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The Assessment of Fatty Acid Composition in Deep-Fried Dough Sticks across Five Cities in China in 2020

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Abstract: Objective: To analyze and compare the concentrations and dietary intake of different fatty acids (FAs) in deep-fried dough sticks (Chinese fried bread) across various cities in China. Method: Sixty-one deep-fried dough stick samples were collected from five cities (Beijing, Shijiazhuang, Guangzhou, Chongqing, and Hangzhou), and the contents of FA monomers were determined using gas chromatography. Moreover, the dietary FA intake was estimated. Results: The mean FA concentration was 18.83 g/100 g (maximum, 41.59 g/100 g; minimum, 4.88 g/100 g). Polyunsaturated FAs (PUFAs) accounted for the highest proportion of the total FAs at 41.7% (7.86 g/100 g), followed by monounsaturated FAs (MUFAs) at 30.77% (5.79 g/100 g), saturated FAs (SFAs) at 26.27% (4.95 g/100 g), and trans-FAs (TFAs) at 1.18% (0.22 g/100 g). The Guangzhou deep-fried dough stick samples had a significantly different FA composition than those from the other cities, presenting with the highest concentration of SFAs (8.64 $\pm$ 4.74 g/100 g) and lowest concentration of PUFAs (5.01 $\pm$ 3.41 g/100 g). Beijing had the highest intake of PUFAs and MUFAs, whereas Guangzhou had the highest intake of SFAs. Conclusion: The contents and intake of saturated and unsaturated FAs in deep-fried dough sticks varied across the five cities in China. These results are useful for comparing the nutritional characteristics of deep-fried dough sticks in the different cities of China, thereby promoting further research on the relationship between deep-fried dough stick consumption and human health.

Keywords: deep-fried dough sticks; fatty acid composition; gas chromatography; China; fatty acid ratio; trans fatty acids

1. Introduction

Deep-fried dough sticks are a traditional Chinese breakfast food item served in cafeterias, food stalls, roadside eateries, and food factories. Although fried foods have a crispier texture and enhanced flavor, they contain more fatty acids (FAs) and fewer nutrients, particularly vitamins [1]. Deep-fried dough sticks are also frequently consumed in Indonesia, Laos, Malaysia, Thailand, Myanmar, and Singapore. As deep-fried dough sticks are considered a deep-fried food item, dietitians and public health advocates are concerned about the high levels of fat and trans-FAs (TFAs) in individuals who consume them.

Numerous studies have investigated the physiological necessity of dietary FAs as nutrients as well as the association between FA intake and the incidence of obesity, hypertension, and cardiovascular disease, which are major health issues in China. Although dietary FAs have various functions, such as providing energy for metabolism and forming the structural components of cellular membranes, their role in human nutrition remains unclear.

Traditional Chinese dietary patterns dominated by plant consumption have rapidly shifted to more Western patterns in recent years, one of them being an increased consumption of dietary FAs [2,3]. Another trend includes the shift from an extremely high-carbohydrate diet to a relatively high-fat diet characterized by an increase in the consumption of animal-based products; furthermore, population-based surveys have revealed a substantial increase in the energy contribution from fat from 12.0% in 1982 to 32.3% in 2010–2012 [2]. According to the Chinese Dietary Guidelines (2022), the recommended intake of cooking oil is 25 g/person/day; however, the current intake of cooking oil by residents (43.2 g/day) exceeds this level [4,5].

Saturated FAs (SFAs) are synthesized by the body and are therefore not required in the diet. Although studies have not revealed a strong association between SFA intake and human all-cause mortality, coronary heart disease (CHD), ischemic stroke, or diabetes, the total dietary intake of FAs and SFAs is directly proportional to the total cholesterol content in the human body. To reduce the incidence of cardiovascular and related chronic diseases, controlling the dietary intake of SFAs is essential [6]. This should be considered when establishing nutrient goals and recommendations.

TFAs are unsaturated FAs with at least one carbon double bond in the trans configuration. Most dietary TFAs are derived from the partial hydrogenation of vegetables or derived foods (dairy products and meat), but they are also produced when food items are fried in edible oil [7]. Industrially produced TFAs (IP-TFAs) are prevalent in fast food, margarine-containing snacks, and commercial baked goods, whereas ruminant TFAs (R-TFAs) are prevalent in meat and dairy products, accounting for 3–8% of the total fat content. High consumption of TFAs from industrial or natural sources has been shown to decrease high-density lipoprotein cholesterol (HDL-C) levels, increase low-density lipoprotein cholesterol (LDL-C) levels, and increase the risk of cardiovascular disease (CVD)-related morbidity and mortality [8]. The World Health Organization (WHO) has identified the elimination of IP-TFAs as a priority objective of its 13 general work programs and developed an action framework to provide a road map for eliminating IP-TFAs in several countries [9].

