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Determination and comparison of volatile compounds of different poultry species eggs

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Abstract

All fresh poultry eggs differ greatly in chemical components. Many chemicals have been investigated in this field, but the presence of differences in odor components between species has not yet been investigated. For this reason, this study aimed to determine the volatile compounds of the eight different poultry species eggs and the differences among them. In this context, 180 eggs (20 from each species) were purchased from different farms, and the volatile compounds of raw eggs were determined by the solid phase micro-extraction method. Following the analysis, 41 volatile compounds and 12 organic groups were identified. The variety and ratios of these compounds varied among the species, with pigeon eggs containing the greatest number of compounds (19 compounds) and quail, partridge, and pheasant eggs containing the lowest numbers (seven compounds). Acetamide, 2-fluoro-, and D-limonene compounds were found in every species of eggs. The other species eggs did not contain any of the 10 volatile chemicals detected in pigeon eggs, eight in chicken eggs, and one in quail eggs. It was discovered that the eggs volatile compounds counts and chemical profiles varied, indicating differences in their tastes, smells, and aromas. The volatile chemicals found in this study may be species-specific and can be used as indicators to identify which eggs belong to which species.

Introduction

All poultry eggs are similar in general structure; however, they differ greatly from each other in terms of their chemical composition. The presence and levels of components like proteins, fats, carbohydrates, vitamins, minerals, energy, and fatty acids, have been demonstrated by various studies.[1-8] Thus, it has been stated that chemical compounds show great differences among poultry species. Fatty acid, carotenoid, and protein compounds have been characterized in different species and alterations have been determined among species.[4,5,8,9] Furthermore, haptoglobin in pigeons, serpin-like proteins in ducks, and ovodefensins in chickens were detected as proteins thought to be species-specific.[4,5] Esters, alcohols, alkenes, and nitrogenous compounds were determined as volatile compounds of egg yolk, and the main compounds contributing to the differentiation of eggs were listed as ethyl acetate, phthalic acid, butyl isohexyl ester, O-methyl-isourea hydrogen sulfate, 1-butanol, and N-isopropylbenzamide.[10]

The combination of volatile compounds causing odor and aroma is an important group of molecules. Indeed, aroma and odor are the primary parameters determining the sensory quality of products in the food industry.[9,11-13] As known, eggs have a distinctive odor and farming practices, such as rearing conditions and the content of the feed used, affect the eggs odor. In addition, stale eggs, spoilage, and ill-advised practices related to cooking also cause a bad odor by causing the loss of the natural smell of eggs. A bad smell in eggs can be irritating and a subject of complaints by sensitive consumers. For this reason, odor is an important limiting factor in the consumption of eggs. Features, such as the taste, aroma, and smell of eggs belonging to various species were stated as sub-factors affecting the egg preferences of consumers.[14] Therefore, it is important to determine which volatile compounds are present in the eggs of different species. Determining the volatile compounds forming the source of bad odors will allow studies to be carried out to eliminate these odors.

This study was aimed to determine the volatile compounds in whole eggs of eight different types of poultry, including chicken, turkey, goose, duck, quail, pheasant, Guinea fowl, pigeon, and partridge.

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Materials and Methods

Eggs. In this study, chicken (Leghorn), turkey (Standard Bronze), goose (Linda), duck (Peking), pheasant (*Phasianus colchicus*), Guinea fowl (*Numida meleagris*), pigeon (*Columba livia*), quail (*Coturnix japonica*), and partridge (*Alectoris chukar*) eggs were used. A total of 180 eggs, 20 of each species, were purchased from poultry farms located in Adana, Mersin, and different districts of different provinces in Türkiye. The eggs were brought to the laboratory, washed with tap water, cleaned with tissue paper, and checked for cracks. Clean and unbroken eggs were selected for analyses. Before analysis, each egg was carefully disinfected with 75.00% ethanol, dried at room temperature, and stored in a refrigerator at 4.00 ˚C. Fifteen approximately same-sized eggs from each species were taken out of the refrigerator on the day of the analysis, broken, and mixed homogeneously with the help of a mixer. Samples taken into sterile tubes were made ready for analysis in the gas chromatography-mass spectrometry (7890B GC-7010B MS; Agilent Technologies Inc., Santa Clara, USA) device.

Analysis of volatile compounds. Instrumental analysis methods are used for the determination of volatile compounds.[15] A widely used method is the GC-MS method combined with multi-variate data analysis, being utilized for the characterization of volatile profiles in order to determine odor properties.[16,17] Also, in recent years, the solid phase micro-extraction (SPME) method has been preferred in many analytical fields, especially in the analysis of volatile compounds in poultry products, due to its high activity, selectivity, and faster and more successful results.[18,19] In this study, volatile compound analyses were carried out using the Agilent GC-MS system. With the SPME method, 3.00 g of sample was placed in a 20.00 mL vial and kept at 38.00 ˚C for 45 min. Then, the volatile components were absorbed for 30 min with SPME apparatus 50.00/30.00 µm fiber coated with divinyl-benzene/carboxen/polydimethylsiloxane (Supelco, Bellefonte, USA). Then, DB-Wax (60.00 m × 0.25 mm × 0.25 µm; J&W Scientific, Folsom, USA) was injected into the capillary column by desorption for five min. The injection temperature was set at 250 ˚C, the column temperature was 40.00 ˚C for 4 min, and then, it was increased by 3.00 ˚C *per* min to 90.00 ˚C. After this, it was increased by 4.00 ˚C *per* min to 130 ˚C. After keeping the sample at this temperature for 4 min, the temperature was adjusted to 240 ˚C at a heating rate of 5.00 ˚C *per* min and kept at this value for 8 min. Helium was used as a carrier gas (Linde, Adana, Türkiye). The electron energy was 70.00 eV, mass range was 30.00 - 600 m/z (mass-to-charge), and split ratio was 1:10.

