The pre-column was packed with bonded packing CSP-20M (Chromatographic Specialities Ltd., Brockville, Ontario, Canada) and shaped into a coil to facilitate cooling with liquid nitrogen. A fused-silica capillary column (60 m × 0.32 mm i.d.) with 1 mm of DB-5 (J&W Scientific, Folsom, CA) was used. Injector and flame-ionization detector temperatures were 125 and 250°C, respectively. Column temperature was programmed from 45 to 85°C at a rate of 2°C/min, then 85 to 125°C at a rate of 3°C/min, and finally from 125 to 235°C at a rate of 4°C/min. Initial and final temperatures were held for 2 and 10 min, respectively. An internal standard, tridodecane in fresh canola oil, and a reference sample with standard components of interest were used to identify and quantify individual components and to determine if there was a shift in retention time from day to day.

A glass insert tube with a side opening close to the end of the tube was used to hold the sample in the injector. A glass wool plug was inserted into the tube 15 mm opposite the side opening. Potato chips were crushed in a mortar after which 0.2–0.3 g crushed chips were placed into the tube and protected with a second glass wool plug. Before adding the internal standard, the pre-column was prepared for purging. The container was placed under the coil of the pre-column, liquid nitrogen was poured into the container, and the valve with purging gas was opened. After this preparation was completed, 5 μL of internal standard, containing 175 ng of dodecane, was applied onto the glass wool plug at the end opposite the side opening. After the tube with the sample was placed in the injector it was closed immediately. Purging continued for 15 min, and liquid nitrogen was topped up as required. After 15 min had elapsed, the tube with the sample was replaced with a blank one, the pressure in the system was allowed to normalize, liquid nitrogen removed, and the run started.

Lipid extraction from potato chips. Lipid extraction from the potato chips was based on the method of Folch *et al.* (11). Crushed chips (about 8–9 g) were placed in a 100-mL beaker and 50 mL of chloroform/methanol mixture (2:1 vol/vol) was added. The mixture was homogenized in a Polytron homogenizer (Kinematica, GnbH, Lucerne, Switzerland) for 30 s at speed 4 and the upper layer was carefully transferred into a separatory funnel. Another 50 mL of chloroform/methanol mixture was added to the residue and homogenized again. The content of the beaker was transferred into the same separatory funnel. The crude extract was mixed with 0.2 of its volume with glass-distilled water (20 mL). The mixture was gently shaken and was allowed to stand overnight to separate the mixture into two phases. The lower layer from the separatory funnel was transferred into a preweighed round-bottomed flask, and the extract was evaporated to dryness in a rotary vacuum evaporator. Isopropanol or benzene (1–2 mL) was added at the end of evaporation, and the solvent was again evaporated to ensure that there was no water in the sample. The extracted oil was then transferred with a pipette into a 5-mL vial, flushed with nitrogen, and stored at –25°C until analyzed.

Chemical analyses of extracted lipids. The extracted oil was analyzed for PV using a colorimetric method based on the conversion of Fe^{2+} to Fe^{3+} by hydroperoxides present in the solution. The resulting ferric ion forms a purple complex with xylenol orange that has an absorbance maximum at 560 nm. The reagent was prepared according to Nourooz-Zadeh *et al.* (12), but the amount of xylenol orange and ammonium ferrous sulfate was increased five times. FFA and CDA were determined using AOCS methods Cd 8-53 and Ti 1a-64, respectively (13). Tests were performed in duplicate. Polar components were determined by modifying the method of Sebedio *et al.* (14), as described by Petukhov *et al.* (15).

Statistical analyses. Sensory data were analyzed using the mixed procedure (PROC MIXED) (16). Analysis of the full model was done initially followed by testing against the null model for any significant improvement. This model-building process resulted in the most appropriate model being selected to account for the variability in the data. Fixed effects of storage day and frying day were then determined within each oil.

Analysis of covariance was used to analyze the chemical data using the general linear model procedure (PROC GLM) (16). Fixed effects of oil, storage day, fry day, and interactions were determined. A *t*-test with 28 degrees of freedom ($\alpha = 0.05$) was used to estimate the difference in slopes and intercepts among oils. When the distribution of the residuals lacked normality a natural logarithm or square root data transformation was used in the model.