A risk assessment of TFAs in food items was conducted in China in 2011, wherein the TFA content in 13 categories of food items (including deep-fried dough sticks) was measured in samples collected from Xi'an, Chengdu, Beijing, Shanghai, and Guangzhou. The mean concentration of TFAs in deep-fried dough sticks was 0.31 g/100 g; however, considering the shift in the Chinese diet over the past 10 years, this assessment may not represent the current consumption patterns. To evaluate the current content and intake of FAs from deep-fried dough sticks in China, we determined the concentrations of various FAs in deep-fried dough stick samples collected from five cities in China, namely, Beijing, Shijiazhuang, Guangzhou, Chongqing, and Hangzhou, representing a population of 16,049 residents.

2. Materials and Methods

2.1. Reagents

A mixed-component standard containing 52 FAs (NU-CHEK GLC 674) was purchased from NU-CHEK (Shanghai, China), and conjugated linoleic acid was purchased from Sigma (Sigma40495-U, Shanghai, China). Hydrochloric acid (HCl), ethanol (C_2H_6O, 95% [*v*/*v*]), pyrogallic acid ($C_6H_6O_3$), sodium hydroxide (NaOH), methanol, heptane [$CH_3(CH_2)_5CH_3$], boron trifluoride (NaOH), met(C0495-(15% BF_3 [*w*/*w*] in methanol)), and sodium sulfate:anhydrous (Na_2SO_4) were all of analytical grade or higher in this study.

2.2. Sample Collection and Preparation

According to the China National Monitoring Handbook of Food Safety, big cities in the north, south, east, west, and center of China were chosen. A total of 61 deep-fried dough stick samples were collected from supermarkets, local markets, restaurants, street vendors, and fast-food chains in the five cities in 2020. All samples made by wheat flour dough were fried for 3 min in 180–200 °C edible oil. Food samples were analyzed in the local laboratories of the five cities. All laboratories used the same analysis procedures, and training was provided before the analysis. Overall, the whole process followed timely sampling, rapid transportation, complete information, and safe storage. After sample collection, the samples were refrigerated or frozen based on their actual condition to avoid the oxidation of grease. Before the test, 500 g of deep-fried dough stick samples were evenly pulverized by a food processor (BRAUN 3205, Magyarország) according to WHO Laboratory Protocol [10], to get finely ground and homogenized test samples. After weighing the homogenized test portion (containing ca. 200 mg fat), transferred into a labeled flask, we added ca. 100 mg pyrogallic acid and 10 mg C11:0 TAG (internal standard, IS). Then, it was uniformly divided and placed in brown glass bottles that were sealed, labeled, and stored at −80 °C before the hydrolysis of sample and fat extraction.

2.3. Sample Hydrolysis

Based on the characteristics of the deep-fried dough sticks, we used the acid hydrolysis method to hydrolyze the samples. The hydrolysis of FAs was based on the national standards GB 5009.257-2016 [11] and GB 5009.168-2016 [12] with minor modifications. A uniform sample of 5.0 g was weighed and transferred into a 250 mL flat-bottled flask with 2.0 mL of the internal standard solution of triglyceride undecanoate, 100 mg of pyrogallic acid, 2 mL of 95% ethanol, and 4 mL of zeolite solution, and the contents were mixed well. A total of 10 mL of hydrochloric acid was added and hydrolyzed in a 70 °C water bath for 40 min with shaking every 10 min. When the hydrolysis was complete, the flask was removed and cooled to room temperature.

2.4. Fat Extraction and Methylation

After hydrolysis, 10 mL of 95% ethanol was added and then transferred to the separation funnel. The test tube was washed with 50 mL ether, added to the funnel, shaken for 5 min, and allowed to stand for 10 min. Finally, the organic layer was collected into the flask. After repeating the above steps thrice, the solvent was concentrated and removed by a rotary evaporator, and the residue was the fat extract.

Next, we added 8 mL of 2% sodium hydroxide–methanol solution to the fat extract, connected it to a reflux condenser, and refluxed it in an 80 °C water bath until the oil droplets disappeared. Then, we added 7 mL of 15% boron trifluoride–methanol reagent from the top of the reflux condenser and refluxed it for 2 min in an 80 °C water bath. The flask was quickly cooled to room temperature; 20 mL of n-heptane was added and shaken for 2 min, followed by the addition of saturated sodium chloride solution. After standing stratification, the upper n-heptane extract was absorbed into a 15 mL test tube, and 4 g of anhydrous sodium sulfate was added and shaken for 1 min. The tube was allowed to stand for 5 min, and the upper solution was added into the sample bottle to be tested.

Briefly, the samples were acid-hydrolyzed to remove fat from the food matrix and then treated with n-hexane to extract fat according to AOAC official method 996.06, AOCS official method Ce 1h-05, and WHO guidelines [13–15]. Approximately 1.0 g of deep-fried dough sticks, which would yield 200 mg of fat, was weighed, and fat extraction was performed via acid hydrolysis. The FA methyl ester (FAME) solution contained approximately 21 mg/mL hexane. A membrane with a 0.2 μM pore size was used to filter the solution, following which the filtrate was tested.

