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1 **Egg yolk phospholipids: a functional food material to generate**

2 **deep-fat frying odorants**

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3

4   **Abstract**

5   BACKGROUND

6   Phospholipids are an important precursor for the generation of carbonyl compounds

7   which play a significant role in the characteristic aroma of deep-fat fried foods.

8   RESULTS

9   Phospholipids extracted from hen egg yolks were added into sunflower oil (2.0 g/kg)

10   and heated with or without chicken meat at 160 °C for 10 min, and then dynamic

11   headspace extraction and GC-MS were used to extract and analyze the volatiles. The

12   results showed that the characteristic deep-fat frying odorants, such as

13   (*E,E*)-2,4-decadienal, (*E,Z*)-2,4-decadienal, as well as 1-octen-3-one, (*E*)-2-nonenal,

14   octanal, methional, dimethyl disulfide and alkylpyrazines had increased by 3-65

15   times in the sunflower oil with added phospholipids, and increased up to 6 times in

16   chicken meat which had been treated with phospholipids prior to heating.

17   CONCLUSION

18   There is potential for the food industry to use low levels of phospholipids,

19   particularly egg yolk phospholipids, to increase deep-fat frying odorants in a wide

20   range of deep fried products.

21   **Keywords**: deep-fat frying; odorants; phospholipids; egg yolk; chicken meat;

22   2,4-decadienal.

Introduction

Deep-fat frying is a popular cooking method, and the deep-fat frying aroma is very attractive for the consumer. Deep-fat frying aroma comes from the oxidation and decomposition of the lipids, as well as Maillard reaction, and it always occurs at high cooking temperatures.[1] (*E,E*)-2,4-Decadienal (deep-fried), (*E,Z*)-2,4-decadienal (deep-fried), pyrazines (roasty), 2- and 3-methylbutanal (malty), and methional (cooked potato-like odor) are the key odorants in fried potato chips.[1-3]

Thuerer et al showed that the fatty acid profile of the frying oil significantly influenced the concentration of 2,4-decadienals.[3] They found that the concentration of 2,4-decadienals in safflower oil was about 12 times higher than in coconut oil, as safflower oil is richer in linoleic acid, the main precursor of 2,4-decadienals. The concentration of the Strecker aldehydes and alkylpyrazines were not clearly influenced by the frying oils, but frying temperature is an important parameter as it has a great influence on their formation.[4] Compared with conventional fried (at 165 °C) crisps, vacuum frying (at 120 °C) crisps reduced the formation of lipid-derived compounds and Maillard reaction products, especially alkylpyrazines.[4]

Egg yolk phospholipids are rich in linoleic acid and arachidonic acid,[5] and it can be used as a source of important precursors for the generation of lipid-derived odorants.[6,7] For example, hexanal, (*E,E*)-2,4-decadienal, 1-octen-3-one, (*E*)-2-decenal and (*E*)-2-undecenal were produced when egg yolk phospholipids were thermally treated at 145 °C for 20 min.[6] In our previous work,[7] the lipid-derived compounds contributing to the characteristic chicken meat aroma

45 increased sharply when egg yolk phospholipids were heated in water at 100 °C for

46 20 min, and chicken meat aroma was improved when egg yolk phospholipids were

47 added to minced chicken meat prior to heating under the same conditions.

48 The hypothesis of this work is that egg yolk phospholipids can be the primary

49 precursors of deep-fat frying odorants, which could be used specifically to increase

50 the key odorants of deep-fried food. Although deep-fat frying odorants have been

51 widely studied and produced by different methods, to the best of our knowledge, no

52 research has been published where egg yolk phospholipids have been used in the

53 deep-fried food. The objective of this work is to study the impact on deep-fried

54 odorants when egg yolk phospholipids are added into sunflower oil and heated at

55 frying temperatures with and without chicken meat.