RESULTS

Fatty acid composition of oils. RCO had expected levels of oleic, linoleic, and linolenic acids (Table 2). Compared to RCO, LLCO had lower levels of linolenic and slightly higher

TABLE 2
Fatty Acid Composition of Canola Oils[a]

Oil	18:1	18:2	18:3[b]	SFA	MUFA	PUFA
Regular	56.5	22.3	10.8	7.3	58.4	33.1
Hydrogenated	73.7	8.0	—	16.0	75.8	8.0
Low linolenic	58.2	27.9	3.7	6.4	60.0	31.6
High oleic	75.2	8.0	5.5	6.6	76.9	13.5

[a]SFA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids.
[b]Combined *cis* and *trans* isomers.

levels of oleic and linoleic acids whereas HOCO had higher levels of oleic acid similar to the level found in HYCO.

Sensory evaluation. Storage day had a significant effect ($P < 0.05$) on painty odor in chips fried in RCO, LLCO and HOCO from frying day 1, with painty odor intensity increasing with storage time (Fig. 1). All three oils showed a rapid increase in painty odor after 4 d of storage. Similar findings were found for chips from frying day 5 (results not shown) and comparison of slopes within each oil between frying day 1 and 5 revealed no significant differences in the development of painty odor over the 16 d of storage.

A significant ($P < 0.05$) storage day × frying day interaction was found for stale/musty odor in chips fried in HYCO. For both frying days, the intensity of stale/musty odor increased as storage days increased, but the rate of increase was more rapid for chips fried on frying day 5 (Fig. 2).

Peroxide PV. On frying day 1, the accumulation of peroxides increased with increasing storage for all chips (Fig. 3). Chips fried in HYCO had a significantly lower rate of accumulation of peroxides than chips fried in RCO ($t_{28} = 6.62$, $P = 0.001$), LLCO ($t_{28} = 4.77$, $P = 0.001$), and HOCO ($t_{28} = 2.69$, $P = 0.012$). Potato chips fried in HOCO also had a significantly lower rate of peroxide accumulation than chips fried in RCO ($t_{28} = 3.93$, $P = 0.001$) and LLCO ($t_{28} = 2.09$, $P = 0.046$). Similarly, for frying day 5 (results not shown), chips fried in HYCO had a significantly lower rate of accumulation of peroxides than chips fried in RCO ($t_{28} = 5.05$, $P = 0.001$) and LLCO ($t_{28} = 3.86$, $P = 0.001$), and chips fried in HOCO had a significantly lower rate of accumulation than chips fried in RCO ($t_{28} = 5.35$, $P = 0.001$) and LLCO ($t_{28} = 4.16$, $P = 0.001$). When the accumulation rates of peroxides in potato chips were compared between the two frying days within each oil no significant difference was found between

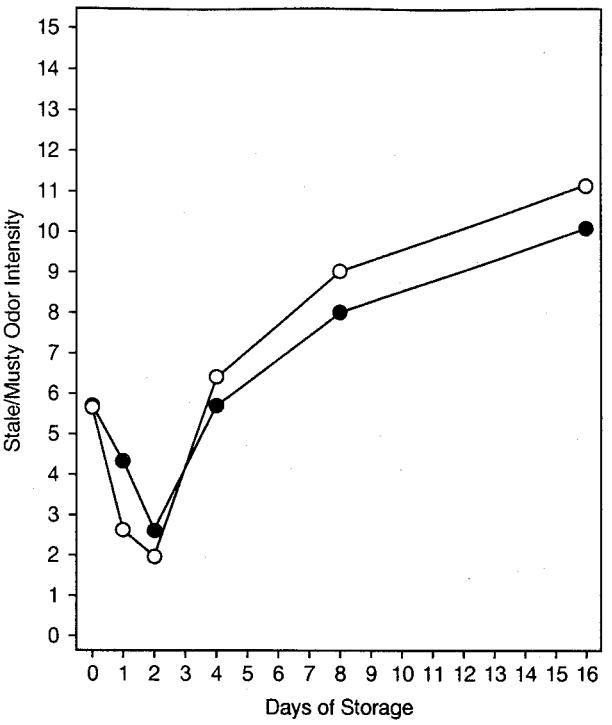

FIG. 2. Stale/musty odor intensity of stored potato chips fried in hydrogenated canola oil: frying day 1 (●); frying day 5 (○).