Statistical analysis. The experimental data were analyzed using SPSS Software (version 17.0; IBM Corp., Armonk, USA) package program and the results were presented as the mean and standard error of mean. The differences between the volatile compounds found in the poultry species eggs were analyzed by analysis of variance and Tukey's test ($p < 0.05$).

Results

The volatile compounds of the chicken, turkey, goose, duck, quail, pheasant, Guinea fowl, pigeon, and partridge eggs were analyzed using the SPME method with a GC-MS device. The distribution (%) and comparison of volatile compounds by species are presented in Table 1.

The D-limonene and acetamide, 2-fluoro- compounds and phenethylamine, p,.alpha.-dimethyl-, nonanal and phenethylamine, and p,.alpha.-dimethyl- compounds found in eight species were found to be significant at $p <$ 0.01, while heptanal, decanal, and 2-decenal, (E)- were found to be significant at $p < 0.05$. Other compounds found in more than one species being detected to be insignificant were as follows: Benzene, methyl/ toluene, hexanal, propanenitrile, 2-hydroxy/hexanal, tricyclo[4.3.1.1(3,8)] undecane-3-carboxylic acid, octanal, heptanal, hexadecanoic acid, ethyl ester, pentanal/hexane, thieno[2,3-c]furan-3-carbonitrile, 2-amino-4,6-dihydro-4,4,6,6-tetramethyl-, 2-butanamine, 3,3-dimethyl-/methylene chloride, 4-occten-3-one/methylpent-4-enylamine, formic acid, ethenyl ester, 1,2,4-benzene-tricarboxylic acid, and 1,2-dimethyl ester.

According to the results of the analysis, 41 different volatile compounds were detected in eight species. The Guinea fowl eggs were found to contain eight volatile compounds, while D-limonene (37.40%), benzene, methyl/ toluene (19.85%), and nonanal (11.75%) were the compounds with the highest area and percent ratio values. A total of 19 compounds were characterized in the pigeon eggs, and the compounds with the highest ratios were D-limonene (23.09%), benzoic acid/(2R,3R)-(-)-DI-O-BENZOYLWEINSAEURE/N-Benzoyl-3-hydroxy-2,3-di-dehydroproline ethyl ester (19.53%), and hexanal (13.97%). In the quail eggs, seven compounds were determined. D-limonene (23.26%), 2-butanamine, 3,3-dimethyl-/methylene chloride (25.48%), and 2-ethyl-1-hexanol (15.89%) had the highest ratios.

Ten compounds were found in the turkey eggs. D-limonene (33.13%), propanenitrile, 2-hydroxy/hexanal (11.07%), and tricycle [4.3.1.1(3.8)]undecane-3-carboxylic acid (10.59%) were detected at the highest ratios. The goose eggs were found to contain 11 different compounds. The compounds with the highest ratios were nonanal (18.25%), 1,2,4-benzenetricarboxylic acid, 1,2-dimethyl ester (17.48%), and octanal (14.43%). Nine compounds were detected in the duck eggs, and D-limonene (39.43%) and nonanal (17.26%) were observed to have the highest ratios.

Table 1. Distribution and comparison of the volatile compounds by species (%).

Compounds	Guinea fowl	Pigeon	Quail	Turkey	Goose	Partridge	Duck	Pheasant	Chicken	SEM	*p*-value
Benzene, methyl/toluene	19.85	.	.	2.92	.	3.73	.	38.77	.	4.46	0.000
Hexanal	.	13.97	.	.	5.79	.	5.48	.	.	4.97	0.013
Propanenitrile, 2-hydroxy/hexanal	8.94	.	.	11.07	12.77	.	.	.	.	3.61	0.185
Propanenitrile, 2-hydroxy	.	.	.	.	.	4.60	.	.	0.98	-	-
Phenethylamine, p,.alpha.-dimethyl-	2.85	.	.	.	.	.	.	2.78	.	0.12	0.594
D-limonene	37.40	23.09	23.26	33.13	12.00	71.78	39.43	27.49	44.98	5.96	0.000
Tricyclo[4.3.1.1(3,8)]undecane-3-carboxylic acid	4.01	.	.	10.59	.	3.96	.	.	.	1.95	0.002
Octanal	2.35	5.12	.	1.76	14.43	.	5.66	.	.	1.05	0.172
Nonanal	11.75	6.81	.	10.04	18.25	6.61	17.26	2.43	.	1.49	0.056
Acetamide, 2-fluoro-	2.99	1.40	4.06	4.35	5.60	4.47	1.43	5.40	4.60	1.03	0.158
2-Propanamine	.	1.43	.	.	.	.	.	.	.	-	-
Heptanal	.	.	.	1.89	3.11	.	2.20	.	.	0.52	0.853
Cyclobutanol	.	.	.	3.53	.	.	.	.	.	.	.
Heptanal/cyclobutanol	.	2.30	.	.	.	.	.	.	.	.	.
Pyrimidine-2,4(1H,3H)-dione, 5-amino-6-nitroso-	.	1.19	.	.	.	.	.	.	.	.	.
Furan, 2-pentyl-	.	3.40	.	.	.	.	.	.	.	.	.
3-Pyridinecarboxaldehyde, O-acetyloxime, (E)-:	.	2.04	.	.	.	.	.	.	.	.	.
Octodrine	.	1.95	.	.	.	.	.	.	.	.	.
1-Octen-3-ol	.	4.49	.	.	.	.	.	.	.	.	.
Decanal	.	1.51	.	.	2.12	.	1.37	.	.	0.61	0.980
Cathinone	.	3.54	.	.	.	.	.	.	.	-	-
Bicyclo[2.2.1]heptane-5-(ethyl-1-amine):	.	0.72	.	.	.	.	.	.	.	-	-
3,5-Octadien-2-one, (E,E)-:	.	2.77	.	.	.	.	.	.	.	-	-
2-Decenal, (E)-	.	1.30	.	.	3.54	.	3.26	.	.	0.67	0.093
Benzoic acid/(2R,3R)-(-)-DI-O-BENZOYLWEINSAEURE/N-benzoyl-3-hydroxy-2,3-didehydroproline ethyl ester	.	19.53	.	.	.	.	.	.	.	-	-
Hexadecanoic acid, ethyl ester	.	1.28	.	.	4.61	2.47	7.43	.	.	1.76	0.041
Pentanal/hexane	.	.	3.07	.	.	.	.	.	1.43	1.65	0.118
Thieno[2,3-c]furan-3-carbonitrile, 2-amino-4,6-dihydro-4,4,6,6-tetramethyl-	.	.	15.34	.	.	.	.	.	3.29	5.40	0.000
2-Butanamine, 3,3-dimethyl-/methylene chloride	.	.	25.48	.	.	.	.	.	18.14	1.81	0.159
4-occten-3-one/methylpent-4-enylamine	.	.	7.08	.	.	.	.	.	3.53	1.93	0.018
2-Ethyl-1-hexanol	.	.	15.89	.	.	.	.	.	.	-	-
Formic acid, ethenyl ester	.	.	.	3.46	.	.	.	10.78	.	1.84	0.361
1,2,4-Benzenetricarboxylic acid, 1,2-dimethyl ester	.	.	.	.	17.48	.	.	10.68	.	11.40	0.494
Propane, 2-isocyanato	.	.	.	.	.	.	.	.	1.18	-	-
2-Heptanol, 6-methyl-	.	.	.	.	.	.	.	.	2.14	-	-
Decane/N,N'-dimethylpiperazine	.	.	.	.	.	.	.	.	2.86	-	-
2-Isononenal	.	.	.	.	.	.	.	.	2.66	-	-
Octanoic acid	.	.	.	.	.	.	.	.	2.21	-	-
n-Decanoic acid	.	.	.	.	.	.	.	.	1.27	-	-
Acetic acid, [(aminocarbonyl)amino]oxo-	.	.	.	.	.	.	.	.	1.83	-	-
Cyclopropanetetradecanoic acid, 2-octyl-, methyl ester	.	.	.	.	.	.	.	.	7.89	-	-

