Are Chinese Edible Oils Safe? A Survey of Trans Fatty Acid Contents in Chinese Edible Oils

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Abstract Nine different edible oil types from 7 cities in China were analyzed. Trans fatty acid (TFA) contents in edible oils were determined, TFA distribution characteristics were analyzed, and a risk assessment was performed. Total TFA contents varied from 0.075 ± 0.011 to 2.243 ± 0.770 g/100 g of oil, with a mean content of 0.66 g/100 g of oil. TFA contents differed among different oil types and among different cities. Generally speaking, oil samples from northern areas of China contained more TFA, and lard usually had higher levels of TFA than other oils. An exposure assessment showed that the estimated daily intake of TFA from Chinese edible oils was low, and a risk assessment indicated that there was a low risk for TFA consumption in Chinese edible oils.

Keywords: edible oil, trans fatty acid, risk assessment

Introduction

Trans fatty acids (TFAs) are unsaturated fatty acids with 1 or more non-conjugated double bonds in a trans conformation (1). TFAs are mostly produced using industrial hydrogenation and partially from bio-hydrogenation in the rumen of ruminants (2). Unlike other dietary fats, TFAs are neither essential nor salubrious and are, in fact, harmful to human health. Reports have demonstrated that intake of high levels of TFAs can increase the risk of cardiovascular disease (CVD) (3), cancer, obesity, diabetes (4) and even allergies (2). Therefore, TFA safety evaluation of foods has attracted public attention.

Variations in TFA amounts in foods from Western countries have been reported (1,2) in recent decades. However, in China, current TFA contents and TFA risk management have seldom been reported. In addition, Chinese food safety issues have occurred frequently in recent years, affecting consumer confidence both at home and abroad. Both governmental and food industry practitioners have made great efforts to ensure food safety and improve food quality. Therefore, scientific surveys of TFA contents in Chinese foods and risk assessments are of great importance.

Edible oils, the most commonly used ingredient in Chinese traditional cooking, should never be overlooked. Hou *et al.* (5) made an assessment of TFA contents in Chinese edible oils in 2011 based on a total of 93 samples collected from a single city, which did not represent the entire situation in China. Consequently, in this study, 165 oil samples were collected from 7 cities in China for study of TFA contents, and an exposure assessment and a risk assessment were performed for evaluation of the safety and quality of oil products.

Materials and Methods

Oil sample collection and preparation Commonly consumed edible oils from 9 different sources as a total of 165 samples including rapeseed oil (RSO), tea oil (TO), soybean oil (SBO), peanut oil (PNO), salad oil (SO), corn oil (CO), lard (L), palm oil (PO), and blended oil (BO) were purchased from supermarkets in Harbin, Lanzhou, Chongqing, Wuhan, Shijiazhuang, Guangzhou, and Nanjing, located in different areas of China. Harbin and Shijiazhuang are located in the southeast, Lanzhou is located in the southwest, Chongqing is located in the northwest, Wuhan is located in the middle, Guangzhou is located in the north, and Nanjing is located in the east near the ocean. Three product brands were collected for each oil type in each city. Manufacture dates of oils were in the same year within a 3-month period. Oil samples were stored in clean opaque bottles at room temperature prior to analysis.

The American Oil Chemists' Society (AOCS) (6,7) method for determination of TFA contents in foods was used with minor modification. An amount of 1.5–2.0 mg of oil and 10 μ L of a 4.5 mg/mL internal standard (C21:0) (Sigma-Aldrich, St. Louis, MO, USA), were dissolved in 1.5 mL of n-hexane (Aladdin Reagents, Shanghai, China). Then, 40 μ L of methyl acetate (Aladdin Reagents) and 100 μ L of methanolic sodium methoxide (Aladdin Reagents) were added and allowed to react at 65°C for 40 min for formation of fatty acid methyl esters (FAME).

FAME profiles were determined using an Agilent 6890N capillary gas chromatograph (Agilent Technologies, Santa Clara, CA, USA) equipped with a flame ionization detector (FID). A CP-Sil88 capillary

column (100 m×0.25 mm×0.2 µm) (Varian-Chrompack, Middelburg, The Netherlands) was used (5). The injector temperature was 250°C and 1.0 µL of an oil sample was injected into the GC. The temperature program was 45°C for 4 min, increased by 13°C/min to 175°C, then increased by 4°C/min to 215°C. Conditions for the FID detector were 250°C and flow rates for H₂, air, and N₂ were 30.0 mL/min.

Individual FAME species were identified based on comparison of retention times with corresponding GLC-463 reference oil samples (Nu-Chek-Prep, Elysian, MN, USA). Quantification was achieved using internal standards (Sigma-Aldrich). Oil samples contained few TFA isomers and only contents of 9*t* C16:1, *trans* C18:1, and 9*t*12*t* C18:2 were calculated. Each *trans* C18:1 variety did not completely separate leading to calculation as a whole. The sum of the 3 isomer contents was calculated as the total TFA content.

