ARTICLES

Role of Glycerophosphorylcholine and Glycerophosphorylethanolamine in Linoleic Acid Oxidation

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The effect of adding glycerophosphorylcholine (GPC) and glycerophosphorylethanolamine (GPE) on the decomposition of linoleic (18:2) acid was evaluated at 70 °C by monitoring the production of low molecular weight headspace volatiles from 4 to 154 min using gas chromatography and gas chromatography–mass spectrometry. Sixteen compounds were isolated of which the concentrations of four were not affected by the heating time (butane, 2-methyl-3-buten-2-ol, hexanol, and undecane). Hexanal was the most prominent volatile produced in all treatments. Pentane was produced at a significantly greater rate in the 18:2 only treatment compared to the GPC and GPE added treatments. Volatile production rates in the 18:2 + GPE treatment were generally greater as compared to the 18:2 + GPC and 18:2 treatments. In addition, the rate of increase for the sum of the gas chromatographic peak areas over the last half of the heating interval was greater for the 18:2 + GPE treatment compared to that of the 18:2 + GPC and 18:2 treatments. The rate of production was volatile specific and varied due to treatment effects. While the overall rate of volatile production appeared to be increased by the addition of GPE to 18:2, the rate of production of several individual volatiles was higher for the 18:2 + GPC and the 18:2 treatments.

INTRODUCTION

Lipid oxidation is responsible for the production of a variety of low molecular weight compounds (<200 MW) which can result in off flavors in meat (Tims and Watts, 1958). The reactive species produced during oxidation can also react with proteins to damage membranes, enzymes, vitamins, and cell functions (Frankel, 1980), to destroy vitamins in foods, and to form Maillard browning reaction compounds (Montgomery and Day, 1965). Lipid oxidation yields a variety of reactive compounds that have been implicated as factors in cancer (Ames, 1983), atherosclerosis (Goto, 1982), and age-related changes in humans (Hirai et al., 1982).

Individual phospholipids (PL) have been theorized to have different rates of oxidation due to their phosphoryl moieties. Tsai and Smith (1972) measured the oxygen uptake of methyl linoleate emulsions as affected by the addition of choline, serine, ethanolamine, and the phosphoryl derivatives of these amines. These researchers concluded that choline had no effect and that serine retarded and ethanolamine accelerated the oxidation of linoleate. Acosta et al. (1966) found that in cooked turkey phosphatidylcholine (PC) and phosphatidylserine were more susceptible to oxidation than phosphatidylethanolamine (PE). Corliss and Dugan (1971) measured the oxygen uptake of PC and PE extracted from egg and soybean and determined that PE reacted faster with oxygen than PC. However, PE contained 10% more polyunsaturated fatty acids than PC in both egg and soybean extracts. Since polyunsaturated fatty acids will oxidize faster than more saturated fatty acids, it could not be concluded whether the nitrogen moiety associated with the PL had an effect on the rate of oxygen uptake.

Linoleic acid (18:2) oxidation has been extensively studied in meat model systems to determine the catalytic effect of heme and non-heme iron (Decker and Schanus, 1986), metal salts (Kanner and Mendel, 1977), and phosphoryl derivatives (Tsai and Smith, 1972; Corliss and Dugan, 1971). Linoleic acid readily oxidizes due to its two unsaturated sites yielding fewer decomposition pathways than other more unsaturated fatty acids. Thus, 18:2 is generally chosen over other unsaturated fatty acids in studying oxidation. The thermally catalyzed oxidation of 18:2 results in the production of aldehydes, ketones, alcohols, hydrocarbons, and cyclic carbon compounds (Henderson et al., 1980). The mechanisms of lipid oxidation are important to understand since these reactive byproducts can damage cell components in biological systems and produce off flavors and toxic compounds in food systems. The objective of this study was to determine the effect of the addition of glycerophosphorylcholine and glycerophosphorylethanolamine to heated 18:2 on the production of oxidatively generated volatile compounds.