2.5. Gas Chromatography Analysis of FAMEs

The detection method was based on AOAC 996.06, AOAC 2012.13, WHO Laboratory Protoco, and WHO guidelines with minor modifications [10,13–15]. In order to detect and measure all the fatty acids present in samples at levels ≥0.1% of total fatty acids, optimization of the amount of extracted fat and the internal standard (IS) C11: 0 TAG, modification of the GC operating parameters and replacement the carrier gas had been carried out.

We optimized the amount of extracted fat and the internal standard (IS) C11: 0 TAG, modified the GC operating parameters and replaced the carrier gas. C11:0 triglyceride IS was used as the internal standard, and separation was performed using a Shimadzu gas chromatograph GC2010, equipped with a flame ionization detector (FID) and autosampler, and a capillary column CPTM-Sil88 (100 m × 0.25 mm × 0.2 µm). For the extraction of fat and IS, the weight of the representative homogenized composite subsample yielded 200 mg of fat, and its corresponding C11: 0 TAG added was 10 mg. After transmethylation, the FA methyl ester (FAME) solution contained approximately 21 mg/mL hexane. Polydicyanopropyl siloxane was used as the polar stationary phase, and the injector and detector temperatures were set to 270 °C and 280 °C, respectively. Elution was performed under the following conditions. The initial column temperature was 100 °C for 16 min, and the subsequent steps were as follows: (1) Increase the temperature at a rate of 10 °C/min to 175 °C and maintain it for 15 min; (2) Increase the temperature at a rate of 1 °C to 195 °C and maintain it for 13 min; (3) Increase at a rate of 5 °C/min to 230 °C and maintain it for 22 min. Helium was used as the carrier gas with a flow rate of 0.65 mL/min, split ratio of 100:1, and injection volume of 1 µL. Single and mixed standard FAME solutions were used to characterize the chromatographic peaks after the injection of FA standard solution and sample solution into the gas chromatograph. A correction factor was incorporated based on the response area under the chromatographic peak of the standard solution. In this study, 87 fatty acid isomers were analyzed in food samples.

2.6. Calculation of FA Composition

FAMEs were identified and quantified based on the peak time, and the areas of FAMEs were identified and quantified based on the peak time and area relative to the standard solution. We referred to the atlas in the WHO Global FA Detection Programme for identifying FAMEs without standards. In total, 87 FAs were identified and quantified.

The SFA, MUFA, PUFA, and total fat contents; FAME; and response factor for each component are shown in Table S1. The relative mass fraction of the components of TFA methyl ester, TFA mass fraction in fat, FA mass fraction in food, and TFA mass fraction in food are shown in Table S2.

2.7. Intake Assessment of FAs in Deep-Fried Dough Sticks

The data of 2012 Chinese residents' TFA assessment were used to analyze their TFA intake at baseline, whereas the data of the 2020 Chinese residents' food consumption survey were used to analyze the TFA intake in 2020.

A 3-day recall-based nutrition survey of 16,049 adult residents in the five cities was conducted to assess their dietary intake. Intake of different FAs in deep-fried dough sticks was calculated according to the following equation:

$$\textit{Intake}\ (\mathrm{g/d}) = \textit{deep-fried dough sticks consumption}\ (\mathrm{g/d}) \times \textit{FA concentration in deep-fried dough sticks}\ (\mathrm{g/g}) \quad (1)$$

2.8. Data Analysis

Excel 2016 and SPSS software (version 21.0, IBM Corporation, New York, NY, USA) were used for data sorting and statistical analyses. All measurements were obtained from at least two replicates and expressed as mean ± standard deviation. One-way ANOVA was used to determine the statistics among multiple groups. Least significant difference was used to analyze the homogeneity of variance [16]. Dunnett's test was used to analyze variance heterogeneity. In addition, *p* values of <0.05 were considered to indicate statistical significance.

3. Results

3.1. Method Establishment

Figure 1 shows the complete chromatogram (A) and segmented spectrum of the FAs present in the reference standard. Figure 1B depicts the C4:0-C18:0 interval, Figure 1C depicts the C18:16 t–C23:0 interval, and Figure 1D indicates the C22:2–C22:6n3 interval. Overall, 87 FA monomers, including 21 SFAs, 18 MUFAs, 16 PUFAs, and 32 TFAs, were successfully separated and identified. Each FA component was adequately separated at the baseline level with the expected peak sequence and retention time.