Seven compounds were determined in the partridge eggs, and D-limonene (71.78%) had the highest ratio among other compounds and other species. Among the analyzed species, the lowest number of different compounds was found as seven in the quail, partridge, and pheasant eggs. It was observed that benzene, methyl/toluene (38.77%), and D-limonene (27.49%) had the highest ratios in the pheasant eggs. Fifteen compounds were characterized in analyses of the chicken eggs, which had the second highest number of different compounds. D-limonene (44.98%) and 2-butanamine, 3,3-dimethyl-/methylene chloride (18.14%) were the compounds with the highest ratios in the pigeon eggs. In general, D-limonene had the highest ratios among the volatile compounds of the Guinea fowl (37.40%), turkey (33.13%), partridge (71.78%), duck (39.43%), chicken (44.98%), and pigeon (23.09%) eggs. Additionally, 2-butanamine, 3,3-dimethyl-/methylene chloride (25.48%) in the quail eggs, benzene, methyl/ toluene (38.77%) in the pheasant eggs, and nonanal (18.25%) in the goose eggs were determined as the compounds with the highest ratios.

Eggs with a high number and ratio of common compounds will likely have similar tastes and aromas. Goose and duck have nine common compounds, pigeon, goose, and duck have eight, Guinea fowl and turkey have seven, quail and chicken have six, and Guinea fowl, turkey, and pheasant have five common compounds. Goose and duck may have similar aromas since they are waterfowl and have many common compounds. The pigeon, goose, and duck, Guinea fowl and turkey, quail and chicken, and Guinea fowl, turkey, and pheasant eggs are likely to have similar aromas.

Figures 1, 2 and 3 present the total ion chromatogram of the Guinea fowl, quail, pigeon, turkey, goose, partridge, duck, pheasant, and chicken eggs, and the first retention times were different. In the ion chromatogram, the compounds started to spread in the GC-MS device in the shortest time were detected in the quail (Fig. 1B) and chicken (Fig. 3C) eggs, and the first retention time in both groups of eggs was determined as 3.13 min. Similarly, the goose (Fig. 2B) and pheasant (Fig. 3B) eggs had the same initial retention time, and the compounds in these two eggs were first found at 4.99 min.

In contrast, the first retention time was approximately 10 min in the Guinea fowl (Fig. 1A), turkey (Fig. 2A), and partridge (Fig. 2C) eggs and 11.73 min in the duck (Fig. 3A) and 11.74 min in the pigeon (Fig. 1C) eggs. As seen in the figures, the peak time and peak number of volatile compounds in each group of poultry eggs were different.

Although many volatile compounds were detected as a result of the analyses, it was observed that only the acetamide, 2-fluoro-, and D-limonene compounds were found in all eggs. Besides, the nonanal compound was determined in the eggs of seven species, while it was not found in two species. On the other hand, the pigeon (19 compounds) and chicken (15 compounds) eggs have higher numbers of compounds compared to the other groups of eggs, and they contained many different compounds that were not found in the other eggs.