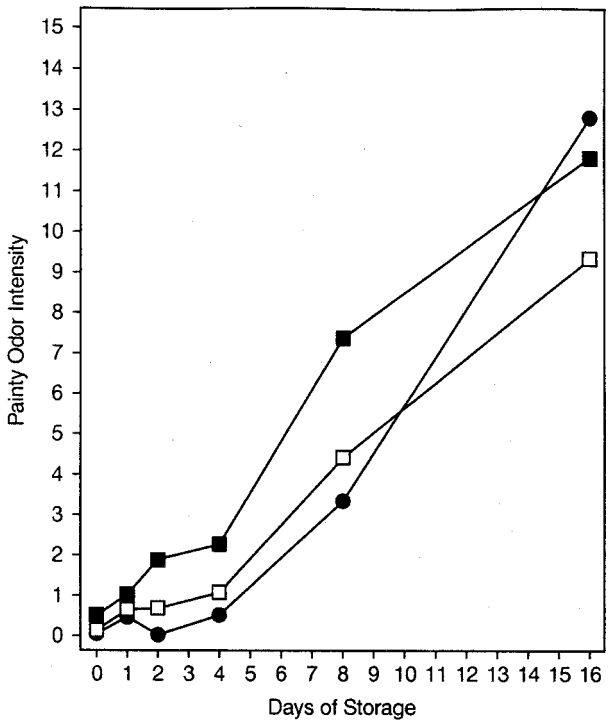

FIG. 1. Painty odor intensity of stored potato chips fried in (●) regular; (■) low-linolenic, and (□) high-oleic canola oils.

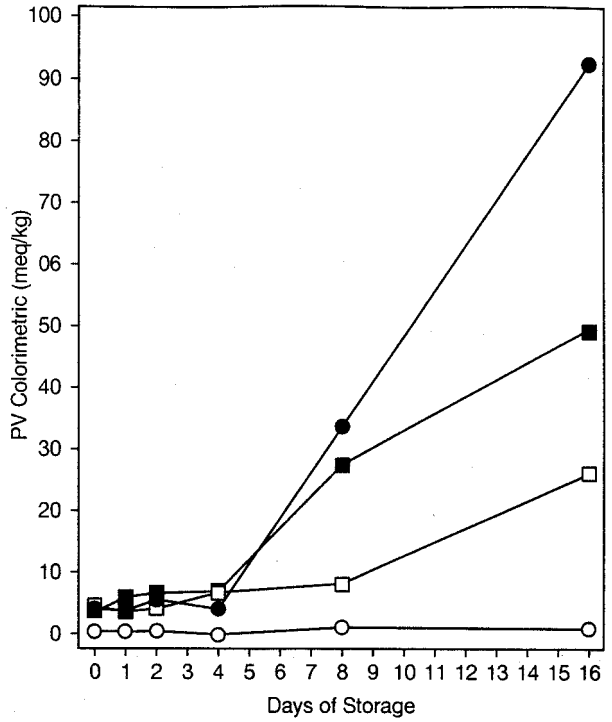

FIG. 3. Peroxide values (PV) of oil extracted from stored potato chips fried in (●) regular; (■) low-linolenic, (□) high-oleic, and (○) hydrogenated canola oils.

the two frying days except for chips fried in HOCO where peroxides were found to accumulate faster on day 1 than on day 5 ($t_{28} = -2.02$, $P = 0.05$).

FFA. For frying day 1, the rate of accumulation of FFA was significantly higher in chips fried in RCO than the other three oils (HYCO: $t_{28} = -6.18$, $P = 0.001$; LLCO: $t_{28} = -2.89$, $P = 0.007$; HOCO: $t_{28} = -5.73$, $P = 0.001$), and chips fried in LLCO had a significantly greater rate of FFA production than HYCO ($t_{28} = -3.28$, $P = 0.003$) and HOCO ($t_{28} = -2.84$, $P = 0.008$) (Fig. 4). The rate of FFA accumulation in potato chips fried in RCO from frying day 5 was significantly faster than in chips fried in HOCO ($t_{28} = -2.87$, $P = 0.008$) and HYCO ($t_{28} = -1.77$, $P = 0.088$), and chips fried in LLCO accumulated FFA at a faster rate than chips fried in HOCO ($t_{28} = -2.05$, $P = 0.05$) (data not shown). Comparison of the two frying days within each oil revealed that there were significantly lower accumulation rates of FFA for frying day 5 than frying day 1 for chips fried in RCO ($t_{28} = 4.77$, $P = 0.001$), LLCO ($t_{28} = 2.89$, $P = 0.007$), and HOCO ($t_{28} = 2.33$, $P = 0.027$).