MATERIALS AND METHODS

Model Sample Preparation. In this study a model system was chosen in an attempt to minimize the confounding effect of the pro- and antioxidant factors associated with meat or emulsion systems such as water activity, metal catalysts, fatty acid unsaturation, penetration of oxygen, etc. Linoleic acid and PL derivatives (Sigma Chemical Co., St. Louis, MO) were frozen (−20 °C) upon arrival and kept frozen until used. The PL bases were dissolved in methanol. Linoleic acid (10–13 mg) was weighed into a 5-mL Perkin-Elmer (Norwalk, CT) headspace vial. Three treatments were tested; 18:2 alone, 18:2 plus glycerophosphorylcholine (GPC), and 18:2 plus glycerophosphorylethanolamine (GPE). Since PLs normally contain two fatty acids moieties, PL derivatives were mixed into the 18:2 at a 2:1, 18:2 GPC/GPE, molar ratio. The methanol was evaporated under a stream of nitrogen. All vials were equilibrated at room temperature (23 °C) with air for 5 min before they were sealed with Teflon-lined silica septa.

Headspace Gas Chromatography. Individual sample vials were heated at 70 °C for either 0, 30, 60, 90, 120, or 150 min

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Table I. Retention Times and m/z Values for Compounds Formed from Thermally Oxidized Linoleic Acid (70 °C/154 min)

peak no.	compd	retention time, min	m/z (%)	ID[a]
1	butane	2.85	58 (16), 43 (100), 41 (37), 39 (19)	MS,[b] RT[c]
2	pentane	3.88	72 (19), 57 (15), 56 (19), 55 (18), 43 (100), 41 (62), 39 (29)	MS, RT
3	2-methyl-3-buten-2-ol	5.39	86 (4), 71 (18), 45 (100), 43 (60)	MS
4	butanal	6.19	72 (100), 57 (67), 44 (80), 43 (77), 41 (98), 39 (81)	MS, RT
5	2-methyl-1-pentene	6.99	84 (53), 69 (58), 56 (100), 55 (61), 41 (86), 39 (63)	MS
6	pentanal	9.63	86 (4), 71 (4), 67 (4), 57 (55), 44 (100), 41 (57), 39 (41)	MS, RT
7	hexanol	11.62	70 (48), 55 (74), 42 (100)	MS
8	hexanal	13.18	100 (1), 82 (15), 72 (22), 67 (11), 56 (88), 44 (100), 41 (88), 39 (43)	MS, RT
9	MW 98[d]	14.56	98 (33), 83 (97), 69 (89), 55 (100), 41 (85), 39 (96)	MS
10a/10b	heptanone/2,4-octadienal	15.44	114 (8), 99 (5), 71 (18), 58 (60), 124 (21), 81 (100), 71 (13), 58 (17), 43 (100), 53 (17), 43 (26)	MS, RT
11	heptanal	15.76	114 (2), 96 (19), 86 (27), 81 (36), 70 (100), 57 (56), 44 (78), 41 (73)	MS, RT
12	2-pentylfuran	18.47	138 (12), 109 (2), 95 (5), 81 (100)	MS, RT
13	MW 124[d]	19.40	124 (34), 109 (23), 95 (54), 81 (16), 77 (11), 67 (100), 65 (20)	MS
14	2-(1-pentenyl)furan	19.65	136 (24), 107 (100), 79 (24), 77 (30), 51 (9)	MS
15	2-octenal	20.08	124 (1), 111 (6), 97 (21), 83 (79), 70 (97), 69 (45), 57 (49), 55 (100), 41 (96)	MS, RT
16	undecane	21.09	156 (10), 127 (4), 99 (6), 95 (8), 85 (32), 71 (55), 57 (97), 43 (100)	MS, RT

[a] Methods of identification used for each volatile. [b] Mass spectrometry. [c] Comparison of retention time of standards to the retention time of unknowns. [d] Unknown compound with a MW of 98 or 124.