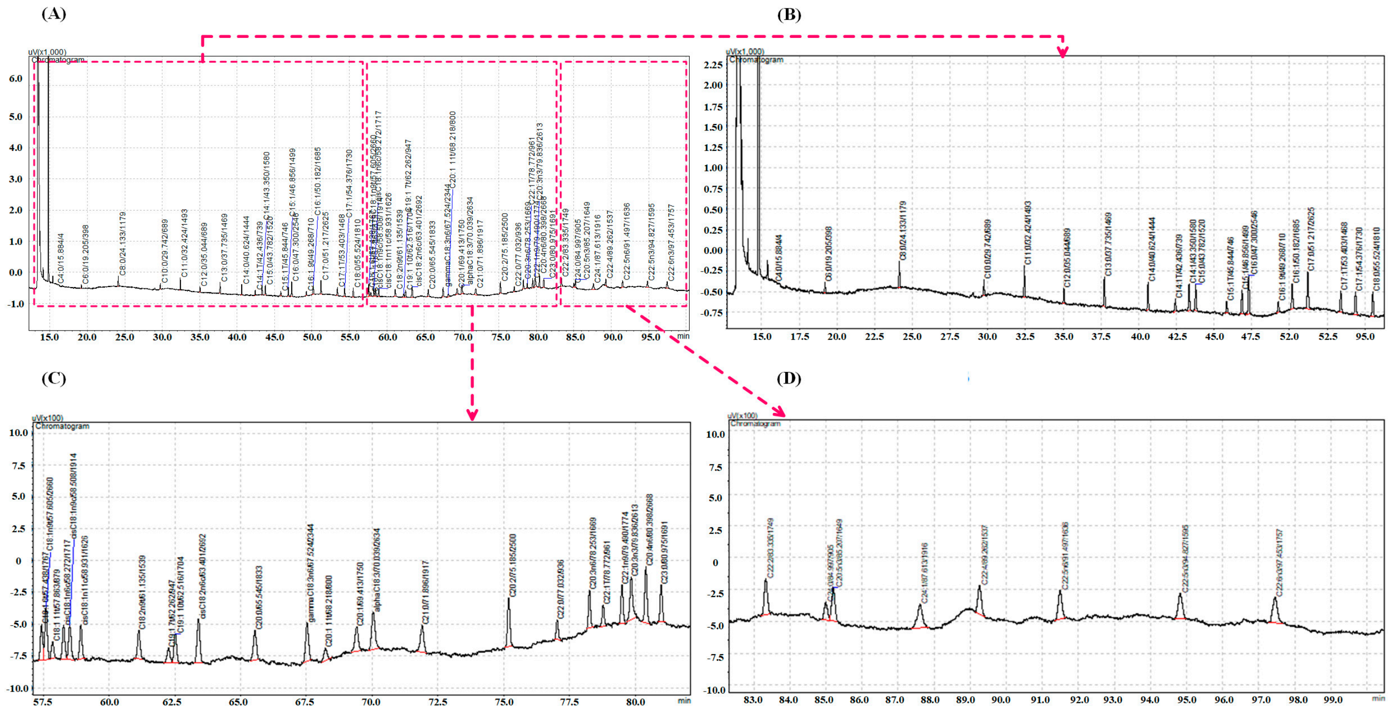

Figure 1. Segmented spectrum of the FA profiles. Overview of the of 52 FA profiles (**A**); (C4:0–C18:0) (**B**); (C18:16t–C23:0) (**C**); and (C22:2–C22:6n3) (**D**).

3.2. FA Content in Deep-Fried Dough Sticks

The mean value of total FAs in 61 deep-fried dough stick samples was 18.83 g/100 g, the maximum value was 41.59 g/100 g, and the minimum value was 4.88 g/100 g, respectively (Table 1). PUFAs accounted for the highest proportion of total FAs at 41.7% (7.86 g/100 g), whereas the proportion of MUFAs and SFAs was 30.8% and 26.3 %, respectively. The mean proportion of TFAs was 1.18% (0.22 g/100 g).

Table 1. MUFA, PUFA, TFA, SFA, and total FA contents (g/100 g) in deep-fried dough stick samples.

Category	Subclass	N	Mean	Min	Max	P25	P50	P75	P95
Total fatty acids	MUFA	61	5.80	1.96	19.413	3.33	5.25	6.83	13.12
	PUFA	61	7.86	0.88	13.642	5.41	7.75	10.46	13.13
	TFA	61	0.22	0.02	0.734	0.12	0.21	0.29	0.45
	SFA	61	4.95	2.00	17.840	3.00	3.83	5.70	11.63
	total FA	61	18.84	4.88	41.589	14.27	19.51	23.45	27.34

There were significant differences in FA content in different cities (Figure 2, Table S3). For example, the PUFA content in Guangzhou (5.01 g/100 g) was different from that in

Chongqing (9.48 g/100 g) and the PUFA content in Beijing (8.97 g/100 g) (Figure 2A). The MUFA content in Shijiazhuang (3.69 g/100 g) was different from that in Guangzhou (7.24 g/100 g), Chongqing (6.52 g/100 g), and Beijing (6.19 g/100 g), respectively (Figure 2B). The SFA content in Guangzhou (8.64 g/100 g) was approximately twice that in other cities (Beijing: 4.23 g/100 g, Shijiazhuang: 4.05 g/100 g, Hangzhou: 4.13 g/100 g, Chongqing: 3.62 g/100 g) (Figure 2C). No significant differences were observed among the five cities with respect to the TFA content (Figure 2D). In addition, compared with the other cities, the lowest level of total FA content was shown in Shijiazhuang (14.41 g/100 g) (Figure 2E).