The 2-Propanamine,heptanal/cyclobutanol,pyrimidine-2,4(1H,3H)-dione, 5-amino-6-nitroso-, furan, 2-pentyl-, 3-pyridinecarboxaldehyde, O-acetyloxime, (E)-, octodrine, 1 -octen-3-ol, cathinone, bicyclo[2.2.1]heptane-5-(ethyl-1-amine), 3,5-octadien-2-one, (E,E)-, and benzoic acid/ (2R,3R)-(-)-DI-O-BENZOYLWEINSAEURE/N-Benzoyl -3-hydroxy-2,3-didehydroproline ethyl ester (11 compounds) were determined only in the pigeon eggs. Similarly, only cyclobutanol compound was detected in the Turkey egg and 2-ethyl-1-hexanol only found in the quail eggs, while propane, 2-isocyanato, 2-heptanol, 6-methyl-, decane/N,N'-dimethylpiperazine, 2-isononenal, octanoic acid, n-decanoic acid, acetic acid, [(aminocarbonyl) amino]oxo-, and acetic acid, [(aminocarbonyl)amino]oxo-compounds (eight compounds) were identified in the chicken egg.

The D-limonene and acetamide, 2-fluoro- compounds were common in all of the species' eggs. D-limonene compound was determined respectively as 37.40, 23.09, 23.26, 33.13, 12.00, 71.78, 39.43, 27.49, and 44.98 in the Guinea fowl, pigeon, quail, turkey, goose, partridge, duck, pheasant, and chicken eggs, being found to be statistically significant ($p < 0.01$). The highest level was detected in the chicken eggs (44.98%) and the lowest level was determined in goose eggs (12.00%).

The acetamide, 2-fluoro- compound as the second most common compound was detected respectively in the Guinea fowl, pigeon, quail, turkey, goose, partridge, duck, pheasant, and chicken eggs as 2.99, 1.40, 4.06, 4.35, 5.60, 4.47, 1.43, 5.40, and 4.60, being found to be statistically significant ($p < 0.01$). The highest levels were found in goose eggs (5.60%), followed by pheasant (5.40%), chicken (4.60%), partridge (4.47%), and turkey (4.35%), and the lowest level was in pigeon eggs (1.40%).

The molecular weights, formulae, Chemical Abstracts Service numbers, substance classifications, and scent descriptions of the identified volatile compounds are given in Table 2. In total, 12 groups of volatile compounds were identified, which were alkyl, aldehyde, amine, alkene, acid, amide, alcohol, ester, alkane, ketone, isocyanate, and ester in the eggs of eight different species. Among the organic groups detected, the aldehyde group was found as the highest (25.00%), followed by acid and amine (13.64%), alcohol (11.36%), others (9.09%), ester and alkane (6.82%), ketone (4.55%) while the alkyl, isocyanate, amide and alkene (2.27%) was detected as the least (Fig. 4).

The distribution of organic groups of volatile compounds in eggs of eight species is presented in Figure 5. The most abundant organic group in the eggs examined was the aldehyde group. The species with the highest amount were pigeon, goose, and duck.

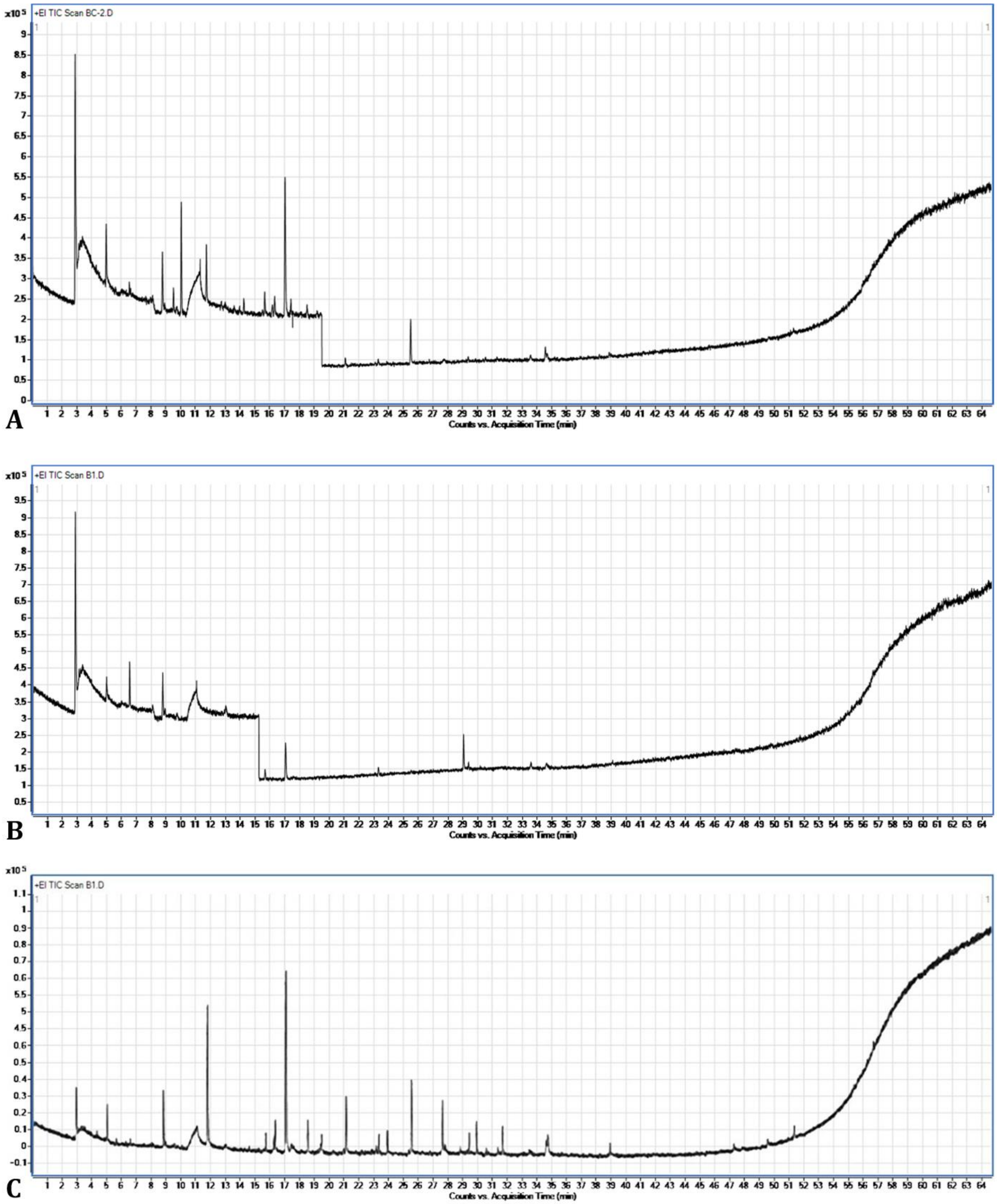

Fig. 1. Total gas chromatography-mass spectrometry ion chromatogram of volatiles in eggs of different species. **A)** Guinea Fowl eggs, **B)** Quail eggs, **C)** Pigeon eggs.