56 **Materials and methods**

57 **Reagents and Chemicals**

58 Authentic chemicals of reference aroma compounds were purchased from a range

59 of laboratory chemical suppliers in U.K.. 1,2-Dichlorobenzene in methanol (130.6

60 ng/µL) and alkane standard C5−C25 (100 ng/µL in diethyl ether), used as GC-MS

61 standards, were obtained from Sigma-Aldrich Co. Ltd. (Gillingham, U.K.).

62 **Phospholipids extraction**

63 Commercial fresh hen eggs were bought from a local supermarket for this study.

64 The extraction method employed was that reported by Chen et al.[7] Briefly, fresh egg

65 yolk (40 g, obtained from six hen eggs) lipids were extracted with ethanol; then the

66 crude phospholipids were dissolved in hexane; next, cold acetone was used to

67 precipitate phospholipids; finally the high purity phospholipids were obtained. The

68 minor residual solvents in the phospholipids were removed under high vacuum at

69 room temperature for 10 h.

70 **Phospholipids purity**

71 This method was according to the AOCS Official Method.[8] Firstly, the

72 phospholipids sample was ashed in the presence of zinc oxide, followed by the

73 spectrophotometric measurement of phosphorus as a blue phosphomolybdic acid

74 complex, and finally a conversion factor of 30 was used to convert phosphorus to

75 phospholipids.

76 **Sample preparation**

77 To disperse the phospholipids, 0.50 g phospholipids and 9.50 g salt were ground

78 and thoroughly mixed. Commercial sunflower oil and fresh chicken breast fillets

79 without skin or bone were bought from a local supermarket for this study. The

80 chicken meat (~200 g) was ground in a domestic meat mincer (Kenwood, Havant,

81 UK) and thoroughly mixed. The samples were prepared as follows:

82 1) Sunflower oil sample: 0.57 g salt, 15.0 g sunflower oil.

83 2) Sunflower oil & phospholipids sample: 0.60 g phospholipids and salt mixture,

84 15.0 g sunflower oil.

85 3) Chicken meat sample: 1.50 g chicken meat, 0.57 g salt, 15.0 g sunflower oil.

86 4) Chicken meat & phospholipids sample: 1.50 g chicken meat, 0.60 g phospholipids

87 and salt mixture, 15.0 g sunflower oil.

88 Finally the samples were sealed in 100 mL glass Duran bottles and heated in an oil

89 bath (160 °C) for 10 min and then cooled in an ice-bath. Each treatment was carried

90 out in quadruplicate and all samples were prepared from the same batch of egg,

91 sunflower oil and chicken mince.

Dynamic Headspace Extraction (DHE)

93 DHE was used for the extraction of the volatiles, following the method described

94 by Chen et al with minor modifications.[7] The entire contents of each Duran bottle

95 were transferred into a 250 mL conical flask fitted with a Dreschel head. The flask

96 was incubated in a water bath at 50 °C, and the volatiles in the headspace were swept

97 onto Tenax absorbent using a flow of nitrogen (40 mL/min) for 60 min. After

98 sweeping, 1.0 µL 1,2-dichlorobenzene in methanol (130.6 ng/µL) was added as an

99 internal standard to the trap, followed by a purge of 100 mL/min for 10 min to

100 remove excess solvent and moisture.

GC-MS Analysis of Volatile Compounds

102 The DHE samples were analysed using an Agilent 7890A-5975 GC-MS system

103 (Agilent Technologies Co. Ltd., Palo Alto, CA, USA) equipped with an automated

104 thermal desorber (Turbomatrix ATD), using a DB 5 column (60 m × 0.25 mm i.d., 1

105 µm film thickness from J&W Scientific, Agilent, Palo Alto, CA, USA) under

106 instrumental conditions described by Chen et al.[7] The identification of the

107 compounds was based on the comparison of their mass spectra with spectra from the

108 NIST 11 Mass Spectral Database.[9] The linear retention index (LRI) was calculated

109 for each volatile using the retention times of a series of C5−C25 n-alkanes. The

110 identities of most of the volatiles were confirmed if their mass spectra and LRI

111 matched those of authentic compounds run under the same analytical conditions in

112 our laboratory. Volatiles were considered as tentatively identified by matching their

113 mass spectra with the reference mass spectra in the NIST mass spectral library, and

114 by comparison of their LRI to the NIST Chemistry WebBook database.[10] Volatiles

115 were semi-quantitatively determined by comparison of the peak areas against that of

116 the internal standard using a response factor of 1 for each compound.