followed by a 4-min pressurization and 1-min injection sequence. A temperature of 70 °C was chosen since it falls near the endpoint cooking temperature of most meat products. Volatiles were injected and separated by using a Perkin-Elmer Model HS-6 headspace sampler interfaced with a Varian Model 3700 dual-flame gas chromatograph. A 30 m × 0.32 mm i.d. bonded phase fused silica capillary column (DB-5, J&W Scientific, Folsom, CA) with a 1-μm film thickness was used for separation. The column inlet pressure was 20 psi (138 kPa) He with a 10:1 injection split ratio and a 9.1 mL/min flow rate. The column oven was temperature programmed from −20 to 220 °C at 6 °C/min. The injector and detector temperatures were 260 and 270 °C, respectively. Gas chromatographic peaks were integrated with a Waters 820 chromatography data station.

Volatiles were tentatively identified on the basis of the retention times of reference standards (Polyscience Corp., Niles, IL; Aldrich Chemical Co., Inc., Milwaukee, WI). Confirmation of volatile identities was accomplished on a Hewlett-Packard Model 5987 GC–MS (Table I). The ionization energy was 70 eV, and a scan range of 30–300 m/z was used. Volatiles were introduced into the GC–MS with a Tekmar (Cincinnati, OH) OSC-I purge and trap unit. One hundred milligrams of 18:2 were heated at 90 °C for 60 min in a 25-mL glass vial interfaced to the purge and trap unit via a glass-lined stainless steel tube. The headspace volatiles were purged with prepurified He for 5 min every 10 min of heating and collected on a Tenax trap (Anspec Co., Ann Arbor, MI). Trapped volatiles were thermally desorbed at 170 °C from the trap onto a DB-5 capillary column held at −20 °C. The GC conditions were identical with those described earlier for separation of volatiles. On the basis of relative retention times, both headspace/GC and purge and trap/GC–MS methods yielded similar volatile profiles.

Statistical Analysis. The GC headspace volatile peak areas and slopes of peak area (three replications) were analyzed as a randomized complete block design with the treatments; 18:2, GPC + 18:2, and GPE + 18:2 blocked with the six heating times. Main effects and dual interactions were included in the General Linear Model with the three-way interaction (replication × treatment × heating time) used as the error term. Means were separated by using Duncan's multiple range test (Helwig and Council, 1982).

RESULTS AND DISCUSSION

Effect of Added GPC and GPE on the Oxidation of 18:2. The effect of GPC and GPE on 18:2 oxidation was measured by monitoring the production of volatile compounds generated from heated 18:2. Due to the qualitative similarities of the chromatograms within sampling times, only two representative headspace chromatographic profiles of 18:2 following 4 and 154 min of heating at 70 °C are presented in Figure 1. As confirmed in previous studies

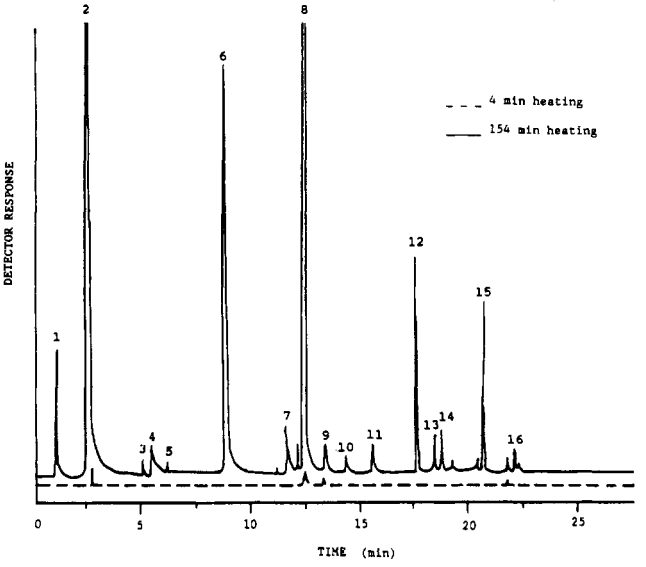

Figure 1.