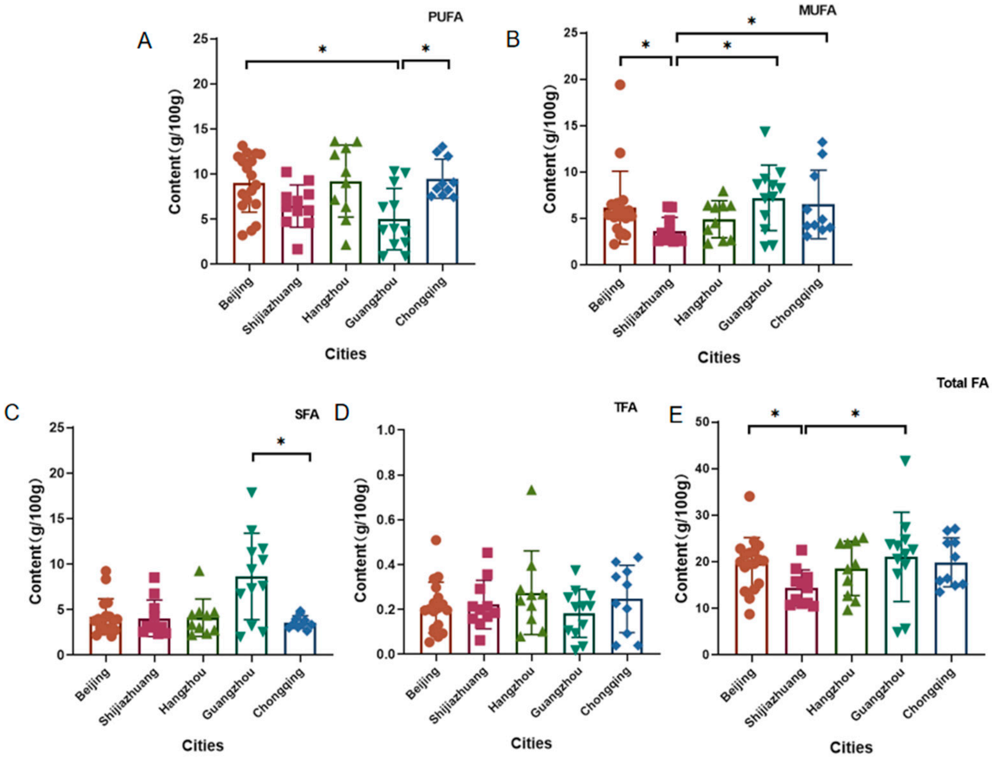

Figure 2. Contents of PUFA (**A**), MUFA (**B**), SFA (**C**), TFA (**D**), and total FA (**E**) in deep-fried dough stick samples from the five cities. * = $p < 0.05$.

The SFA, MUFA, and PUFA contents in deep-fried dough stick samples were approximately 9 g/100 g, 7 g/100 g, and 5 g/100 g, respectively. The ratio of PUFAS:MUFAs:SFAs (P:M:S) was 0.6:0.8:1 in Guangzhou, which was much lower than that in other cities, such as Chongqing (2.6:1.8:1) (Table 2). This indicates differences in the production process or the frying oil used in these cities.

Table 2. FA ratio in Beijing, Shijiazhuang, Hangzhou, Guangzhou, and Chongqing.

Region	FA Ratio				
	P:S	M:S	P:M	P:M:S	ω-6/ω-3
Beijing	2.1	1.5	1.5	2.1:1.5:1	12.58
Shijiazhuang	1.6	0.9	1.7	1.6:0.9:1	14.44
Hangzhou	2.2	1.2	1.9	2.2:1.2:1	12.08
Guangzhou	0.6	0.8	0.7	0.6:0.8:1	14.79
Chongqing	2.6	1.8	1.4	2.6:1.8:1	9.81

The main component of SFA in samples from Guangzhou was C16:0, accounting for approximately two-thirds of the SFA composition, which suggests that the frying oil in Guangzhou may be mixed with a plant oil with a high C16:0 ratio, such as palm oil (Table 3).

Table 3. Content of SFAs C12:0, C14:0, and C16:0 in the deep-fried dough stick samples from different regions (g/100 g).

Region	Subclass	N	Mean	Min	Max	P25	P50	P75	P90
Beijing	C12:0	18	0.01	<0.01	0.04	<0.01	<0.01	0.02	0.03
Beijing	C14:0	18	0.04	0.01	0.14	0.01	0.02	0.06	0.13
Beijing	C16:0	18	2.80	1.12	7.66	1.66	2.32	2.84	6.94
Shijiazhuang	C12:0	11	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01
Shijiazhuang	C14:0	11	0.04	0.01	0.12	0.01	0.02	0.06	0.11
Shijiazhuang	C16:0	11	2.75	1.22	6.97	1.33	2.01	4.08	6.55
Hangzhou	C12:0	10	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	0.02
Hangzhou	C14:0	10	0.03	0.01	0.15	0.01	0.02	0.02	0.14
Hangzhou	C16:0	10	2.68	1.16	7.68	1.51	2.37	2.87	7.20
Guangzhou	C12:0	12	0.02	<0.01	0.06	0.01	0.02	0.03	0.05
Guangzhou	C14:0	12	0.1s	0.01	0.28	0.03	0.11	0.24	0.26
Guangzhou	C16:0	12	5.56	0.02	15.28	1.67	5.54	9.12	13.02
Chongqing	C12:0	10	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Chongqing	C14:0	10	0.03	0.01	0.07	0.02	0.02	0.03	0.07
Chongqing	C16:0	10	2.63	1.52	6.40	1.87	2.13	2.86	6.11