117 **Statistical Analysis**

118   The GC–MS data were analyzed using Independent-Samples T Tests (SPSS, 23,

119 IBM) comparing the sunflower oil sample with the sunflower oil & phospholipids

120 sample, and comparing the chicken meat sample with the chicken meat &

121 phospholipids sample. Significant differences are shown by **, $p \leq 0.01$; *, $p \leq 0.05$;

122 ns, $p > 0.05$.

123 **Results and Discussion**

124 **The purity of the extracted phospholipids**

125   The purity of the extracted egg yolk phospholipids was 95.2±3.0%, which was

126 coincided with the report of Gladkowski et al.[11] According to their report, the purity

127 of the phospholipids extracted by this method was very high (95.9%), and the

128 phospholipids contained phosphatidylcholine (78%) and phosphatidylethanolamine

129 (21%).

130 **Characteristic deep-fat frying odorants derived from lipids**

131   The results are shown in Table 1. The most abundant odorants detected were

132 mainly aldehydes, such as (*E*)-2-heptenal, hexanal and (*E,E*)-2,4-decadienal.

133   (*E,E*)-2,4-Decadienal (fatty, fried), (*E,Z*)-2,4-decadienal (fatty, fried), 1-octen-3-one

134   (mouldy, mushroom-like), (*E,E*)-2,4-nonadienal (fatty, fried, green), are the

135   characteristic deep-fat frying odorants.[1] These compounds are formed from the

136   thermal oxidation of unsaturated fatty acids, especially from the ω-6 fatty acids

137   (linoleate and arachidonate).[12, 13] Both (*E,E*)-2,4-decadienal and hexanal are often

138   used as primary marker compounds of the oxidation of ω-6 fatty acids.[14]

139   Sunflower oil is widely used for deep-fat frying process,[15] and it is rich in linoleic

140   acid (about 62% of the total fatty acids),[16] and the linoleate residues are present as

141   triglycerides (as there are only trace phospholipids presented in the refined sunflower

142   oil). Both the C9 and C13 position of the linoleate residues in triglycerides are

143   favored positions to form the hydroperoxides during autoxidation,[14, 17] and the C9

144   and C13 hydroperoxide are the precursors for 2,4-decadienal and hexanal,

145   respectively. So linoleate residues present in triglycerides can produce both

146   2,4-decadienal and hexanal.

147   **Characteristic odorants derived from the Maillard reaction**

148   Alkylpyrazines, originating via the Maillard reaction, are important contributors to

149   typical roasted, nutty, meaty, earthy, and popcorn-like note of many heated food

150   products. The dominant alkylpyrazines in the present study were methylpyrazine and

151   2,5-dimethylpyrazine. The Strecker aldehydes, for example, 2- and 3-methylbutanal

152   (malty), methional (cooked potato-like odor), as well as phenylacetaldehyde (green,

153   sweet), are the key odorants in fried potato chips, which are originated from

154   isoleucine, leucine, methionine and phenylalanine, respectively. 2-Methylpropanal

155 (pungent) is formed from valine.[18] Benzaldehyde (almond) is formed from

156 phenylacetaldehyde,[19] and methional may degrade to methanethiol, which in turn

157 could produce dimethyl disulfide and dimethyl trisulfide.[20]

158 **Sunflower oil samples**

159   The contents of hexanal and (*E,E*)-2,4-decadienal in the headspace collected from

160 the heated sunflower oil sample were approximately 800 ng and 2 ng respectively.