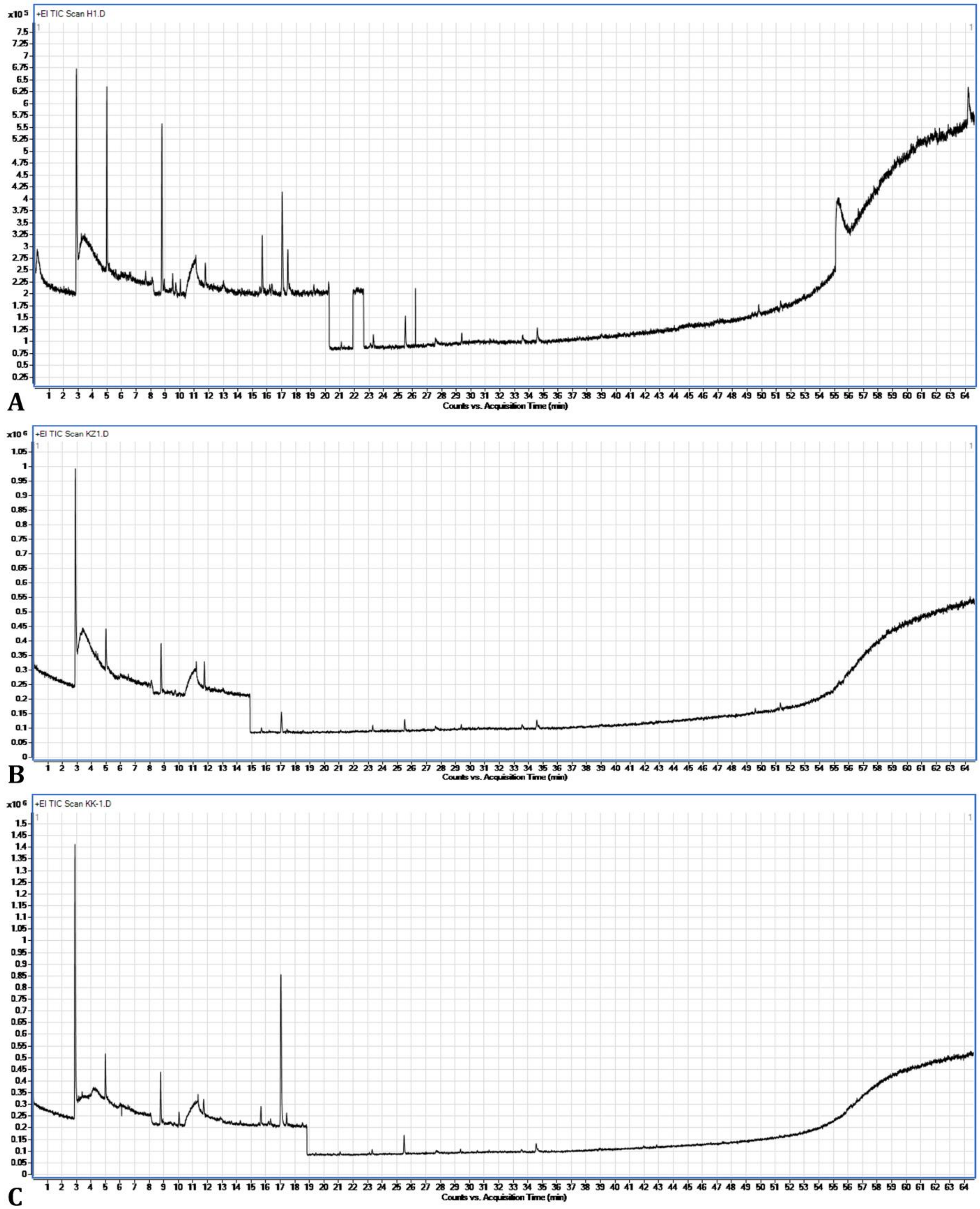

Fig. 2. Total gas chromatography-mass spectrometry ion chromatogram of volatiles in eggs of different species. **A)** Turkey eggs, **B)** Goose eggs, **C)** Partridge eggs.

