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Effects of the Addition of Glutamic Acid and Glucose to Wet Gluten on the Volatile Compounds in Deep-Fried Gluten Balls

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ABSTRACT

Wet gluten for producing deep-fried gluten balls was obtained by washing wheat flour with water. After adding glutamic acid and glucose, the wet gluten was cut and shaped into balls and deep-fried in soybean oil for deep-frying. The frying process proceeded for eight hours per day for twelve days. The balls deep-fried on the first and the twelfth days were stored in an oven at 60° C for eight weeks. The volatile compounds in the balls isolated by Likens-Nickerson steam distillation and dichloromethane extraction were analyzed by using gas chromatography and gas chromatography-mass spectrometry to investigate the effects of the addition of glutamic acid and glucose on the flavor change in the balls during storage. The results showed that the total amount of volatile compounds isolated from the deep-fried gluten balls obtained in the first-day frying and prepared with the addition of glutamic acid and glucose was larger than that from those prepared without the addition of these two substances. When the frying oil was used continuously for twelve days, the total amounts of volatile compounds isolated from the balls prepared with and without the addition of the acid and glucose were very similar. However, when the balls obtained on the twelfth day were stored for four or eight weeks, the total amount of volatile compounds isolated from the balls with the addition of these substances was smaller than that from those prepared without such additions.

Key Words: deep-frying, deep-fried gluten balls, glucose, glutamic acid, volatile compounds.

添加麩胺酸及葡萄糖於濕麵筋對油炸麵筋球揮發性成分之影響

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摘 要

本研究以麵粉水洗所得的濕筋產製油炸麵筋球。濕筋添加麩胺酸及葡萄糖後，經切粒及以黃豆油油炸製成油炸麵筋球。油炸每天進行 8 小時，共進行 12 天。將第 1 天及第 12 天所得之油炸麵筋球分別置於 60°C 恒溫烘箱中進行儲存，並以 Likens-Nickerson 蒸氣蒸餾法和二氯甲烷萃取其揮發性化合物，再以 GC 及 GC-MS 進行成分之鑑定，以探討麩胺酸及葡萄糖的添加對油炸麵筋球揮發性成分之影響。結果發現在第 1 天油炸所得且添加麩胺酸與葡萄糖的油炸麵筋球之總揮發性化合物含量大於未添加麩胺酸及葡萄糖者。當油炸進行至第 12 天，則有、無添加麩胺酸和葡萄糖之油炸麵筋球其總揮發性化合物含量相近，但在第 12 天油炸所得之麵筋球經儲存 4 或 8 週後，則有添加麩胺酸和葡萄糖之油炸麵筋球之總揮發性化合物含量小於未添加麩胺酸和葡萄糖者。

關鍵詞：油炸，油炸麵筋球，葡萄糖，麩胺酸，揮發性成分

I. INTRODUCTION

Volatile compounds in foods always give foods a characteristic flavor. The Maillard reaction and lipid oxidation are two major reactions that often occur in foods during cooking or processing which can generate volatile compounds [14]. Lipid oxidation not only causes food to become rancid, but its products also react with some food constituents such as proteins and amino acids, resulting in deterioration. Therefore, antioxidants, usually synthetic antioxidants, are often added to foods to prevent or retard lipid oxidation. However, the safety of synthetic antioxidants is still controversial [2]. Thus, a demand for natural antioxidants is increasing. Products of the Maillard reaction are naturally formed in foods during cooking or processing and have been demonstrated to have an antioxidative property; therefore, they are recognized as natural antioxidants [17].

The Maillard reaction occurs during cooking or processing of foods containing amino compounds and carbohydrates and results in the formation of various browning products [12]. Melanoidins, the final products of Maillard reactions, have a strong scavenging ability for free radicals. Elizalde *et al.* [5] reported that the volatile compounds generated from Maillard reactions could scavenge free radicals and retard the lipid oxidation rate. Kato *et al.* [9] also found that the products generated from a Maillard reaction between glucose and glycine had an ability to capture oxygen molecules. Elizalde *et al.* [5] found that soybean oil added with glucose plus glycine and heated at 90 °C for 12-18 hrs had maximum antioxidant ability. Yen and Hsieh [16] also found that the products of a Maillard reaction between xylose and lysine had an ability to scavenge peroxide and hydroxyl radicals. Lingnert [10] reported that a Maillard reaction between histidine and glucose or lysine and xylose could generate more antioxidant products than that between other amino acids and sugars.