161 When the phospholipids were added to the sunflower oil prior to heating, hexanal

162 increased by about 20% whereas the concentratrion of (*E,E*)-2,4-decadienal was 65

163 times higher than in the heated sunflower oil alone. As both (*E,E*)-2,4-decadienal

164 and hexanal are the markers of oxidation, this shows that the egg yolk phospholipids

165 under the present frying condition (160 °C, 10 min) were more prone to oxidation. It

166 also demonstrates how the chemical environment of the linoleate residue influences

167 the relative rates of formation of hexanal and (*E,E*)-2,4-decadienal.

168   The presence of phospholipids in the oil has two effects. Firstly it is clear that

169 incorporation of the phospholipids increased the rate of oxidation. Owing to the

170 amphiphilic nature of phospholipids, they tend to be present in a dispersed form,

171 increasing their surface area, and increasing their exposure to water soluble

172 pro-oxidants. In meat, these are likely to be pro-oxidant metals, rendering the

173 phospholipids highly susceptible to oxidation and to the generation of large

174 quantities of lipid-derived volatiles.[21] Linoleic acid is the predominant PUFA (about

175 14% of the total fatty acids) in egg yolk phospholipids.[5] Secondly, phospholipids

176 direct the position of oxidation, promoting formation of the C9

177 hydroperoxide-derived volatiles in linolate residues over those derived from C13

178 hydroperoxides.[22] It was reported that for linoleate residues bound in a phospholipid,

179 autoxidation at the C9 position is the most favored position for formation of

180 hydroperoxides.[22] The C9 hydroperoxide is the precursor for 2,4-decadienals, so

181 2,4-decadienals are the dominant product for linoleate assembled in phospholipids.

182 When the phospholipids were added to the sunflower oil sample, there was a sharp

183 increase in (*E,E*)-2,4-decadienal (130 ng vs. 2 ng) and only a relatively small

184 increase in hexanal (988 ng vs. 804 ng) which corroborates the finding of Reis and

185 Spickett.[22] In our previous study,[7] we also observed a much greater increase in

186 (*E,E*)-2,4-decadienal than in hexanal when phospholipids were added to water prior

187 to a mild heating procedure.

188 Once the lipid oxidation process has been initiated by the more reactive fatty acids,

189 this can promote the oxidation of the less reactive fatty acids.[23] The oxidised

190 phospholipids not only produced lipid-derived aldehydes, but also promoted the

191 oxidation of sunflower oil, explaining the increase in ω-3 and ω-9 derived volatiles

192 in the sunflower oil & phospholipids sample.

193 The presence of some Maillard reaction products in the sunflower oil &

194 phospholipids sample was not surprising, as low levels of Maillard reaction

195 precursors are co-extracted with the phospholipids when polar solvents (ethanol and

196 acetone) are used. In addition, both the primary amine group present in

197 phosphatidylethanolamine and aldehydes produced from lipid oxidation can serve as

198 Maillard reaction substrates.[21] It is also consistent with the previous reports[24, 25] that

199   the products of phospholipids oxidation can contribute to the Maillard reaction.

200   **Sunflower oil samples with chicken meat**

201   The trends in odorants in the heated chicken meat samples were consistent with

202   those in the heated oil samples, but the magnitude of the increases were significantly

203   diminished. Some lipid-derived aldehydes and most of the Maillard reaction

204   products were significantly higher in the chicken meat & phospholipids sample

205   compared to the chicken meat sample. The presence of meat provides a rich source

206   of precursors and reactive intermediates which can influence the formation of

207   volatiles and explain the changes in both lipid- and Maillard-derived compounds. In

208   the chicken meat systems, the smaller increase in lipid-derived compounds with

209   added phospholipids is consistent with previous findings.[7] Examination of Table 1

210   shows that some odorants, such as 2,4-alkadienals, had much smaller increases when

211   chicken meat was added to the samples. This apparent "loss" of 2,4-decadienals in

212   the presence of meat could be attributed to the following. Firstly, the temperature

213   was lower in the frying meat system than in the frying oil system (because of water

214   evaporation), and the formation of those odorants were highly associated with the

215   temperature.[4] Secondly, those odorants may get trapped within the meat.[26] Thirdly,

216   there may be interaction with other components of the meat (such as NH_3, H_2S, free

217   amino groups and reactive dicarbonyls). For example 2,4-decadienal reacts with

218   ammonia to form 2-pentylpyridine via Maillard reaction.[27] Finally, the degradation

219   of this highly reactive alkadienal, such as 2,4-decadienal can undergo

220   retroaldolisation to form hexanal and 2-octenal.[28] The higher productions of

221 2-pentylpyridine, 2-octenal and hexanal in the chicken meat & phospholipids sample

222 could indicate more extensive degradation of 2,4-decadienal.