3.3. TFA Content in Deep-Fried Dough Stick Samples across Different Cities

The TFA contents of C18:2 and C18:3 were approximately 3.3 and 3.9 times higher than that of C18:1, respectively. Table 4 shows the comparison between the contents of several key TFAs in deep-fried dough stick samples from different cities. Among the deep-fried dough stick samples from five cities, the Guangzhou samples showed the highest C18:1 content, whereas the Hangzhou and Chongqing samples showed the highest C18:2 and C18:3 contents, respectively.

Table 4. TFA composition in deep-fried dough stick samples (g/100 g).

TFA Composition	Overall Mean	Beijing	Shijia Zhuang	Hang Zhou	Guang Zhou	Chong Qing
∑transC18:1	0.027	0.018 ± 0.011 *	0.031 ± 0.033	0.021 ± 0.020 *	0.051 ± 0.065	0.013 ± 0.017 *
∑transC18:2	0.090	0.089 ± 0.049	0.090 ± 0.038	0.119 ± 0.093 *	0.070 ± 0.044	0.090 ± 0.042
∑transC18:3	0.106	0.101 ± 0.065	0.099 ± 0.064	0.135 ± 0.089 *	0.062 ± 0.064	0.149 ± 0.111 *
Other monomeric TFA	0.000	0.000	0.000	0.000	0.000	0.000
N	61	18	11	10	12	10

Note: * indicates a significant difference compared with the Guangzhou group ($p < 0.05$).

As shown in Figure 3, Δ9t was the main component of trans C18:1 TFAs in deep-fried dough stick samples, accounting for 37.9% of the trans C18:1 TFA composition. The monomer content of tent0t in the Guangzhou deep-fried dough stick samples was found to be higher than those in the samples from other cities. The main components of trans C18:2 TFAs in the deep-fried dough stick samples were Δ9c and 12t (50.9%) and Δ9t and 12c (43.1%). Moreover, the trans C18:3 TFAs in the deep-fried dough stick samples were mainly composed of Δ9c, 12t, 15t + Δ9c, 12c, and 15t (48.9%) and Δ9t, 12c, and 15c (39.2%).

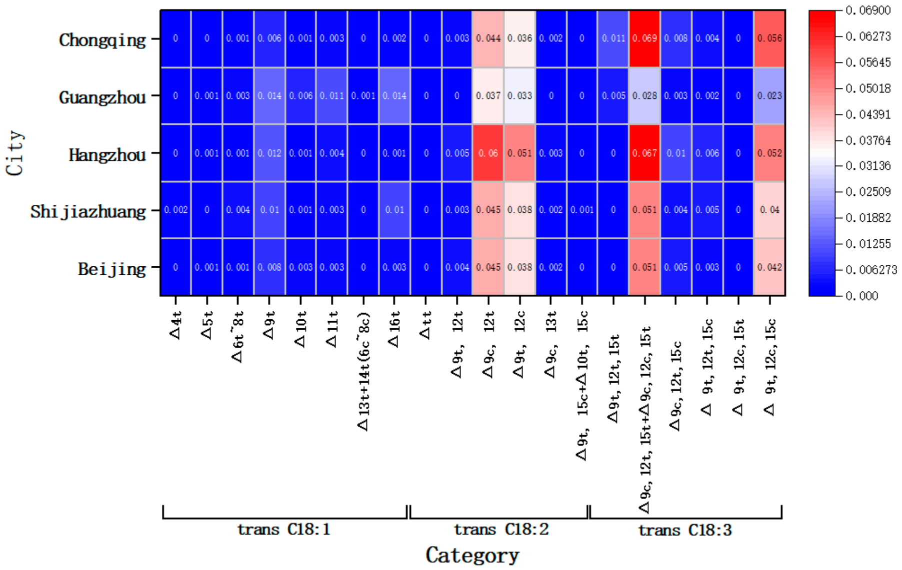

Figure 3. Trans C18:1, C18:2, and C18:3 contents in the deep-fried dough stick samples (g/100 g).

3.4. Intake of FAs via Deep-Fried Dough Stick Consumption in the Five Cities

Deep-fried dough stick consumption in Beijing and Guangzhou, along with the estimated exposures to SFAs and MUFAs in Beijing, Shijiazhuang, Hangzhou, Guangzhou, and Chongqing, is shown in Figure 4. Beijing residents showed the highest intake of PUFAs (5.35 g/day/person) and MUFAs (3.69 g/day/person) via deep-fried dough stick consumption, whereas Guangzhou residents showed the highest SFA intake (2.71 g/day/person). Furthermore, deep-fried dough stick consumers in Shijiazhuang and Hangzhou showed the highest TFA intake (0.13 g/day/person).