Deep-fried gluten balls are a traditional food in Taiwan. For manufacturing high-quality deep-fried gluten balls, wheat flour of a suitable quality should first be selected [3]. The deep-frying process is also an important step in producing deep-fried gluten balls. It is often conducted consecutively through three or four deep-frying pans of different temperatures. Chen *et al.* [4] found that the optimal frying temperature ranges for the first and the second frying pans were 130-143 and 155-161 °C, respectively when the temperature of the third frying pan was set at 190±3 °C. Oil is easily abused during high-temperature frying, and its stability at high temperatures is a matter of concern. Although palm oil is more stable than soybean oil at high temperatures, it is easily solidified at chilling temperatures and might be mistaken to be animal fat by vegetarians. Thus, soybean oil is widely used as frying oil by deep-fried gluten ball manufacturers, and deterioration of the frying oil and the deep-fried gluten balls is still a major problem urgently needing a solution. In order to allow the Maillard reaction to occur during frying and, thus, to enhance the flavor and to improve the storage stability of deep-fried gluten balls, wet gluten treated with a solution of glutamic acid and glucose was used in this study. The flavor changes of deep-fried gluten balls during storage were also investigated.

II. MATERIALS AND METHODS

1. Materials

The wheat flour for making gluten dough was commercially milled from American hard red wheat and was provided by the Sanhow Co. (Chang-Hwa, Taiwan). The proximate compositions of the flour were analyzed by AACC

standard methods [1]. The crude protein, moisture, and ash contents of the wheat flour were 14.39, 11.9, and 0.77% (w.b.), respectively. Commercial soybean oil, obtained from Taisan Inc. (Changhua, Taiwan) and produced without the addition of antioxidants, was used as the frying oil.

2. Frying of Gluten Balls

A portion (200 g) of gluten dough was prepared from 450 g of wheat flour following the AACC method [1]. The dough (200 g) was put into a solution (10 mL) containing glutamic acid (0.2 g) and glucose (0.2 g) and kneaded until the solution was absorbed by the dough. The gluten dough was covered with a wet cloth and tempered for 30 minutes to release the internal stress generated during the preparation of the dough. After tempering the dough was cut and shaped into balls and deep-fried in three consecutive frying pans at 135±3, 157±3, and 190±3 °C, respectively, for 120, 90 and 70 sec, respectively [3]. This frying process was repeated on different balls once an hour and eight batches of wet gluten balls were deep-fried every day. The frying process was continued for twelve days. The frying oil was used for twelve days with refreshed oil, which was added after one-day frying to maintain a constant volume (3 L).

3. Storage of Deep-Fried Gluten Balls

The deep-fried gluten balls obtained in the first-day and the twelfth-day frying were respectively sealed in polyester bags and stored in an oven at 60 °C. During storage, 80g portion of the stored balls was sampled once every four weeks to study the volatile compound changes during storage. The flow chart of the sample preparation is shown in Figs. 1 and 2.

4. Isolation of Volatile Compounds

A deep-fried gluten ball sample (80 g) was placed in a 5-L round-bottom flask. Distilled water (2 L) was added to the sample. The sample was subjected to a Likens-Nickerson steam distillation and solvent extraction apparatus and then distilled for two hours to isolate the volatile components by the use of steam as the heating medium and dichloromethane

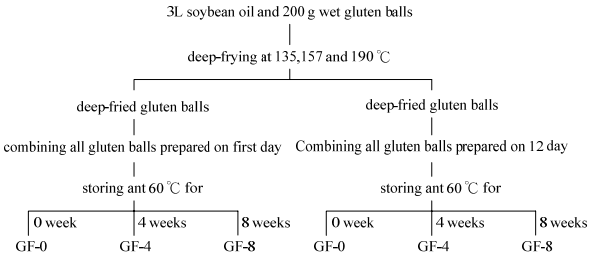

Fig. 1. Sample preparation flow chart of stored deep-fried gluten balls

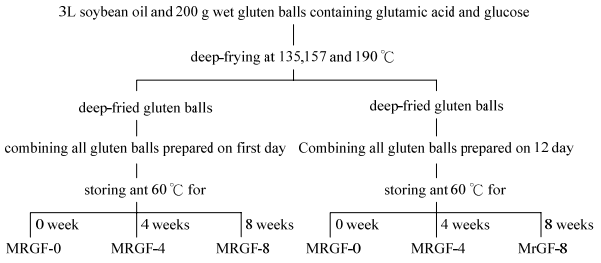

Fig. 2. Sample preparation flow chart of stored deep-fried gluten balls with glutamic acid and glucose addition

(40 mL) as the extraction solvent. This procedure was repeated three times and the extracts were combined. After isolation of the volatile components, 3 mL of a naphthalene solution (0.001 g in 100 mL of dichloromethane) was added to the combined extracts as an internal standard. The combined extracts were dried over anhydrous sodium sulfate, concentrated using a fractionation-concentration apparatus, and further concentrated under a stream of nitrogen in a small vial to a final volume of about 0.05 mL.