involving the oxidation of linoleates, the origin of many of these compounds is through the autoxidation of linoleic acid (Selke et al., 1980). The peak areas of compounds 1 (butane), 3 (2-methyl-3-buten-2-ol), 7 (hexanol), and 16 (undecane) were not affected by heating. Both alcohols and two of the three saturated hydrocarbons identified in this study were not significantly affected by heating. These compounds are generated during heating and either reach a steady state or decrease in concentration with continued heating. All volatiles would be expected to be in a dynamic state of equilibrium, being produced, degraded, or acting as substrates in the formation of secondary compounds. Compounds 1, 3, 7, and 16 appear to reach a critical concentration, after which their rate of production is less than or equal to the rate at which they disappear from the system. These compounds, are, therefore, poor indicators of oxidation in this system.

Compound identification was based on retention times and/or mass spectral data (Table I). The compounds identified included saturated and unsaturated hydrocarbons, aldehydes, alcohols, furans, and a ketone. Some volatiles have mass spectra that closely resemble more than one known compound. The mass spectrum of compound 3 can be closely matched to the mass spectra

of both 2-methyl-3-buten-2-ol and 3-penten-2-ol. However, the branched hydrocarbon may be a slightly better match since the loss of the methyl group is more likely to produce m/z 71. This fragment (m/z 71) is found in a slightly higher ratio in 2-methyl-3-buten-2-ol (10%) than in 3-penten-2-ol (8%) and thus is closer to the concentration of the mass spectrum fragment in compound **3** (18%). The production of branched-chain hydrocarbons from the thermal oxidation of unsaturated fatty acids has been previously documented by Stern et al. (1985). The rearrangements to produce such compounds have not been elucidated, but we believe compounds **3** and **5** are yet another example of the production of branched-chain hydrocarbons from unsaturated fatty acid oxidation. Two unidentified compounds with molecular weights of 98 and 124 were also isolated. Compound **9** (MW 98) has been tentatively identified on the basis of mass spectrum data as either methylcyclohexane or 3,4-dimethyl-2-pentene. The mass spectrum for compound **9** indicates that four carbon groups are removed since the presence of fragments m/z 98, 83, 69, 55, and 41 reflects the loss of a CH_3 group followed by three CH_2 groups. The mass spectra of both compounds cited will display this ionogram. Compound **13** (MW 124) is tentatively identified as 3-ethyl-2-methyl-1,3-hexadiene. Compound **10b** is tentatively identified as either 2,4-octadienal or 2-butylfuran. The leading shoulder peak appearing just before hexanal (compound 8) in the 154-min heating chromatogram may be octane on the basis of retention time comparisons to a standard.

The peak areas of 12 volatiles were significantly ($P < 0.05$) affected by heating time (Table II). Similar heating effects were reported by Henderson et al. (1980) and Selke et al. (1980) for linoleates and by Lomanno and Nawar (1982) for linolenate. These researchers reported that longer heating times yielded more complex profiles. Molecular weight 124 and 2-octenal were found in significantly higher concentrations in the 18:2 + GPE treatment after 154 min of heating compared to the other two treatments. The compound 2-(1-pentenyl)furan was detected in higher concentrations in both 18:2 + GPC and 18:2 + GPE treatments than in the 18:2 treatment. Pentane was produced in significantly higher concentrations in 18:2 than in the PL derivative supplemented treatments. Both pentane and hexanal are derived from the decomposition of 18:2 via the 13-hydroperoxide pathway (Selke et al., 1980). Carbon–carbon cleavage on either side of the peroxy carbon yields either pentane or hexanal. The higher concentration of pentane in the 18:2 control treatment may indicate the preferential decomposition of the 13-hydroperoxide to hexanal when the phosphoryl bases are added to 18:2. The absence of 2,4-decadienal in these GC profiles is indicative of the temperature dependency of this compound to formation (Selke et al., 1980). At temperatures below 75 °C, only 1–2% of the total carbonyl fraction is 2,4-decadienal, yet at 85–210 °C, 2,4-decadienal comprises 43–72% of the carbonyls.