CDA. Chips fried in RCO from frying day 1 accumulated CDA faster than chips fried in HYCO ($t_{28} = -12.04$, $P = 0.001$), LLCO ($t_{28} = -3.21$, $P = 0.003$), and HOCO ($t_{28} = -9.27$, $P = 0.001$); chips fried in LLCO had greater rates of CDA accumulation than chips fried in HYCO ($t_{28} = -6.05$, $P = 0.001$) and HOCO ($t_{28} = -8.83$, $P = 0.001$); and chips fried in HOCO accumulated CDA faster than chips fried in HYCO ($t_{28} = -2.77$, $P = 0.01$) (Fig. 5). For chips fried on day 5, there was a significantly greater rate of CDA accumulation in chips fried in RCO than chips fried in HYCO ($t_{28} = -6.43$, $P = 0.001$), LLCO ($t_{28} = -3.04$, $P = 0.005$), and HOCO ($t_{28} = -6.14$, $P = 0.001$) and in chips fried in LLCO than chips fried in HYCO ($t_{28} = -3.38$, $P = 0.002$) and HOCO ($t_{28} = -3.09$, $P = 0.004$) (data not shown). There was a significantly greater rate of CDA accumulation in chips stored from frying day 1 than frying day 5 for RCO ($t_{28} = -4.58$, $P = 0.001$), LLCO ($t_{28} = -4.72$, $P = 0.001$), and HOCO ($t_{28} = -2.21$, $P = 0.0357$).

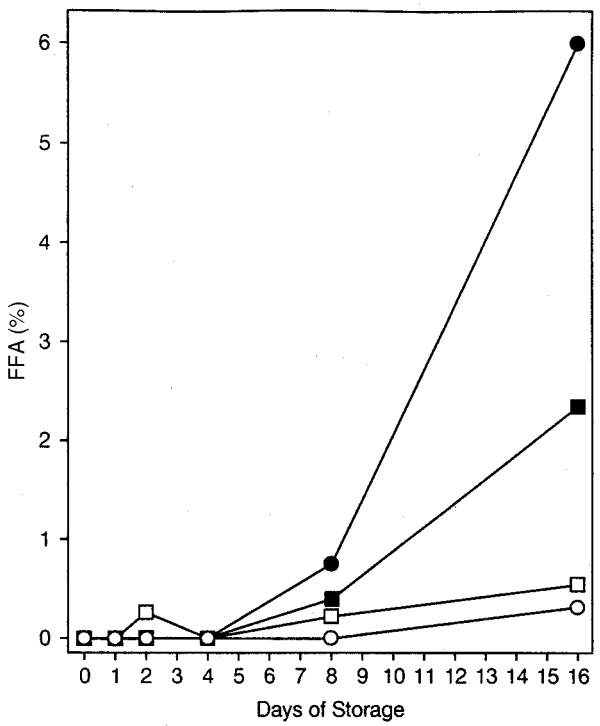

FIG. 4. Free fatty acids (FFA) in oil extracted from stored potato chips fried in (●) regular; (■) low-linolenic, (□) high-oleic, and (○) hydrogenated canola oils.

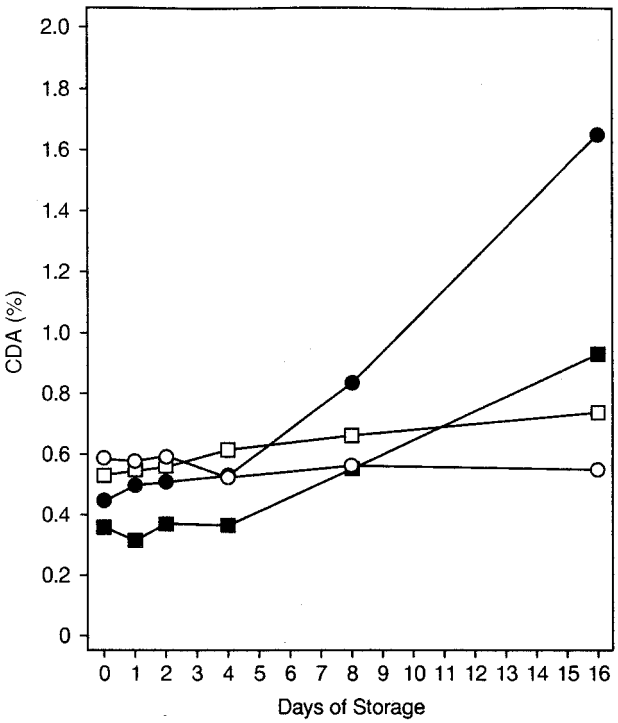

FIG. 5. Conjugated dienoic acids (CDA) in oil extracted from stored potato chips fried in (●) regular; (■) low-linolenic, (□) high-oleic, and (○) hydrogenated canola oils.