5. Gas Chromatography (GC) Analysis

A Hitachi G-3000 gas chromatograph equipped with a fused silica capillary column (50 m x 0.32 mm i.d.; 1 μm thickness, DB-Wax, J&W Inc.) and a flame ionization detector were used to analyze the volatile compounds. The operating conditions were as follows: injector temperature, 250 °C; detector temperature, 270 °C; nitrogen carrier flow rate, 1.2 mL/min; temperature program, 40 °C (5 min), 2 °C/min, 240 °C (99 min). A split ratio of 50:1 was used. The sample size for injection was 2 μL.

6. Gas Chromatography-Mass Spectrometry (GC-MS) Analysis

The concentrated isolate was analyzed by GC-MS using a Hewlett-Packard 5890 gas chromatograph coupled to a Hewlett-Packard 5971 MSD and the same column and operating conditions as those for the gas chromatography was used. Mass spectra were obtained by electron ionization at 70 eV and an ion source temperature of 250 °C.

7. Quantification of Volatile Compounds

The amount of volatile compounds in deep-fried gluten balls was estimated by computing the GC peak area against that of the internal standard (I.S., naphthalene); the same amount of volatile compounds was assumed to have the same peak area. The response factor of all volatile compounds to the Flame Ionization Detector was assumed to be one. The amount of the volatile compounds in each sample was estimated using the following equation:

$$\text{ppb} = \frac{(\text{Area of target compd.} / \text{area of I.S.}) \times (\text{weight of I.S. added (g)})}{\text{Weight of deep - fried gluten balls used (g)} / 1{,}000{,}000{,}000} \quad (1)$$

8. Identification of Volatile Compounds

Identification of the volatile compounds in the isolate was based mainly on GC-MS. The structural assignment of volatile compounds was accomplished by comparing the mass spectral data of the samples with those of authentic compounds available from the Browser-Wiley computer library, the EPA/NIH data base [6, 7], the NBS computer library, TNO [13], or previously published literature [8, 11, 15]. Retention indices were used for the confirmation of the structural assignments.

In this study, each experiment was carried out twice. All data are expressed as the mean value of two determinations.

III. RESULTS AND DISCUSSION

1. Changes in Volatile Compounds Isolated from Deep-Fried Gluten Balls

Table 1 shows the volatile compounds isolated from the stored gluten balls obtained in the first-day and the twelfth-day frying. On the basis of functional groups, these volatile compounds were divided into eight groups: aldehydes, ketones, alcohols, furans, esters, pyrazines, acids, and hydrocarbons. In the fresh deep-fried gluten balls obtained in the first-day frying (GF-0), the major volatile compounds were 2,4-decadienal of the aldehyde group, 2-propylcyclopentanone of the ketone group, 1-octen-3-ol of the alcohol group, 2-pentylfuran of the furan group, 3-ethyl-2,5-dimethylpyrazine of the pyrazine group, and pentanoic acid and hexadecanoic acid of the acid group. The volatile esters could not be detected. The amount of the volatile hydrocarbons was only a trace.

The major volatile compounds of the aldehyde group isolated from the deep-fried gluten balls obtained in the first-day frying and subsequently stored for four and eight weeks (GF-4 and GF-8) were hexanal, E-2-octenal, nonanal, and 2,4-decadienal. The amounts of hexanal in the GF-0, GF-4 and GF-8 samples were 60.6, 10814.4, and 22390.0 ppb, respectively. The amounts of E-2-octenal in the GF-0, GF-4 and GF-8 samples were 284.9, 10901.2, and 34500.2 ppb, respectively. The amounts of 2,4-decadienal in the GF-0, GF-4 and GF-8 samples were 4973.5, 9489.2, and 16604.4 ppb, respectively. The variation in the amount of 2,4-decadienal during storage was less than those of hexanal and E-2-octenal. This result revealed that the larger molecular weight (MW) size aldehyde molecules, such as 2,4-decadienal, continued to undergo oxidation and were degraded and generated during storage. However, the rate of degradation was higher than that of generation, and therefore the smaller MW size aldehyde molecules, such as hexanal and E-2-octenal, accumulated more rapidly than 2,4-decadienal.

The major volatile ketones isolated from GF-4 and GF-8 samples were 3-octen-2-one and 2-propylcyclopentanone. The amounts of 3-octen-2-one in the GF-0, GF-4, and GF-8 samples were trace, 8569.1, and 18717.9 ppb, respectively. The variation in the amount of 3-octen-2-one was the largest in the ketone group during storage. The major volatile alcohols isolated from GF-4 and GF-8 samples were 1-pentanol and 1-octen-3-ol; the major volatile ester was pentyl hexanoate; the major volatile acids were E-2-hexenoic acid and octanoic acid; and the major volatile hydrocarbons were 4-nonyne and 1-undecene. The amounts of volatile aldehydes, ketones, alcohols, esters, acids, and hydrocarbons isolated from GF-4 and GF-8 samples were increased by increasing the storage time, and the amounts of volatile furans and pyrazines were decreased by increasing the storage time.