The rate of linoleate thermal oxidation has been evaluated by using oxygen uptake in a closed system (Labuza et al., 1969). The rate was determined from the slope of the line produced from the square root of oxygen uptake plotted against time. Since the concentration of each volatile generated from heated linoleate is in a dynamic state of equilibrium, it is difficult to accurately determine a rate constant without first knowing all the possible pathways for their formation and degradation. However, it may be of interest to compare treatment effects by

Table II. Peak Areas for Linoleic Acid (18:2), Glycerophosphorylcholine (GPC) + 18:2, and Glycerophosphorylethanolamine (GPE) + 18:2 Heated for 4, 34, 64, 94, 124, and 154 min at 70 °C

peak no.	compd	18:2						GPC + 18:2						GPE + 18:2					
		4 min	34 min	64 min	94 min	124 min	154 min	4 min	34 min	64 min	94 min	124 min	154 min	4 min	34 min	64 min	94 min	124 min	154 min
2	pentane	331[a]	3268[a]	8045[a]	25698[a]	41276	78438[a]	1[b]	132[c]	1971[b]	16843[b]	38811	46256[b]	1[b]	1249[b]	3635[b]	9750[c]	29758	44615[b]
4	butanal	33[b]	333	288[b]	1531	1318[c]	1832[b]	1[c]	251	1005[a]	1687	4257[a]	10007[a]	452[a]	310	713[ab]	1278	2672[b]	3327[b]
5	4-methyl-2-pentene	1[b]	90[b]	236	556	362	993[a]	267[a]	217[a]	278	286	450	713[ab]	247[a]	282[a]	174	191	404	605[b]
6	pentanal	534	1941	2759[b]	9669	9777[b]	14679[b]	389	2670	3525[ab]	10615	14572[ab]	21829[ab]	169	2984	4864[a]	10470	22765[a]	32191[a]
8	hexanal	1733[a]	9561[b]	9265[b]	33924	33535[b]	79708[b]	961[b]	10614[ab]	21202[ab]	56607	66660[ab]	107526[ab]	1835[a]	15330[a]	22351[a]	39702	111456[a]	140137[a]
9	MW 98[d]	449[a]	329[b]	888	1417	1179	2620	1[b]	724[a]	785	798	1212	1726	406[a]	806[a]	914	1176	1765	1901
10a/10b	heptanone/2,4-octadienal	1	1[c]	1[b]	141[c]	197[b]	1076[ab]	1	67[a]	377[a]	832[a]	904[a]	636[b]	1	17[b]	193[ab]	529[b]	1170[a]	1514[a]
11	heptanal	86[a]	218	233	333[b]	413[b]	1117[b]	105[a]	190	381	501[a]	1128[a]	1391[a]	1[b]	199	325	376[b]	647[ab]	830[c]
12	2-pentylfuran	1[c]	915[b]	1192[b]	3109	3290[b]	7295	323[a]	608[c]	1094[b]	3388	4156[ab]	7926	115[b]	1223[a]	2303[a]	4245	6659[a]	10317
13	MW 124[d]	113[c]	128[c]	264[c]	766[b]	795[b]	2394[b]	858[b]	913[b]	1048[b]	1014[b]	1630[b]	1900[b]	1796[a]	1831[a]	2677[a]	3118[a]	4092[a]	4632[a]
14	2-(1-pentenyl)-furan	1[c]	90[b]	143[c]	556[b]	551[b]	1398[b]	53[b]	427[a]	1590[a]	2031[a]	4048[a]	4038[a]	128[a]	722[a]	1226[a]	1819[a]	3167[a]	3802[a]
15	2-octenal	166[a]	705[ab]	601[b]	1893	2152	3540[b]	169[a]	372[b]	659[b]	1676	2207	3467[b]	70[b]	932[a]	1224[a]	2010	2931	5135[a]

[a–c] Means with different letter superscripts within heating time and peak number indicate a significant difference between treatments ($P < 0.05$). [d] Unknown compound with a MW of 98 or 124.