Polar components. For frying day 1, potato chips fried in RCO had a significantly greater rate of accumulation of polar components compared to potato chips fried in HYCO ($t_{28} = -5.35$, $P = 0.001$), LLCO ($t_{28} = -4.52$, $P = 0.001$), and HOCO ($t_{28} = -4.70$, $P = 0.001$) (Fig. 6). For frying day 5 chips fried in RCO exhibited the greatest rate of accumulation of polar components compared to chips fried in HYCO ($t_{28} = -4.16$, $P = 0.001$), LLCO ($t_{28} = -4.06$, $P = 0.001$), and HOCO ($t_{28} = -4.24$, $P = 0.001$) (data not shown). Comparison of the two frying days within each oil revealed no significant differences between the two frying days.

Volatile components. Although 25 components could be identified, there were more than 15 components that could not. Volatiles were grouped according to their chemical structures into hydrocarbons, saturated and unsaturated carbonyls, dienals, and pyrazines. Total volatiles included both identified and unidentified components. For frying day 1, there was a gradual increase in the accumulation of total volatiles in chips fried in HYCO, LLCO, and HOCO, whereas there was a rapid increase in volatiles for chips fried in RCO (Fig. 7) which was about 25–40 times greater than the chips fried in the other three oils. On frying day 5, the sharp increase ob-

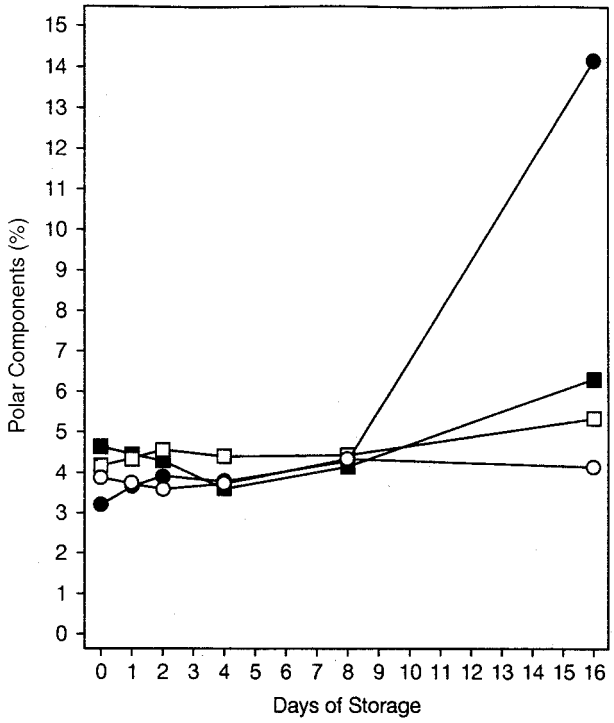

FIG. 6. Polar components in oil extracted from stored potato chips fried in (●) regular; (■) low-linolenic, (□) high-oleic, and (○) hydrogenated canola oils.