223 The small increase in 3-methylbutanal, and a similar trend for the other Strecker

224 aldehydes, is due to the participation of unsaturated lipid-derived compounds in the

225 Strecker degradation.[29] The parallel formation of α-aminoketones may also promote

226 the formation of pyrazines. This increase is observed for 4 of the 5 pyrazines

227 detected.

228 **The key odorants in chicken & phospholipids sample**

229 Both isomers of 2,4-decadienal not only impart characteristic deep-fried odor,[1] but

230 were also the odorants with highest flavour dilution factor in chicken meat broths.[30,]

231 [31] (*E,E*)-2,4-Decadienal contributes a fatty chicken note with a very low odour

232 detection threshold (0.07 µg/kg).[32] In the present study, the contents of both isomers

233 of 2,4-decadienal had a 3-4 times increase in the chicken meat & phospholipids

234 samples, which indicated that the characteristic fatty fried chicken notes could arise

235 from the increases in 2,4-decadienals. Besides (*E,E*)-2,4-decadienal, 1-octen-3-one,

236 alkylpyrazines and the Strecker aldehydes are also the most significant contributors

237 to deep-fried chicken meat flavor. Under the present processing conditions, the

238 content of most of alkylpyrazines and the Strecker aldehydes had significantly

239 increased, especially methional had a about 4 times increase in the phospholipids

240 added chicken meat samples, which means that the fried meat note was enhanced by

241 egg yolk phospholipids.

242 **Conclusion**

243   It has been demonstrated that the characteristic deep-fat frying odorants and fried

244   chicken meat odorants, such as (*E,E*)- and (*E,Z*)- 2,4-decadienal, 1-octen-3-one,

245   (*E*)-2-nonenal, octanal, methional, disulfide dimethyl, methylpyrazine and

246   trimethylpyrazine significantly increased when a small amount (2.0 g/kg) of egg

247   yolk phospholipids was added into sunflower oil samples with or without chicken

248   present prior to heating at frying temperatures. This is of potential interest to the

249   food industry and catering industry, however, its usage and effects on the deep-fat

250   frying aroma need further sensory research, as food aroma is a delicate balance of

251   the odorants.

255   **Conflict of interest**

256   There is no conflict of interest about this article.

257   **References**

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338   Table 1. Mean Values (approx ng/sample extraction) (n=4) of the Volatile Compounds Identified in Headspace of the Samples.