The major volatile compounds isolated from the fresh deep-fried gluten balls obtained in the twelfth-day frying (GL-0 sample) were 2,4-decadienal of the aldehyde group, 3-octen-2-one of the ketone group, 1-pentanol of the alcohol group, 2-pentylfuran of the furan group, 3-ethyl-2,5-dimethylpyrazine of the pyrazine group, and hexadecanoic acid of the acid group. After storage for four and eight weeks, the major volatile compounds isolated from the deep-fried gluten balls obtained in the twelfth-day frying (GL-4 and GL-8 samples) were hexanal, E-2-octenal, nonanal, and 2,4-decadienal of the aldehyde group and 3-octen-2-one and 2-propylcyclopentanone of the ketone group. The increment of volatile compounds was bigger in hexanal and E-2-octenal of the aldehyde group, 3-octen-2-one of the ketone group, 1-pentanol of the alcohol group, pentyl hexanoate of the ester group, octanoic acid of the acid group, and 4-nonye of the hydrocarbon group. The amounts of volatile aldehydes, ketones, alcohols, esters, acids, and hydrocarbons isolated from the stored deep-fried gluten balls (GL-4 and GL-8 samples) were increased by increasing the storage time, however, the amounts of volatile furans and pyrazines were decreased by increasing the storage time.

2. Changes in Volatile Compounds Isolated from Deep-Fried Gluten Balls Prepared with Addition of Glutamic Acid and Glucose

Table 2 shows the changes in the amounts of volatile

Table 1. Amounts of volatile compounds isolated from deep-fried gluten balls prepared in first-day and twelfth-day frying and stored for 4 and 8 weeks

	Amount (ppb)					
Compound	GF-0*	GL-0*	GF-4*	GL-4*	GF-8*	GL-8*
Aldehyde						
Propanal	n.d.**	n.d.	T***	n.d.	T	n.d.
Pentanal	105.6	130.4	1350.5	2720.8	3755.6	7915.8
trans-2-Hexenal	T	96.1	T	925.7	901.4	1290.7
Hexanal	60.6	55.1	10814.4	48555.1	22390.0	68953.4
E,E-2,4-Heptadienal	T	T	299.5	416.2	654.4	1321.9
E-2-Heptenal	445.3	284.0	2752.4	7557.6	4364.1	9653.9
cis-4-Heptenal	n.d.	T	T	T	T	T
Heptanal	432.3	612.2	1443.5	4675.4	2956.7	5436.0
E-2-Octenal	284.9	487.2	10901.2	24794.4	34500.2	57349.1
Octanal	T	172.1	2495.2	7128.5	6233.9	10142.4
E,E-2,4-Nonadienal	T	T	1001.5	1827.9	3801.5	4331.6
E-2-Nonenal	180.1	295.3	2428.8	2835.2	3200.9	5790.4
Nonanal	218.6	175.1	4558.0	8145.7	13482.0	18207.8
2,4-Decadienal	4973.5	8240.2	9489.2	17390.1	16604.4	19107.6
E-2-Decenal	284.5	T	3359.6	T	4328.3	797.7
Decanal	n.d.	469.7	197.0	3805.7	520.8	7039.8
2-Undecenal	n.d.	192.5	1320.7	3175.8	2873.5	4889.4
trans-2-Tridecenal	265.2	464.7	875.9	1748.9	3837.6	4617.3
subtotal	7250.6	11674.6	53287.4	135703.0	124405.3	226844.8
Ketone						
2-Hexanone	n.d.	57.7	T	133.5	T	671.8
2-Heptanone	73.8	141.4	1308.4	2583.3	1745.2	5590.1
3-Octen-2-one	T	473.1	8569.1	18009.7	18717.9	27832.6
2-Propylcyclopentanone	356.1	T	5744.8	7108.4	7017.0	13622.5
3-Octanone	T	149.3	370.7	580.2	810.7	1006.4
2,3-Octanedione	n.d.	n.d.	T	T	347.8	565.5
3-Nonen-2-one	n.d.	T	T	T	T	T
2-Decanone	n.d.	n.d.	1807.5	2347.8	3240.6	4091.6
6-Dodecanone	n.d.	T	566.8	T	972.1	836.2
2-Pentadecanone	n.d.	T	T	T	T	868.9
subtotal	429.9	821.5	18367.3	30762.9	32851.3	55085.6
Alcohol						
1-Butanol	T	T	T	524.6	210.9	1280.3
1-Pentanol	87.6	707.8	8321.4	17142.1	8864.7	28807.9
Isoamyl alcohol	n.d.	n.d.	n.d.	T	n.d.	475.7
1-Hexanol	n.d.	n.d.	262.5	821.9	731.5	1366.6
1-Heptanol	155.2	92.5	470.5	857.3	736.8	1934.7
1-Octen-3-ol	390.3	414.4	1979.3	5850.9	3607.8	6576.2
subtotal	633.1	1214.7	11033.7	25196.8	14151.7	40441.4
Furan						
2-Pentyl-furan	5220.4	8558.5	3220.4	5217.2	735.2	1735.1
subtotal	5220.4	8558.5	3220.4	5217.2	735.2	1735.1
Ester						
gamma-Octalactone	n.d.	n.d.	n.d.	130.5	T	494.2
gamma-Nonalactone	n.d.	n.d.	984.9	901.4	1390.1	2315.4
5-Hydroxy-2-decenoic acid lactone	n.d.	n.d.	n.d.	730.1	240.3	1033.4
gamma-Decalactone	n.d.	n.d.	T	250.3	463.3	676.9