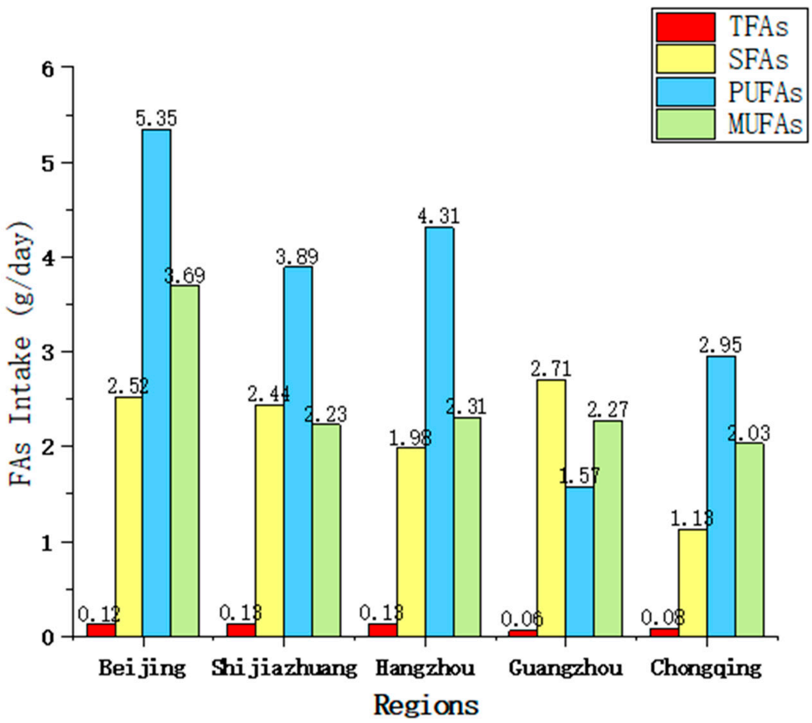

Figure 4. An assessment of exposure to different FAs through deep-fried dough stick consumption in five cities.

3.5. Comparison of TFA Contents in Deep-Fried Dough Sticks between 2012 and 2020

As shown in Table 5, the mean and maximum TFA contents in deep-fried dough sticks declined by 40.9% and 79.9%, respectively, between 2012 and 2020.

Table 5. Comparison of TFA contents in the deep-fried dough stick samples between 2012 and 2020.

Years	N	TFA		
		Mean	Median	Max
2012	42	0.31	0.13	3.64
2020	61	0.22	0.21	0.73

4. Discussion

4.1. FA Content in Deep-Fried Dough Stick Samples

The SFA, MUFA, PUFA, and TFA contents varied across different cities. Notably, the SFA content in Guangzhou was found to be considerably higher than that in other cities. Moreover, the FA contents were quite different across the five cities, as indicated by the ratios of different FAs.

The total fat content in deep-fried dough stick samples varied between 15% and 20%. However, individual samples from Guangzhou and Beijing exceeded the recommended value of 30 g/100 g, with contents of 41.58 g/100 g and 30.04 g/100 g, respectively. These higher values may be attributed to the different manufacturing processes and/or excessive use of oil across the cities.

The SFA content in deep-fried dough stick samples varied across cities, with Guangzhou samples having the highest content. In Guangzhou, the C16:0 content was high at 5 g/100 g, indicating that palm oil was predominantly used for the cooking. Considering the potential adverse health effects, the intake of SFAs from deep-fried dough sticks must be reduced in all regions. More specifically, exposure to FAs in Guangzhou could be reduced by substituting unhealthy frying oil with a healthier alternative.

The proportion of PUFAs and MUFAs in deep-fried dough stick samples was higher than that of SFAs. Studies have shown that the consumption of plant-derived MUFAs exerts a protective effect against CHD [17–19]. Among the 61 deep-fried dough stick samples, MUFAs accounted for 30.8% of the total FA content, whereas PUFAs accounted for the highest proportion of total FA content in deep-fried dough stick samples, with an average of 41.7% (7.86 g/100 g) and a maximum of 9.48 g/100 g in Chongqing.

At the same time, we should not only consider the composition of FAs in foods, such as deep-fried dough sticks, but also take into account that deep-fried dough sticks are made using flour that is deep-fried in edible oil at a high temperature. Moreover, a Maillard reaction may occur during the reprocessing, resulting in the end products of glycosylation that are harmful to the human body and have a potential impact on human health [20,21]. It has been observed that temperature and time both affect the Maillard reaction, and when the temperature increases by 10 °C, the Maillard reaction rate increases at least twofold [22].