Compound Name	LRI DB5[1]	ID[2]	Sunflower oil Mean±SD[3]	Sunflower oil & Phospholipids Mean±SD[3]	Sig[4]	Chicken meat Mean±SD[3]	Chicken meat & Phospholipids Mean±SD[3]	Sig[5]
ω-3 derivatives								
2-Hexenal, (*E*)-	857	A	112±19	310±57	**	106±48	116±51	ns
2,4-Heptadienal, (*E,Z*)-	1000	B	1.73±0.30	3.82±1.09	*	0.79±0.52	0.91±0.26	ns
2,4-Heptadienal, (*E,E*)-	1015	A	5.52±0.79	8.89±2.39	*	2.33±1.32	2.77±0.91	ns
5-Ethyl-1-cyclopentene-1-carboxaldehyde	1036	A	0.80±0.18	81.5±15.5	**	17.7±5.2	28.5±13.5	ns
ω-6 derivatives								
Pentane	500	A	59.9±35	282±99	*	53.3±12.2	69.2±32.9	ns
Pentanal	706	A	156±43	257±39	**	201±100	150±48	ns
1-Pentanol	765	A	23.7±2.2	47.6±7.2	**	191±60	214±86	ns
Hexanal	813	A	804±121	988±158	*	352±110	423±278	ns
1-Hexanol	869	A	8.07±1.14	10.5±2.6	ns	10.6±1.8	22.1±4.3	**
2-Heptanone	889	A	9.43±1.01	25.9±5.4	**	8.12±3.94	13.6±3.6	ns
Heptanal	904	A	35.6±3.5	135±36	**	36.2±21.6	53.5±14.9	ns
2-Heptenal, (*E*)-	966	A	655±260	1456±286	**	603±297	608±181	ns
1-Octen-3-one	978	A	10.2±3.7	55±22	**	11.8±4.5	22.9±4.6	*
1-Octen-3-ol	983	A	101±16	174±26	**	72.8±45.4	63.7±37.0	ns
2,3-Octanedione	984	A	1.42±0.28	33.9±8.6	**	4.48±2.25	9.54±4.11	*
2-Pentylfuran	990	A	16.7±3.6	33.2±13.5	*	9.71±7.35	13.1±6.9	ns

2-Octenal, (*E*)-	1060	A	25.8±3.2	145±48	**	40.1±27.9	57.2±18.5	ns
2-Octen-1-ol, (*E*)-	1067	A	1.49±0.50	7.59±1.44	**	3.15±0.89	4.37±1.61	ns
3-Nonen-2-one	1142	A	1.05±0.21	7.30±1.65	**	1.34±0.39	2.09±0.62	ns
2,4-Nonadienal, (*E,Z*)-	1200	B	0.27±0.05	1.15±0.36	**	0.35±0.20	0.25±0.11	ns
2,4-Nonadienal, (*E,E*)-	1222	A	0.79±0.12	4.22±1.31	**	1.11±0.59	1.33±0.68	ns
2,4-Decadienal, (*E,Z*)-	1299	B	1.20±0.20	47.92±26.53	*	3.29±1.36	10.4±3.6	*
2,4-Decadienal, (*E,E*)-	1325	A	2.01±0.83	130±70	*	5.68±1.91	22.4±7.6	*
ω-9 derivatives								
1-Octene	791	A	20.7±3.8	184±50	**	15.4±12.4	40.88±28.67	ns
Octane	800	A	43.2±6.9	147±32	**	73.0±23.1	70.6±20.6	ns
2-Octene, (*Z*)-	815	A	22.4±3.8	160±45	**	28.3±22.4	93.4±57.0	ns
Octanal	1004	A	16.4±1.8	59.0±19.0	**	18.5±6.2	28.5±6.7	ns
1-Octanol	1070	A	2.21±0.46	6.86±2.55	**	3.70±0.94	3.79±0.91	ns
Nonanal	1108	A	51.8±8.2	113±28	**	41.5±14.7	57.4±18.1	ns
2-Nonenal, (*E*)-	1164	A	2.79±0.39	10.9±2.1	**	2.66±0.64	5.14±1.29	*
1-Nonanol	1173	A	3.50±0.62	2.88±0.82	ns	2.94±0.67	2.73±0.52	ns
Decanal	1208	A	25.2±2.9	17.9±7.20	ns	22.8±6.5	22.3±1.4	ns
2-Decenal, (*E*)-	1266	A	3.60±0.81	17.4±7.3	**	5.42±1.59	8.21±2.79	ns
2-Undecenal	1368	A	3.55±1.35	3.11±1.5	ns	2.15±0.60	0.96±0.64	*
Maillard reaction products								
2-Methylpropanal	555	A	65.5±44.6	118±18	ns	45.8±11	74.8±20.0	ns
3-Methylbutanal	665	A	3.55±1.39	660.±90	**	420±65	664±138	**
2-Methylbutanal	674	A	2.50±0.75	275±50	**	144±9.8	170±29	ns
Methylpyrazine	829	A	0.17±0.11	7.78±2.38	**	8.41±0.64	17.4±5.6	**