Table 1. (continued)	Amount (ppb)					
Compound	GF-0*	GL-0*	GF-4*	GL-4*	GF-8*	GL-8*
Pentyl hexanoate	n.d.	n.d.	4776.2	7322.4	6064.1	8894.2
subtotal	0.0	0.0	5761.1	9334.7	8157.8	13414.1
Pyrazine						
2,5-Dimethylpyrazine	n.d.	T	n.d.	T	n.d.	T
3-Ethyl-2,5-dimethylpyrazine	333.6	860.6	130.4	334.2	n.d.	n.d.
subtotal	333.6	860.6	130.4	334.2	0.0	0.0
Acid						
Pentanoic acid	350.0	n.d.	452.2	1336.3	1413.9	2489.1
E-2-Hexenoic acid	n.d.	n.d.	1511.8	3368.6	4017.3	6642.2
Hexanoic acid	n.d.	n.d.	1842.8	2011.9	2803.5	3991.4
2-Heptenoic acid	T	n.d.	T	T	T	T
Heptanoic acid	n.d.	n.d.	451.9	684.7	2288.2	4751.9
2-Ooctenoic acid	n.d.	n.d.	T	2935.3	368.3	5029.8
Octanoic acid	n.d.	n.d.	1280.9	2379.2	3185.2	14773.4
Nonanoic acid	n.d.	n.d.	T	n.d.	n.d.	n.d.
Decanoic acid	n.d.	n.d.	235.6	1383.1	1355.6	1712.8
Hexadecanoic acid	350.0	232.4	303.5	720.1	764.5	1230.6
Oleic acid	T	n.d.	T	T	140.5	166.6
subtotal	700.0	232.4	6078.7	14819.2	16337.0	40621.2
Hydrocarbon						
Octane	T	n.d.	T	T	T	T
4-Nonyne	n.d.	T	4529.3	6754.2	10528.2	9022.4
2,5-Dimethyl octane	T	n.d.	n.d.	n.d.	n.d.	n.d.
1-Undecene	n.d.	n.d.	1181.8	1478.6	1922.4	2275.8
Tridecane	n.d.	n.d.	n.d.	n.d.	n.d.	T
Tetradecane	T	n.d.	n.d.	n.d.	T	T
Hexadecane	n.d.	n.d.	n.d.	n.d.	n.d.	T
Heptadecadiene	T	n.d.	n.d.	n.d.	n.d.	T
8-Heptadecene	T	n.d.	n.d.	n.d.	n.d.	n.d.
subtotal	0.0	0.0	5711.1	8232.8	12450.6	11298.2
total	14567.6	23362.3	103590.1	229600.8	209088.9	389440.4

* Samples refer to those indicated in Fig. 1.

** n.d.: not detected.

*** T: trace (< 0.05 ppb).

Table 2. Changes in amounts of volatile compounds isolated from deep-fried gluten balls prepared in first-day and twelfth-day frying with glutamic acid and glucose added and stored for 4 and 8 weeks

	Amount (ppb)					
Compound	MRGF-0*	MRGL-0*	MRGF-4*	MRGL-4*	MRGF-8*	MRGL-8*
Aldehyde						
trans-2-Pentenal	T**	T	T	T	T	T
Pentanal	196.9	218.7	1952.1	2917.9	4350.2	6954.5
trans-2-Hexenal	111.4	201.7	230.7	375.6	520.4	778.1
Hexanal	917.9	1184.7	16638.3	29746.4	44844.9	51577.1
Benzaldehyde	n.d.***	n.d.	n.d.	n.d.	n.d.	T
E-2-Heptenal	920.2	1636.4	3136.2	4709.9	5271.6	6941.3
cis-4-Heptenal	T	T	T	T	T	T
Heptanal	589.2	651.5	1515.8	1684.5	2468.2	4101.4
E-2-Octenal	410.6	912.3	19200.8	33851.6	47375.4	58312.1
Octanal	324.5	505.0	4240.8	5399.7	6543.2	8596.6