Table III. Slopes of the Peak Areas for Volatiles Produced from Linoleic Acid (18:2), Glycerophosphorylcholine (GPC) + 18:2, and Glycerophosphorylethanolamine (GPE) + 18:2 Heated at 70 °C for 4, 34, 64, 94, 124, and 154 min

		slope for 4–154 min[d]			slope for 94–154 min[e]		
peak no.	compd	18:2	GPC	GPE	18:2	GPC	GPE
2	pentane	497[a]	345[b]	300[b]	879[a]	490[b]	581[b]
4	butanal	13[b]	60[a]	21[b]	5[c]	207[a]	34[b]
5	4-methyl-2-pentene	5	3	3	12[a]	7[b]	10[a]
6	pentanal	96[b]	143[b]	214[a]	107[b]	187[b]	362[a]
8	hexanal	463[b]	701[ab]	950[a]	770[b]	1153[ab]	1674[a]
9	MW 98[f]	13[a]	8[c]	10[b]	14	15	12
10a/10b	heptanone/2,4-octadienal	6[b]	8[b]	11[a]	15[a]	3[b]	17[a]
11	heptanal	6[b]	9[a]	5[b]	13[a]	15[a]	8[b]
12	2-pentylfuran	43	49	66	70[b]	117[a]	102[ab]
13	MW 124[f]	13[ab]	7[b]	20[a]	27[a]	16[b]	25[a]
14	2-(1-pentenyl)furan	8[b]	30[a]	25[a]	16[c]	53[a]	33[b]
15	2-octenal	21	22	30	36[b]	30[b]	52[a]
total[g]		1185[b]	1383[ab]	1655[a]	1930[b]	1859[b]	3039[a]

[a–c] Slopes within compounds and heating periods having different superscripts are significantly different ($P < 0.05$). [d] Slopes were calculated from the peak areas at six points (heating times) from 4 through 154 min. [e] Slopes were calculated from the peak areas at three points (heating times) from 94 through 154 min. [f] Unknown compound with a MW of 98 or 124. [g] Represents the slopes calculated from the sum of the peak areas of the 12 compounds shown in the table.

evaluating the concentrations of volatiles at given heating times and their rate of formation (slopes).

Significant interactions between heating times and treatments were noted for 10 volatiles [pentane, butanal, pentanal, MW 98, heptanone + 2,4-octadienal, heptanal, 2-pentylfuran, MW 124, 2-(1-pentenyl)furan, and 2-octenal]. These results indicate that the rate of formation of these 10 volatiles was significantly different between treatments. Slopes (Table III) were calculated for the 12 volatiles listed in Table II over the entire heating period (designated slope A) and over the last three heating times (designated slope B). Both slopes were calculated to identify lag phases and variations in the rate of production over the two time periods. Pentane and the MW 98 peak were generated at a higher rate in the 18:2 treatment over the entire heating period (slope A) and for pentane over the last three heating periods (slope B). Butanal (slopes A and B), heptanal (slope A), and 2-(1-pentenyl)furan (slope B) were generated at the highest rate in the GPC + 18:2 treatment. Pentanal (slopes A and B), heptanone/2,4-octadienal (slope A), 2-octenal (slope B), and the total peak area (slope B) were generated at the highest rate in the GPE + 18:2 treatment. On the basis of slope data, the addition of PL moieties to 18:2 significantly affected the rate of production of several specific volatiles.