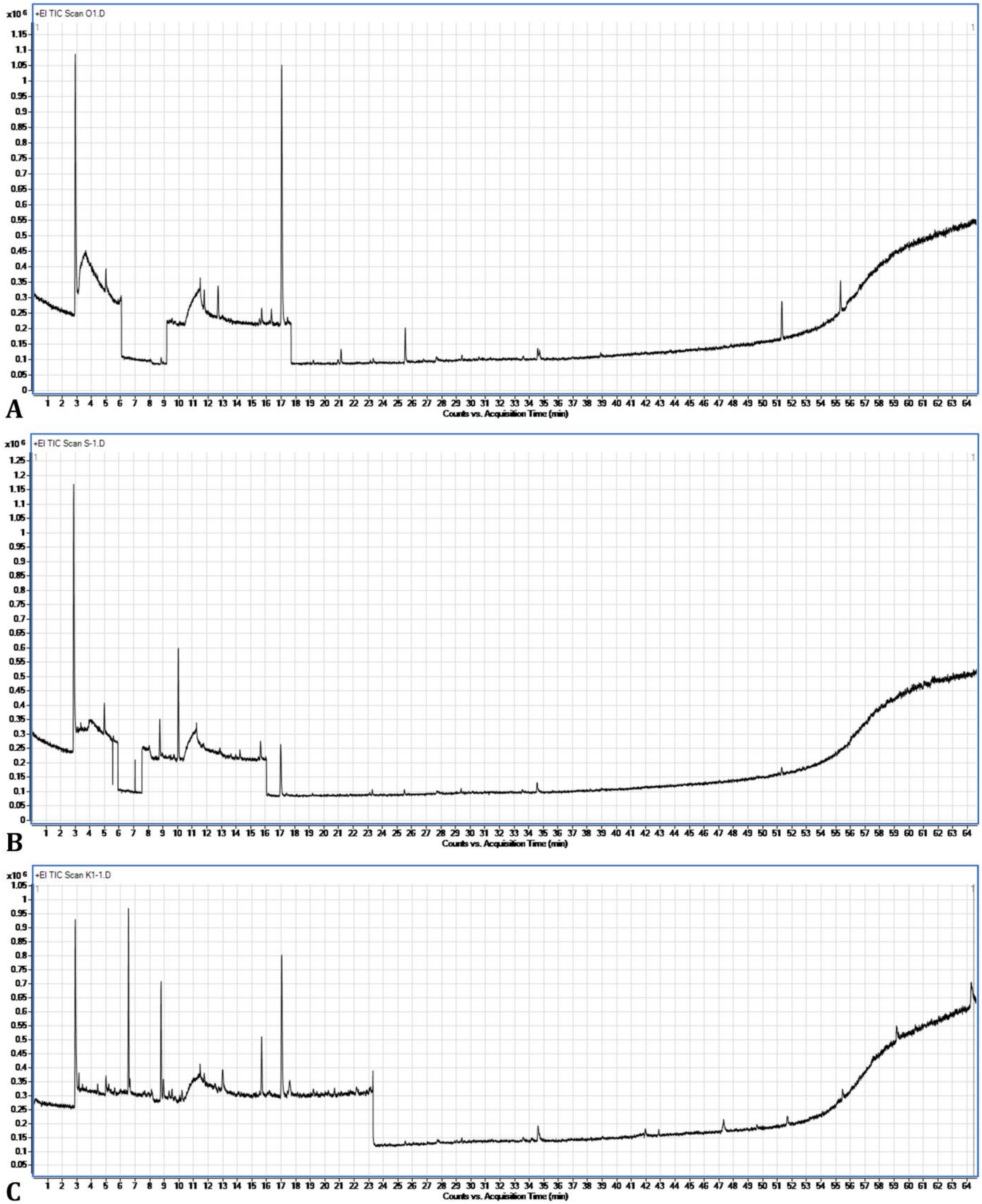

Fig. 3. Total gas chromatography-mass spectrometry ion chromatogram of volatiles in eggs of different species. **A)** Duck eggs, **B)** Pheasant eggs, **C)** Chicken eggs.

Table 2. List of the volatile compounds of species eggs.