Table 2. (continued)

Compound	Amount (ppb)					
	MRGF-0*	MRGL-0*	MRGF-4*	MRGL-4*	MRGF-8*	MRGL-8*
E,E-2,4-Nonadienal	79.4	104.8	2387.9	7762.3	5338.3	12623.4
E-2-Nonenal	255.8	355.4	2229.1	2483.7	3704.7	4637.7
Nonanal	296.1	371.6	4677.5	14724.6	9052.5	16032.1
2,4-Decadienal	6279.7	8521.3	11969.3	19260.3	21058.7	38611.3
Decanal	n.d.	T	T	T	T	48.2
E-2-Decenal	730.5	866.4	2603.1	3802.6	4104.3	5107.9
2-Undecenal	177.4	202.9	2403.3	3695.1	5467.7	6643.6
trans-2-Tridecenal	290.5	315.1	779.4	1320.4	1791.3	3125.2
subtotal	11580.1	16047.8	73964.3	131734.6	161891.4	224090.5
Ketone						
2-Hexanone	n.d.	n.d.	n.d.	n.d.	n.d.	T
2,5-Hexanedione	n.d.	n.d.	T	n.d.	T	T
2-Heptanone	100.4	131.9	1280.7	1497.2	2853.9	3675.0
3-Octen-2-one	252.1	402.5	8251.3	13374.9	10602.1	22087.8
4-Octen-3-one	T	T	1165.6	2158.1	1365.4	3263.4
2-Propylcyclopentanone	T	T	2880.3	4126.4	3923.5	6878.4
3-Octanone	157.9	207.3	351.8	446.9	345.0	995.9
3-Nonen-2-one	T	T	553.5	849.5	1070.3	1316.4
2-Decanone	n.d.	n.d.	3035.2	4842.5	3317.9	6277.1
6-Dodecanone	n.d.	n.d.	230.7	465.2	385.0	632.5
2-Pentadecanone	n.d.	n.d.	T	T	T	T
subtotal	510.4	741.7	17749.1	27760.7	23863.1	45126.5
Alcohol						
1-Butanol	n.d.	n.d,	T	T	286.1	459.2
1-Pentanol	88.9	145.2	6845.9	7265.4	9560.9	15072.4
1-Hexanol	n.d.	n.d,	276.9	478.2	833.2	1323.9
1-Heptanol	176.2	253.8	470.4	630.2	788.6	1021.4
1-Octen-3-ol	728.5	905.2	2397.7	4083.5	2943.4	6020.1
subtotal	993.6	1304.2	9990.9	12457.3	14412.2	23897.0
Furan						
2-Pentyl-furan	2950.3	4433.5	1371.6	2771.5	T	52.6
subtotal	2950.3	4433.5	1371.6	2771.5	0.0	52.6
Ester						
Pentyl formate	n.d.	n.d.	n.d.	n.d.	n.d.	T
gamma-Octalactone	n.d.	n.d.	n.d.	554.3	T	1032.5
gamma-Nonalactone	n.d.	n.d.	n.d.	750.9	T	828.5
5-Hydroxy-2-decenoic acid lactone	n.d.	n.d.	n.d.	T	T	629.9
Pentyl hexanoate	n.d.	n.d.	7710.9	9309.7	8295.5	17311.4
subtotal	0.0	0.0	7710.9	10614.9	8295.5	19802.3
Pyrazine						
Methyl-pyrazine	53.6	T	n.d.	n.d.	n.d.	n.d.
2,5-Dimethylpyrazine	379.5	T	n.d.	n.d.	n.d.	n.d.
3-Ethyl-2,5-dimethylpyrazine	50.3	T	n.d.	n.d.	n.d.	n.d.
subtotal	483.4	0.0	0.0	0.0	0.0	0.0
Acid						
Pentanoic acid	n.d.	n.d.	1149.8	1839.8	1846.7	4183.3

Table 2. (continued)