Methional	912	A	nd	33.0±4.5	**	24.0±5.7	90.8±26.1	**
2,5-Dimethylpyrazine	917	A	nd	7.05±1.52	**	4.03±1.1	12.3±0.8	**
2-Ethylpyrazine	969	A	0.07±0.02	0.95±1.41	ns	0.12±0.23	0.18±0.35	ns
2-Ethy-6-methylpyrazine	1001	A	nd	0.35±0.14	**	0.34±0.16	0.69±0.01	*
Trimethylpyrazine	1006	A	1.60±1.09	6.79±4.12	*	0.19±0.11	1.05±0.26	**
Benzeneacetaldehyde	1049	A	3.72±1.86	17.3±4.8	**	36.7±4.1	102±25	**
2-Pentylpyridine	1204	B	0.04±0.02	2.20±0.63	**	0.05±0.01	0.44±0.24	*
Miscellaneous								
Dimethyl disulfide	745	A	0.05±0.00	14.3±10.9	*	12.1±1.7	30.9±9.9	*
Toluene	767	A	9.66±8.01	11.8±0.87	ns	10.1±2.7	25.6±28.5	ns
Acetylacetone	788	B	5.85±0.85	25.3±41.1	ns	3.35±1.58	16.±33	ns
3-Cyclohepten-1-one	826	C	4.52±0.51	8.47±16.8	ns	5.14±2.38	9.7±3.9	ns
2-Methylcyclopentanone	844	A	3.46±0.57	25.7±14.6	*	5.43±2.61	6.35±2.94	ns
α-Pinene	934	A	11.0±1.2	9.97±0.27	ns	8.26±2.68	5.02±1.51	ns
Benzaldehyde	971	A	42.4±18.8	25.0±4.0	ns	61.7±11.9	21.3±9.0	**
Dimethyl trisulfide	976	A	0.04±0.01	1.28±1.48	ns	14.2±6.23	14.1±2.7	ns
D-Limonene	1031	A	0.38±0.11	0.32±0.09	ns	10.1±4.3	14.0±7.8	ns
Undecane	1100	A	2.35±0.33	4.31±1.23	*	2.84±0.27	2.29±0.19	*
Dodecane	1199	A	1.11±0.38	1.02±0.17	ns	0.92±0.17	0.64±0.12	*
Undecanal	1309	A	2.26±0.34	1.02±0.41	**	2.07±0.64	1.47±0.19	ns
Tetradecane	1399	A	1.23±0.39	0.53±0.29	*	0.79±0.39	0.55±0.21	ns
Dodecanal	1411	A	2.24±0.40	0.75±0.40	**	2.38±1.14	1.06±0.04	*
Pentadecane	1499	A	1.05±0.27	0.44±0.32	*	1.07±0.73	0.36±0.03	ns

339   [1]Linear retention indices determined on a DB 5 column.

340   [2]Confirmation of identity where A = mass spectrum and LRI agree with those of an authentic compound; B = mass spectrum agrees with

341   reference spectrum in the NIST mass spectral database and the LRI value agrees with that in the database (NIST Chemistry WebBook, 2017); C

342   = mass spectrum agrees with reference spectrum in the NIST mass spectral database (NIST/EPA/MSDC, 1992).

343   [3]Approximate amount (mean, n=4) collected from the headspace, calculated by comparison of peak area with that of 1,2-dichlorobenzene

344   (130.6 ng) with a response factor of 1, nd = not detected.

345   [4]Independent-Samples T Tests was used to compare group samples (sunflower oils sample vs. sunflower oils & phospholipids sample), significant

346   differences are shown by **, $p \leq 0.01$; *, $p \leq 0.05$; ns, $p > 0.05$.

347   [5]Independent-Samples T Tests was used to compare group samples (chicken meat sample vs. chicken meat & phospholipids sample), significant

348   differences are shown by **, $p \leq 0.01$; *, $p \leq 0.05$; ns, $p > 0.05$.