There is growing evidence regarding the link between TFA intake from hydrogenated vegetable oils and mortality [23]. In a randomized clinical trial, the reduction in TFA intake over a year was associated with a reduced number of LDL particles (a novel marker of CVD risk) [24]. Oh et al. revealed that TFA intake was positively associated with the incidence of diabetes, with a 39% greater risk in high quintiles than in low quintiles [25]. R-TFA intake was low in the majority of the population. Brouwer et al. compared six randomized controlled trials of R-TFAs with twenty-nine trials of industrial FAs and revealed that the effect of R-TFAs on the increase in the LDL and HDL ratios was slightly less than that of IP-TFAs without any significant difference, and both increased the risk of CHD [26].

The TFA content in samples collected across the five cities in the current study was consistently low (0.21 g/100 g) and significantly decreased (29%) compared with that in samples collected in 2011. This reduction indicates that the food industry has played an effective role in controlling the TFA content in deep-fried dough sticks.

As expected, Δ9t and Δ11t of trans C18:1 were more prevalent in deep-fried dough stick samples, accounting for 37.86% and 17.26% of trans C18:1 TFAs, respectively. Interestingly, the total content of C18:2 or C18:3 trans isomers was considerably higher than that of C18:1 trans isomers in all samples, except for the Guangzhou samples, which may be because the frying oils used in other cities are rich in PUFAs, such as soybean or rapeseed oil, whereas palm oil may be used in Guangzhou.

4.2. FA Ratio in Deep-Fried Dough Stick Samples

The ratio of SFAs to unsaturated FAs in food items or oil may play an important physiological role. Replacing dietary SFAs with PUFAs can effectively reduce the risk of cardiovascular and cerebrovascular diseases and even death [27,28]. The ratio of PUFAs, MUFAs, and SFAs was reported to be 1.1:1.5:1 in urban and rural residents. The Chongqing deep-fried dough stick samples had the highest ratios. Notably, the mean P:M:S ratio in all deep-fried dough stick samples was 0.6:0.8:1, except for the Guangzhou samples that showed a considerably lower ratio.

The differences in FA content and FA ratios between cities may be caused by the differences in the use of edible oil between cities. Studies have observed that the types of edible oils vary in different regions, and the composition of FAs in different edible oils also varies [29]; for example, the content of TFAs in soybean oil and corn oil is higher, whereas it is lower in olive oil and sunflower oil [29]. Huang et al. observed that the oil samples from Northern China had higher TFA levels [30]. The content of corn oil is low in Guangdong and high in Hebei. Furthermore, the content of TFAs in oils and fats from Zhejiang is relatively low [29].

The balance of ω-6/ω-3 polyunsaturated fatty acids is important for cardiovascular health. Many studies have shown that when ω-6/ω-3 polyunsaturated fatty acids is four, the total mortality rate of people will be reduced by 70%. When it reaches 10, it will bring adverse consequences to human health. When it reaches 15 to 16.7, it will promote the incidence of many diseases [31]. Our previous survey of edible vegetable oil consumption of residents in Beijing in 2020 found that the ratio of ω-6/ω-3 fatty acids in the vegetable oil intake of Beijing residents was relatively high (the data have not been published). The present study shows that the consumption of deep-fried dough sticks by different city residents will also cause different ω-6/ω-3 ratios. Long-term excessive intake of a high ω-6/ω-3 diet may affect human health, and we should monitor the health effects of residents' intake in future.

4.3. Evaluation of FAs in Different Cities

In general, the total fat intake from deep-fried dough sticks contributes to approximately 50% of the daily intake of edible oil recommended by dietary guidelines, corresponding to 7–10 g of daily fat consumption, with values as high as 12 g/day in Beijing. The intake of different FAs varied across cities. For example, both PUFA and MUFA intakes in Guangzhou were lower than those in Beijing, which may be related to deep-fried dough stick consumption.

With the introduction of the REPLACE action framework in 2018, the WHO proposed the global eradication of IP-TFAs by 2023 and recommended a reduction in TFA consumption (corresponding to <1% of the total energy intake); thus, the TFA intake from deep-fried dough sticks remains a concern. For instance, Shijiazhuang residents showed an intake of 0.13 g/day, accounting for approximately 6% of the recommended TFA consumption (corresponding to <1% of the total energy intake), whereas Guangzhou residents showed an intake of 0.06 g/day, accounting for 3% of the recommended TFA consumption.

5. Conclusions

The composition of FAs in deep-fried dough sticks varies across cities, indicating that the difference of composition can have a significant impact on product quality, and the use of oil with a high SFA content, such as palm oil, may contribute to a high SFA exposure.

TFA exposure is also associated with consumption patterns, indicating that the intake by some consumers, such as Beijing residents, is primarily influenced by high consumption rates. Although the TFA content in deep-fried dough sticks decreased between 2012 and 2020, its consumption through deep-fried dough sticks remains a concern. These results can be useful for estimating the total intake of various FAs by residents in different regions of China, thereby promoting healthy food consumption among consumers.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/pr11113254/s1, Table S1: FA calculation formulas; Table S2: Formulas for the calculation of TFAs; Table S3: Comparison of FA content of deep-fried dough stick samples from five cities (g/100 g).

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