Compound	Amount (ppb)					
	MRGF-0*	MRGL-0*	MRGF-4*	MRGL-4*	MRGF-8*	MRGL-8*
E-2-Hexenoic acid	n.d.	n.d.	644.4	2747.1	9751.6	14610.4
Hexanoic acid	n.d.	T	1135.5	2050.1	1240.3	3151.7
2-Heptenoic acid	n.d.	n.d.	T	T	T	T
Heptanoic acid	n.d.	n.d.	n.d.	2268.1	2034.5	4601.5
2-Octenoic acid	n.d.	n.d.	977.4	2502.7	2034.5	3071.5
Octanoic acid	n.d.	n.d.	970.9	1770.3	2290.6	4633.7
Decanoic acid	n.d.	n.d.	1067.3	1504.5	1274.5	1989.8
Hexadecanoic acid	339.5	427.9	760.3	847.5	1124.3	1275.6
Oleic acid	T	n.d.	n.d.	n.d.	n.d.	n.d.
subtotal	339.5	427.9	6705.6	15530.1	21597.0	37517.5
Hydrocarbon						
1-Hexene	T	T	n.d.	n.d.	n.d.	n.d.
2,3-Dimethyl-1-pentene	326.1	339.6	T	T	T	T
Octane	n.d.	n.d.	T	n.d.	T	T
4-Nonyne	n.d.	n.d.	7609.7	12573.1	12246.4	18945.2
2,5-Dimethyl octane	T	n.d.	n.d.	n.d.	n.d.	n.d.
1-Undecene	n.d.	n.d.	1075.4	1210.4	1783.5	2039.6
Tridecane	T	T	T	T	T	T
Tetradecane	56.9	99.7	T	T	T	T
Hexadecane	n.d.	n.d.	n.d.	T	T	T
Heptadecadiene	T	T	n.d.	n.d.	n.d.	n.d.
8-Heptadecene	T	n.d.	n.d.	n.d.	n.d.	n.d.
subtotal	383.0	439.3	8685.1	13783.5	14029.9	20984.8
total	17240.3	23394.4	126177.5	214652.6	244089.1	371471.2

* Samples refer to those indicated in Fig. 2

** T: trace (< 0.05 ppb)

*** n.d: not detected

compounds isolated from the deep-fried gluten balls prepared with the addition of glutamic acid and glucose during storage. The total amounts of volatile compounds in the MRGF-0, MRGF-4, and MRGF-8 samples were 17240.3, 126177.5, and 244089.1 ppb, respectively, whereas those in the MRGL-0, MRGL-4, and MRGL-8 were 23394.4, 214652.6, and 371471.2 ppb, respectively. These results showed that at the same storage time, the total amount of volatile compounds isolated from the deep-fried gluten balls obtained in the twelfth-day frying (MRGL samples) was larger than that of volatile compounds isolated from the balls obtained in the first-day frying (MRGF samples). It revealed that the volatile compounds continued to undergo oxidation during storage and generated more volatile compounds.

It was also found that the major volatile compounds isolated from the fresh deep-fried gluten balls prepared with the addition of glutamic acid and glucose (MRGF-0 and MRGL-0 samples) were 2,4-decadienal of the aldehyde group, 3-octen-2-one of the ketone group, 1-octen-3-ol of the alcohol group, 2-pentylfuran of the furan group, 2,5-dimethylpyrazine of the pyrazine group, hexadecanoic acid of the acid group, and 2,3-dimethyl-1-pentene of the hydrocarbon group. Volatile esters were not detected.

The major volatile compounds isolated from the stored deep-fried gluten balls prepared with the addition of glutamic acid and glucose (MRGF-4, MRGF-8, MRGL-4, and MRGL-8) were E-2-octenal and hexanal of the aldehyde group, 1-pentanol of the alcohol group, pentyl hexanoate of the ester group, E-2-hexenoic acid of the acid group, and 4-nonyne of the hydrocarbon group.

During storage the total amounts of volatile aldehydes were increased from 11580.1 ppb in the MRGF-0 sample to 161891.4 ppb in the MRGF-8, and from 16047.8 ppb in the MRGL-0 sample to 224090.5 ppb in the MRGL-8 sample. These results apparently showed that the total amount of volatile aldehydes was increased by increasing the storage time. This phenomenon also revealed the soybean oil used for frying and subsequently absorbed by the deep-fried gluten balls continued to undergo oxidation, resulting in the formation of oxidative products, especially volatile aldehydes.

It was also found that the amounts of smaller MW size aldehydes, such as pentanal, hexanal, and E-2-heptenal, in the

MRGL-4 and MRGL-8 samples were smaller than those in the GL-4 and GL-8 samples. It implied that the addition of glutamic acid and glucose could initiate the Maillard reaction and, therefore, its products could inhibit further oxidation of larger MW size aldehydes to generate smaller MW size aldehydes during storage.

The variation in the amount of volatile alcohols was also especially obvious in the case of 1-pentanol. The total amounts of volatile ketones and alcohols were increased by increasing the storage time. The amount of volatile furans was decreased by increasing the storage time. Volatile esters were not detected in the MRGF-0 and MRGL-0 samples, however, their amounts were increased by increasing the storage time. The amounts of volatile pyrazines were also decreased by increasing the storage time, possibly due to escape through evaporation during storage. The amounts of both volatile acids and hydrocarbons were increased by increasing the storage time.