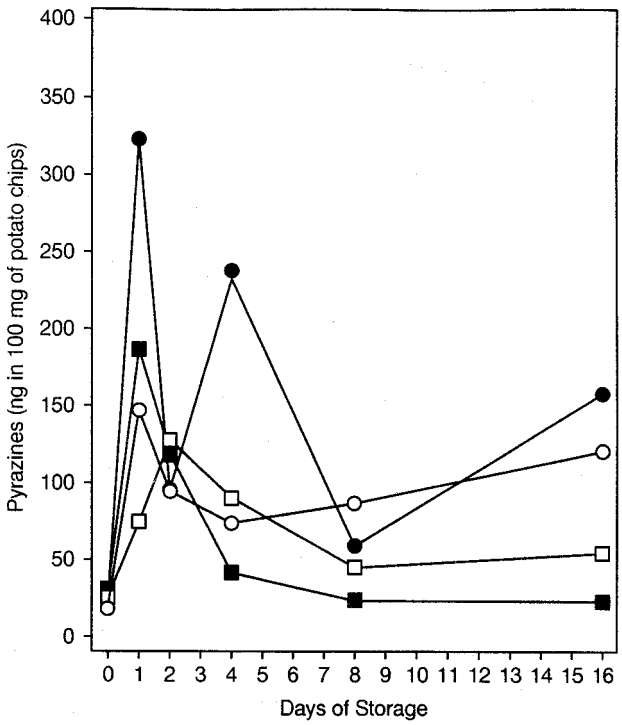

FIG. 8. Pyrazines in stored potato chips fried in (●) regular; (■) low-linolenic, (□) high-oleic, and (○) hydrogenated canola oils.

served for chips fried in RCO on frying day 1 was 2.5 times smaller and chips fried in HYCO showed a slight decrease in total volatiles whereas chips fried in HOCO and LLCO showed an increase over the 16 d of storage (data not shown). Comparison of slopes between frying days 1 and 5 revealed that only the chips fried in LLCO showed a significant increase in the amount of total volatiles on frying day 5 than frying day 1 ($P < 0.05$). Data obtained for individual subclasses of volatiles (hydrocarbons, saturated and unsaturated carbonyls, and dienals) revealed the same trends as found for total volatiles. Since no additional information was found with individual subclasses, the data are not presented.

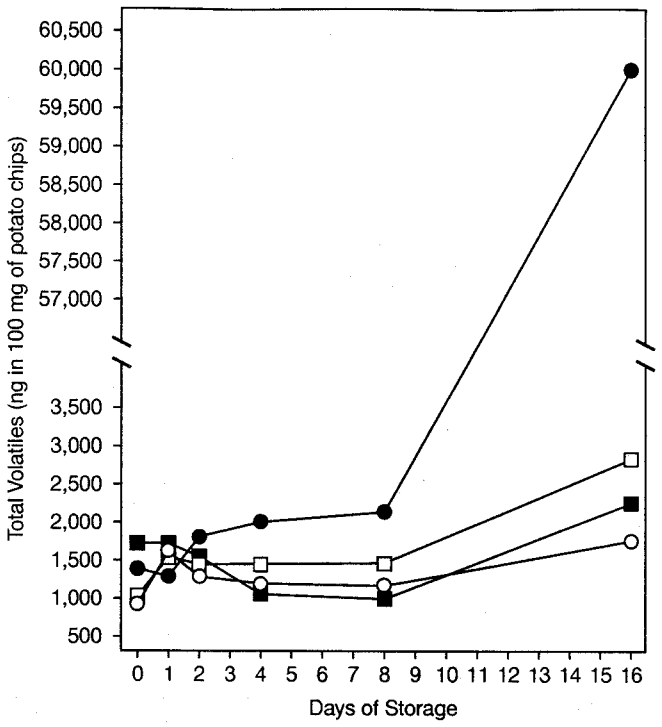

FIG. 7. Total volatiles in stored potato chips fried in (●)regular; (■) low-linolenic, (□) high-oleic, and (○) hydrogenated canola oils.

Pyrazines in potato chips have been associated with potato flavor (2). The amount of pyrazines in chips from frying day 1 showed an increase initially for all oils followed by a decrease (Fig. 8). RCO showed the greatest fluctuations in pyrazine amounts over storage. By the end of the storage period, chips fried in LLCO and HOCO had the lowest levels of pyrazines. For frying day 5, chips fried in HYCO and LLCO showed a steady decrease in pyrazines, whereas for chips fried in RCO and HOCO there was an increase at storage day 2 followed by a decrease (data not shown). The total amount of pyrazines after 16 d of storage for both frying days was similar in potato chips fried in HOCO and LLCO, whereas potato chips fried in RCO and HYCO had lower levels for frying day 5 compared to frying day 1.

DISCUSSION

In this study, painty odor increased in chips fried in RCO, LLCO, and HOCO during the 16-d storage period. These findings are in agreement with Hawrysh (1) who reported that

stored potato chips fried in RCO increased in intensity of off, rancid, and painty odor over 12 d of storage. Hawrysh *et al.* (5) also reported that stored tortilla chips fried in RCO and LLCO had a higher intensity of off, rancid, and painty odor during 16 d of storage; but tortilla chips fried in LLCO only had a slight increase in these odors, whereas chips fried in RCO had a substantial increase in these odors. In our study, potato chips fried in HYCO developed a stale/musty odor during the 16 d of storage. Warner (17) suggested that during early stages of oxidation, a stale odor is present in fried products and that later, in more advanced stages, oxidation is expressed as rancid and painty odors. Thus, it is possible that the chips fried in HYCO and stored for 16 d were only in the early stages of oxidation since the panelists were unable to detect a painty odor in these chips.