Compounds	Weight (g M^{-1})	Formula	CAS No.	Classification	Scent description
Benzene, methyl/toluene	92.14	C_7H_8	108-88-3	Alkyl	Sweet, pungent, benzene-like odor[20]
Hexanal	100.161	$C_6H_{12}O$	66-25-1	Aldehyde	Green, grassy, fruity[21]
Propanenitrile, 2-hydroxy/hexanal	71.08/ 100.161	C_3H_5NO/ $C_6H_{12}O$	78-97-7/ 66-25-1	Aldehyde	Green, grassy, fruity[20,21]
Propanenitrile, 2-hydroxy	71.08	C_3H_5NO	78-97-7	Aldehyde	[20]
Phenethylamine, p,.alpha.-dimethyl-	149.24	$C_{10}H_{15}N$	64-11-9	Amine	[20]
D-limonene	136.24	$C_{10}H_{16}$	5989-27-5	Alkene	Orange and lemon-like aroma[22]
Tricyclo[4.3.1.1(3,8)]undecane-3-carboxylic acid	194.27	$C_{12}H_{18}O_2$	31061-65-1	Acid	[20]
Octanal	128.22	$C_8H_{16}O$	124-13-0	Aldehyde	Honey odor, fat, soap, lemon, green[20]
Nonanal	142.24	$C_9H_{18}O$	124-19-6	Aldehyde	Fat, citrus, green[20]
Acetamide, 2-fluoro-	77.06	C_2H_4FNO	640-19-7	Amide	Rodenticides[20]
2-Propanamine	59.1103	C_3H_9N	75-31-0	Amine	Ammonia like odor[20]
Heptanal	114.19	$C_7H_{14}O$	111-71-7	Aldehyde	Fruity odor[23]
Cyclobutanol	72.107	C_4H_8O	2919-23-5	Alcohol	[20]
Heptanal/cyclobutanol	114.19/ 72.107	$C_7H_{14}O$/ C_4H_8O	111-71-7/ 2919-23-5	Aldehyde/ Alcohol	Fruity odor[20,23]
Pyrimidine-2,4(1H,3H)-dione, 5-amino-6-nitroso-	156.10	$C_4H_4N_4O_3$	959098-29-4	Other	[20]
Furan, 2-pentyl-	138.2069	$C_9H_{14}O$	3777-69-3	Other	Fruity, green earthy beany vegetable, metallic[23]
3-Pyridinecarboxaldehyde, O-acetyloxime, (E)-:	164.16	$C_8H_8N_2O_2$	72989-60-7	Aldehyde	[23]
Octodrine	129.25	$C_8H_{19}N$	543-82-8	Amine	Fishy odor[24]
1-Octen-3-ol	128.22	$C_8H_{16}O$	3391-86-4	Alcohol	Mushroom, lavender, rose, hay aroma[20]
Decanal	156.27	$C_{10}H_{20}O$	112-31-2	Aldehyde	Citrus[20]
Cathinone	149.19	$C_9H_{11}NO$	71031-15-7	Amine	[20]
Bicyclo[2.2.1]heptane-5-(ethyl-1-amine):	-	-	-	Other	-
3,5-Octadien-2-one, (E,E)-:	124.18	$C_8H_{12}O$	30086-02-3	Acid	Fruity, green, grassy[25]
2-Decenal, (E)-	154.25	$C_{10}H_{18}O$	3913-71-1	Aldehyde	Strong, waxy odor[20]
benzoic acid/(2R,3R)-(-)-DI-O-BENZOYLWEINSAEURE/N-benzoyl-3-hydroxy-2,3-didehydroproline ethyl ester	122.12	$C_7H_6O_2$	65-85-0	Acid	Faint, pleasant odor[20]
Hexadecanoic acid, ethyl ester	284.48	$C_{18}H_{36}O_2$	628-97-7	Ester	Wax-like odor[20]
Pentanal/hexane	96.13/ 86.18	$C_5H_{10}O$/ C_6H_{14}	110-62-3/ 110-53-3	Alkane	Strong, acrid, pungent/ petrolic[20]
Thieno[2,3-c]furan-3-carbonitrile, 2-amino-4,6-dihydro-4,4,6,6-tetramethyl-	222.31	$C_{11}H_{14}N_2OS$	447412-24-0	Other	[23]
2-Butanamine, 3,3-dimethyl-/methylene chloride	84.93/ 101.19	CH_2Cl_2/ $C_6H_{15}N$	75-09-2/ 3850-30-4	Alkane	Chloroform-like, sweet odor[20,26]
4-occten-3-one/methylpent-4-enylamine	99.17/ 126.20	$C_8H_{14}O$/ $C_6H_{13}N$	5831-72-1/ 14129-48-7	Amine Ketone	Coconut, fruity[23,25]
2-Ethyl-1-hexanol	130.23	$C_8H_{18}O$	104-76-7	Alcohol	Sweet floral fragrance[20]
Formic acid, ethenyl ester	72.06	$C_3H_4O_2$	692-45-5	Ester	[23]
1,2,4-Benzenetricarboxylic acid, 1,2-dimethyl ester	238.19	$C_{11}H_{10}O_6$	67402-72-6	Acid	[23]
Propane, 2-isocyanato	85.10	C_4H_7NO	1795-48-8	Isocyanate	Pungent odor[23]
2-Heptanol, 6-methyl-	130.23	$C_8H_{18}O$	4730-22-7	Alcohol	Waxy, fatty, citrus[25]
Decane/N,N'-dimethylpiperazine	142.28/ 114.19	$C_{10}H_{22}$/ $C_6H_{14}N_2$	124-18-5/ 156-58-1	Alkane/ Amine	Gasoline-like/saline taste[20]
2-Isononenal	140.23	$C_9H_{16}O$	53966-58-8	Aldehyde	Peach aroma[27,28)]
Octanoic acid	144.21	$C_8H_{16}O_2$	124-07-2	Acid	Slightly unpleasant rancid-like smell[23]
n-Decanoic acid	172.27	$C_{10}H_{20}O_2$	334-48-5	Acid	Rancid odor[23]
Acetic acid, [(aminocarbonyl)amino]oxo-	132.08	$H_2C_2O_4$	144-62-7	Ketone	Odorless[20]
Cyclopropanetetradecanoic acid, 2-octyl-, methyl ester	394.67	$C_{26}H_{50}O_2$	52355-42-7	Ester	[23]

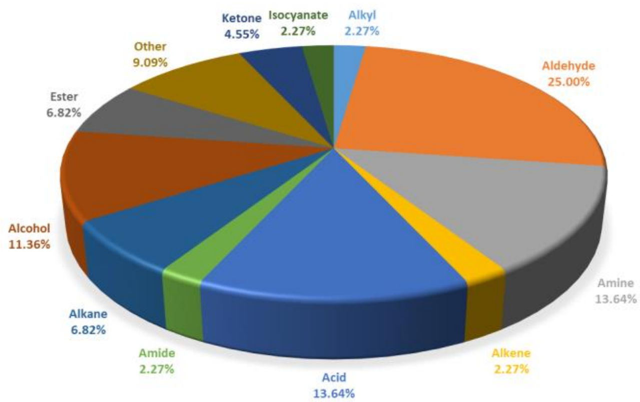

Fig. 4. Organic groups of volatile compounds.

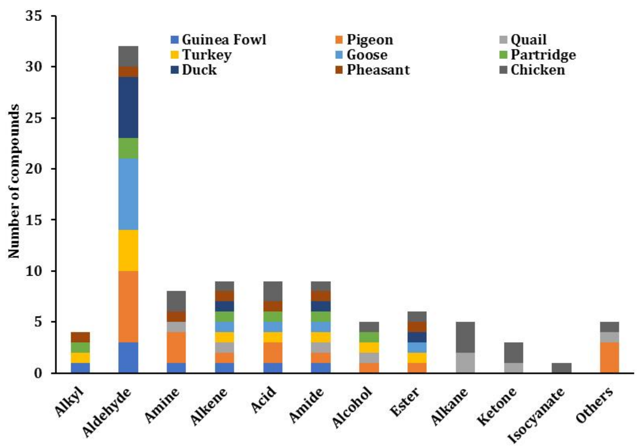

Fig. 5. Distribution of organic groups of volatile compounds in eggs of eight poultry species.