Tsai and Smith (1972) found that the phosphoryl and nonphosphoryl bases of choline had little prooxidant effect on methyl linoleate emulsions at pH 7.9 or 10.2, while ethanolamine acted as a prooxidant at pH 7.9 ($N-H_2$ state) and as an antioxidant at pH 10.2 ($N-H_3$ state). They hypothesized that the prooxidant effect of the ethanolamine primary amine at pH 7.9 may result from the decomposition of hydroperoxides into new radicals which perpetuate the oxidation. In their system, complexes of the primary amine–hydroperoxide may form through hydrogen bonding between the hydrogen of the amino group and the oxygen of the hydroperoxide. These complexes thus may decrease hydroperoxide–hydroperoxide complexing, resulting in the initiation of a monomolecular decomposition of hydroperoxide into RO• and •OH radicals. Conversely, at pH 10.2 the ethanolamine molecule possesses a pair of free electrons on the nitrogen of the amine. These electrons act to decompose hydroperoxides by complexing hydroperoxides to the amine via a hydrogen bond between the pair of free electrons and the hydrogen of the peroxide group. The hydroperoxide would thus be reduced to its corresponding alcohol through a nonradical pathway. Since choline (a quaternary amine) did not affect the autoxidation of methyl linoleate at either pH 7.9 or 10.2 in their studies, they presumed the presence of the N–H bond was necessary for the prooxidant activity of the amine. Since the present study was not conducted in an aqueous system, it can be concluded that the experimental conditions favored a nucleophilic ethanolamine amino group ($N-H_2$). Tsai and Smith (1972) found that GPE increased the rate of production of the total peak area in these studies. However, in the present study the addition of GPC and GPE to 18:2 affected the rate of production of specific volatiles differently. The 18:2 carboxyl and the GPE NH_2 could react as a weak acid and a weak base, respectively. This system contained two 18:2 molecules per one GPE molecule; therefore there would be an abundance of weak acid, possibly forcing the NH_2 to NH_3. A proposed prooxidant mechanism for the NH_3 group via hydrogen bonding with the hydroperoxide has been discussed. In addition, the amino nitrogen might react with the hydroperoxyl hydrogen, which would also decrease hydroperoxide–hydroperoxide complexing, resulting in the prooxidant mechanism described earlier. These findings indicate that other mechanisms besides those hypothesized by Tsai and Smith (1972) may be operative considering that the opportunity for other interactions exists between these multifunctional groups.

Although GPC did not have a prooxidant effect on fatty acids in the Tsai and Smith (1972) study, phosphatidylcholine extracted from turkey tissues did produce a higher rate of fatty acid oxidation than phosphatidylethanolamine (Acousta et al., 1966). Previous research has also revealed that the fatty acids associated with the ethanolamine moiety of mechanically deboned chicken meat (PE, lysoPE, and PE plasmalogen) are more highly unsaturated than those associated with the choline moiety (PC and LPC) (Dawson et al., 1989). Therefore, the fatty acids associated with the ethanolamine moiety in meat systems may be more susceptible to oxidation than the fatty acids associated with other PLs due to their high degree of unsaturation and close proximity to the $N-H_2$ bond of the ethanolamine moiety.

This study presented data showing both pro- and antioxidant effects for GPE and GPC depending on which secondary degradation product is evaluated. The lack of consistent treatment trends across all volatiles generated may be related to the complexity and the number of secondary oxidative degradation reactions that are possible. The association of a specific PL with 18:2 may favor certain oxidative degradation pathways which yield higher

concentrations of specific classes of compounds. Other PLs may favor other pathways that yield higher concentrations of a different set of compounds. Furthermore, the test method chosen (O_2 uptake, monitoring hydroperoxide and secondary degradation products, etc.) to evaluate the prooxidant effects of PL may also yield conflicting results.

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Registry No. Butane, 106-97-8; pentane, 109-66-0; 2-methyl-3-buten-2-ol, 115-18-4; butanal, 123-72-8; 2-methyl-1-pentene, 763-29-1; pentanal, 110-62-3; hexanol, 25917-35-5; hexanal, 66-25-1; heptanone, 29299-43-2; 2,4-octadienal, 5577-44-6; heptanal, 111-71-7; 2-pentylfuran, 3777-69-3; 2-(1-pentenyl)furan, 81677-78-3; 2-octenal, 2363-89-5; undecane, 1120-21-4; linoleic acid, 60-33-3; glycerophosphorylcholine, 563-24-6; glycerophosphorylethanolamine, 1190-00-7.