The results of chemical analysis of the oils extracted from potato chips fried in all four oils showed an increased accumulation of peroxides, FFA, CDA, polar components, and total volatiles with increased storage. Chips fried in RCO were the least stable since they accumulated peroxides, FFA, CDA, polar components and volatiles at a greater rate than the other chips. Potato chips fried in HYCO were the most stable since they developed degradation compounds at the slowest rate and the accumulation of volatiles was the lowest among all potato chips after 16 d of storage. Chips fried in LLCO and HOCO had greater storage stability than chips fried in RCO since they had slower rates of accumulation of peroxides, FFA, CDA, and polar components and had lower amounts of total volatiles after 16 d of storage. Potato chips fried in HOCO showed greater stability to oxidation than chips fried in LLCO, as exhibited by slower rates of accumulation of peroxides, FFA, and CDA. The amounts of total volatiles were similar for chips fried in HOCO and LLCO for frying day 1, but for frying day 5 the total amount of volatiles in potato chips fried in HOCO was smaller than in chips fried in LLCO. These findings are in agreement with results by Hawrysh (1) who found that stored potato chips fried in RCO had greater accumulation of peroxides and CDA and had higher total volatiles than chips fried in partially hydrogenated canola oil. However, Hawrysh (1) did not find differences in FFA between stored potato chips fried in RCO and partially hydrogenated canola oil. Hawrysh *et al.* (5) also found that stored tortilla chips fried in RCO had higher levels of peroxides than chips fried in either partially hydrogenated canola oil or LLCO, but tortilla chips fried in partially hydrogenated canola oil accumulated significantly lower levels of peroxides than chips fried in LLCO. Liu and White (4) also reported increased accumulation of peroxides in stored bread cubes fried in regular soybean oil compared to cubes fried in two low-linolenic soybean oils.

The changes observed by our trained sensory panel in the chips over storage were supported by the volatile analysis data. The increase in painty odor in chips fried in RCO, LLCO, and HOCO and stale/musty odor in chips fried in HYCO corresponded to an increase in the amounts of total volatiles in the chips, especially saturated and unsaturated carbonyls which are associated with oxidized odors, as storage progressed. At the same time, there was a decrease in the amount of pyrazines, which are associated with potato flavor.

The effect of oil degradation products on potato chip storage stability was not shown in this study since, with the exception of the chips fried in HYCO, no differences were found in the rate of off-odor development between frying days 1 and 5. This was unexpected since Asap and Augustin (7) reported that the longer an oil is used for frying the greater the rate of development of rancid odor in stored potato chips. According to Yoon *et al.* (8), the presence of degradation products should induce a rise in the amount of total volatiles. However, in the present study, only the chips fried in LLCO on frying day 5 showed a higher accumulation of volatiles over the 16-d storage period. The addition (10–15%) of fresh oil every day prior to frying to maintain a constant level of frying oil likely slowed down the accumulation of degradation products.

This study has shown that the oxidation of potato chips during storage is accompanied by increased accumulation of primary and secondary oxidation products as measured by PV, CDA, FFA, polar and volatile components. The sensory results also showed that storage had a significant effect on increasing the intensity of odors characteristic of oxidation in the chips. Potato chips fried in RCO had higher rates of accumulation of peroxides, FFA, CDA, and polar components, and higher amounts of total volatiles compared to chips fried in HYCO, LLCO, and HOCO. Chips fried in HYCO had lower rates of accumulation of peroxides and CDA than chips fried in LLCO and HOCO, and lower rates of FFA accumulation than chips fried in LLCO. Chips fried in HYCO and HOCO had the lowest amounts of total volatiles during storage. Potato chips fried in RCO containing the highest level of 18:3 (10.1%) were found to be the least stable, whereas potato chips fried in HYCO containing no 18:3 were found to be the most stable. Potato chips fried in HOCO were found to have similar storage stability to potato chips fried in HYCO, and potato chips fried in LLCO showed slightly better stability than chips fried in RCO, suggesting that fatty acid composition alone is not responsible for the performance of an oil.

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