Discussion

The D-limonene was the volatile compound with the highest percentage in the eggs of six species, other than quail, goose, and pheasant. D-limonene is a colorless liquid aliphatic hydrocarbon classified as a cyclic monoterpene, and it is the main component in the oil of citrus peels. The D-isomer, being more commonly found in nature as a scent compound of orange, is used as a flavoring agent in food production.[22]

The results of the present study showed that the highest number of compounds was found in the pigeon eggs (19 compounds), and the lowest numbers of compounds were detected in the quail, partridge, and pheasant eggs (seven compounds). Furthermore, it was observed that six of the eight volatile compounds found in the Guinea fowl eggs, 17 out of the 19 compounds found in the pigeon eggs, eight out of the ten compounds found in the turkey eggs, five out of the seven compounds found in the partridge eggs, and five out of the seven compounds found in the pheasant eggs were different compounds in comparison with those found in the chicken eggs. Unlike the other eggs, the quail eggs contained 2-ethyl-1-hexanol.

The goose eggs had nine common compounds out of 11 compounds with the duck eggs, while they had two common and nine different compounds with the chicken eggs. The duck eggs contained seven compounds different from those of the chicken eggs. The high number of common compounds in the goose and duck eggs was probably due to their similarities as waterfowls.

It is known that goose and duck eggs are not consumed much because they smell strongly. The 2-decenal, (E)- and hexadecanoic acid, ethyl ester found in these two eggs give the egg a strong and waxy smell.[20,23] The amounts of 2-decenal, (E)- and hexadecanoic acid, ethyl ester in goose were determined as 3.54 and 4.61, and in duck as 3.26 and 7.43, respectively. It is estimated that these two compounds are the cause of the strong smell. At the same time, high amount of aldehyde group compounds gives the eggs a strong odor, just like in pigeon. It was determined that the D-limonene compound found in the partridge eggs had the highest ratio (71.78%) among other compounds found in the eggs of partridge and other species.

In terms of the volatile compounds they contained, the chicken eggs were the group of eggs with the second highest number of compounds after the pigeon eggs. It was determined that the eggs with the most common compounds with the chicken eggs were the quail eggs (six compounds).

The common compound in all of the species' eggs was D-limonene added an orange and lemon-like aroma to the eggs.[22] The other compound was acetamide, 2-fluoro-, an agricultural drug used as a rodenticide and pesticide. The compound may be fatal if swallowed or in the case of skin contact. Also, direct contact with the eyes may cause temporary irritation. Also, it has toxic effects if inhaled.[29]

Ren *et al*.,[13] have detected 21 volatile compounds in the GC-MS analysis of the duck eggs. However, in our study, nine compounds were determined. Studies have reported that the foods eaten by animals affect egg content, volatile compounds, and accordingly flavor.[30,31] The difference between the results of our study and those of other studies in the literature may be due to the differences in rearing conditions, the content of the feeds consumed by the animals, and the method used in the analyses. On the other hand, hexanal, octanal, nonanal, decanal, 2-decenal, (E)-, and hexadecanoic acid were common volatile compounds detected in both studies.

As a result of their analysis of egg yolk samples collected from the eggs of seven different poultry species (duck, free-range chicken, silken chicken, quail, pigeon, goose, and chicken), Wang *et al*.,[10] have found 20 volatile compounds in pigeon eggs, 19 in quail eggs, 24 in goose eggs, 18 in duck eggs, and 26 in chicken eggs. They determined that the volatile compounds of egg yolk were esters, alcohols, alkenes, and nitrogenous compounds, and the main compounds contributing to the differentiation of egg types were ethyl acetate, phthalic acid butyl isohexyl ester, omethylisourea hydrogen sulfate, 1-butanol, and N-isopropylbenzamide. In our study, 19 volatile compounds were detected in pigeon eggs, seven were detected in quail eggs, 11 were detected in goose eggs, nine were detected in duck eggs, and 15 were detected in chicken eggs. Wang *et al*.,[10] have determined more compounds in their study. The conditions in which the animals were reared (free in nature or closed poultry houses), variations in the nutritional composition of their diets,[32] and differences in the methods used in the analyses may have been effective in this finding. In our study, some compounds contributed to the differentiation of the eggs of different species were identified to be the same as those reported by Wang *et al*.[10] For example, 10 volatile compounds in pigeon eggs, eight in chicken eggs, and one in quail eggs were determined to be unavailable in the eggs of the other species examined.

In another study, Xiang *et al*.,[8] performed the characterization and classification of volatiles using the SPME-GC-MS method to compare white Leghorn, Hy-Line Brown, and Jingfen hatching eggs. Their aim was to determine the difference in volatiles between eggs and try to analyze potential biological information encoded in odors. As a result of their study, they identified a total of 18 volatile compounds and determined that the detected volatiles contributed positively to the classification of eggs belonging to different breeds. In the present study, 15 different volatile compounds were determined in the chicken eggs. Eight of these compounds were not found in the eggs of the other species whose eggs were examined in this study, and these compounds can be used to classify eggs by species.

It was revealed in our study that the numbers of volatile compounds in the eggs of different poultry species and the chemical profiles of these eggs were different from each other. The detection of different volatile compounds in terms of numbers and percentages in the eggs of poultry species can cause differences in the odor, aroma, and quality of the eggs. At the same time, the qualitative and quantitative compositions of the volatiles affect the quality and taste, being very important for the consumer.[32,33] The difference in the numbers and chemical profiles of volatile compounds in the eggs of the species analyzed in our study is an explanation of why the odor and flavor of these eggs are different. Likewise, the results suggested that these differences between eggs may be new markers that can be used to distinguish the eggs of different poultry species.

In conclusion, 41 volatile compounds and 12 organic groups were detected, and the number of volatile components of the eggs and their chemical profiles were found to be different from each other. Taken together, these results showed that their odor, taste, and aroma were different and these compounds could be used as an indicator to distinguish species from each other.

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Conflict of interest

The authors declare no conflict of interest.

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