3. Effect of Addition of Glutamic Acid and Glucose on Changes in Volatile Compounds from Deep-Fried Gluten Balls

Table 3 shows comparisons of the amounts of volatile compounds between the deep-fried gluten balls prepared with and without the addition of glutamic acid and glucose. It was found that the amounts of volatile aldehydes, ketones, alcohols, esters, acids, and hydrocarbons isolated from the balls were all increased by increasing the storage time, and the amounts of volatile furans and pyrazines were decreased by increasing the storage time.

By comparing the total amounts of volatile compounds in the GF, GL, MRGF, and MRGL samples, it was found that the total amounts of volatile compounds in the GF-0, GF-4, and GF-8 samples were 14567.6 103590.1, and 209088.9 ppb, respectively, and those in the GL-0, GL-4, and GL-8 samples were 23362.3, 229600.8, and 389440.4 ppb, respectively. The total amounts of volatile compounds in the GF samples were smaller than those in the GL samples. The total amounts of volatile compounds in the MRGF-0, MRGF-4, and MRGF-8 samples, 17240.3, 126177.5, and 244089.1 ppb, respectively, were also smaller than those in the MRGL-0, MRGL-4, and MRGL-8 samples, 23394.4, 229600.8, and 389440.4 ppb, respectively. These comparisons revealed that the deep-fried gluten balls did undergo oxidative deterioration and the extent of oxidation became greater as the frying time and storage time were increased.

A comparison of the total volatile compounds in the GF and MRGF samples indicated that the total amounts of volatile compounds isolated from the MRGF-0, MRGF-4, and MRGF-8 samples, 17240.3, 126177.5, and 2440891.1 ppb, respectively,

Table 3. Comparisons of amounts of volatile compounds in stored gluten balls

	Amount (ppb)					
Compound	GF-0*	GL-0*	GF-4*	GL-4*	GF-8*	GL-8*
Aldehyde	7250.6	11674.6	53287.4	135703.0	124405.3	226844.8
Ketone	429.9	821.5	18367.3	30762.9	32851.3	55085.6
Alcohol	633.1	1214.7	11033.7	25196.8	14151.7	40441.4
Furan	5220.4	8558.5	3220.4	5217.2	735.2	1735.1
Ester	0.0	0.0	5761.1	9334.7	8157.8	13414.1
Pyrazine	333.6	860.6	130.4	334.2	0.0	0.0
Acid	700.0	232.4	6078.7	14819.2	16337.0	40621.2
Hydrocarbon	0.0	0.0	5711.1	8232.8	12450.6	11298.2
Total	14567.6	23362.3	103590.1	229600.8	209088.9	389440.4

	Amount (ppb)					
Compound	MRGF-0**	MRGL-0**	MRGF-4**	MRGL-4**	MRGF-8**	MRGL-8**
Aldehyde	11580.1	16047.8	73964.3	131734.6	161891.4	224090.5
Ketone	510.4	741.7	17749.1	27760.7	23863.1	45126.5
Alcohol	993.6	1304.2	9990.9	12457.3	14412.2	23897.0
Furan	2950.3	4433.5	1371.6	2771.5	0.0	52.6
Ester	0.0	0.0	7710.9	10614.9	8295.5	19802.3
Pyrazine	483.4	0.0	0.0	0.0	0.0	0.0
Acid	339.5	427.9	6705.6	15530.1	21597.0	37517.5
Hydrocarbon	383.0	439.3	8685.1	13783.5	14029.9	20984.8
Total	17240.3	23394.4	126177.5	214652.6	244089.1	371471.2

*Samples refer to those indicated in Fig. 1

**Samples refer to those indicated in Fig. 2

were larger than those of the volatile compounds isolated from the GF-0, GF-4, and GF-8 samples, 14567.6, 103590.1, and 209088.9 ppb, respectively. Obviously, the aroma of MRGF samples could be enhanced by the Maillard reaction and/or caramelization between glutamic acid and/or glucose.

In the deep-fried gluten balls obtained in the twelfth-day frying (GL and MRGL samples), the total amounts of volatile compounds in the GL-0, GL-4, and GL-8 samples were 23362.3, 229600.8, and 389440.4 ppb, respectively, and those in the MRGL-0, MRGL-4, and MRGL-8 samples were 23394.4, 214652.6 and 371471.2 ppb, respectively. These results showed that the total amounts of volatile compounds in the GL and MRGL samples were increased by increasing the storage time. However, the total amounts of volatile compounds in MRGL-4 and MRGL-8 samples became smaller than those of the volatile compounds in GL-4 and GL-8 samples. These results reveals that the addition of glutamic acid and glucose could initiate the Maillard reaction and, therefore, its products could retard the oxidation of the frying oil in the deep-fried gluten balls during storage. Some studies have indicated that the products of Maillard reaction had antioxidant properties [5, 9, 10, 16]. This study also showed the products of the Maillard reaction between glutamic acid and glucose had an ability to retard the oxidative deterioration of the frying oil in the deep-fried gluten balls.

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