All values are shown as a mean and standard deviation (SD) of 3 replicates. Statistical analysis was performed using the analysis of variance (ANOVA) function of SPSS 11.5 (IBM, Chicago, IL, USA) for Windows. Significance was defined as $p < 0.05$.

Exposure assessment for edible oils in China Crystal Ball was used for assessment of exposure conditions for total TFA for oils in this study. Estimated Daily Intake (EDI) values of total TFA values in oils were calculated as (8):

$$EDI = \frac{Cf \times PTR \times ABS \times EF \times ED}{AT \times 100}$$

where Cf is the total TFA content (%) and PTR is the average daily consumption of edible oils per person. The PTR value in 2010 was approximately 0.0414 kg/person/day (8). The absorption coefficient (ABS) is usually=1 (8). The exposure frequency (EF) indicates days of oil consumption per year, and is usually=365 days/year (8). The exposure duration (ED) is considered as a lifetime. The average lifetime for Chinese residents was 69.63 years for males and 73.33 years for females in 2009 (8,9). The averaged time (AT) value was calculated as: AT=ED year×365 day/year.

TFA risk assessment for Chinese edible oils A risk assessment model was first established including hazard identification, does-response assessment, exposure assessment, and risk characterization (9). Then Crystal Ball was used for calculation of the hazard quotient (HQ) as (10):

$$HQ = \frac{Cf \times PIR \times ABS \times EF \times ED}{AT \times RfD \times 100}$$

where RfD is a TFA reference dosage calculated based on reported World Health Organization statistics (8). The RfD value for TFA in 2003 was 2.2 g/person/day (8,11).

An HQ value <1 indicated that the total TFA intake from Chinese edible oils did not reach a critical value (8), indicating no risk for TFA consumption. Otherwise, there was a risk for TFA consumption and the higher the HQ value, the higher the risk.

Results and Discussion

TFA contents in different oils from different cities A summary of TFA contents (g/100 g of oil) of all oil samples is shown in Table 1. TFAs were detected in all oil samples with total concentrations varying from 0.075±0.011 to 2.243±0.770 g/100 g of oil with a mean content of 0.66±1.009 g/100 g of oil. Most oil samples contained less than 2 g/100 g of oil, except lard from Guangzhou at 2.227±0.391 g/100 g of oil and soybean oil from Shijiazhuang at 2.243±0.770 g/100 g of oil. In all, 49.0% of oil samples exhibited a TFA content of less than 0.3 g/100 g of oil, while oil samples with TFA contents between 0.5–1.0 g/100 g of oil and between 1.0 and 2.0 g/100 g of oil constituted approximately 23.6% of all oil samples.

TFA contents differed among different sources and among different cities. Detailed TFA content distribution characteristics and a comparison of TFA contents among different cities (A) and among different oils (B) are shown in Fig. 1. Rapeseed oil, tea oil, and salad oil purchased from different cities exhibited no significant ($p < 0.05$) differences in total TFA contents (Fig. 1A). However, soybean oil, peanut oil, and blended oil from Shijiazhuang contained significantly ($p < 0.05$) more TFAs than oils from other cities with mean concentration values of 2.243±0.770, 1.632±1.541, 1.979±2.082 g/100 g of oil, respectively. The TFA content in corn oil from Chongqing of 1.932±0.072 g/100 g of oil was significantly ($p < 0.05$) higher than corn oils from other cities. Lard obtained from Wuhan, with a TFA content of 0.141±0.086 g/100 g of oil, had the lowest TFA content. Lard from Harbin at 1.989±0.279 g/100 g of oil, Lanzhou at 1.671±0.196 g/100 g of oil, and Guangzhou at 2.227±0.391 g/100 g of oil had significantly ($p < 0.05$) higher TFA contents than lard samples from other cities. Palm oil from Wuhan, with a TFA content of 0.103±0.019 g/100 g of oil, also exhibited the lowest TFA content of oils from Wuhan, while blended oil from Shijiazhuang at 1.979±2.082 g/100 g of oil exhibited the highest TFA content.

Generally speaking, oils with a high TFA content were usually from northern areas. Light industries, such as food processing and textiles are developed in the prosperous southern part of China; while heavy industry dominates the northern areas of China. Therefore, oil production techniques in northern cities may not be as well developed or as efficient as in southern cities and this might account for higher TFA contents in oils from northern cities. Lard from Guangzhou had the highest TFA content of all oil samples.

Wuhan, Shijiazhuang, and Nanjing oil samples showed no significant ($p > 0.05$) differences in TFA contents (Fig. 1B). In Harbin, lard and palm oil had the highest (1.989±0.279 g/100 g of oil) and the second highest (1.617±0.033 g/100 g of oil) TFA contents among Harbin oil samples. In Lanzhou, lard and palm oils contained significantly ($p < 0.05$) higher TFA contents than other Lanzhou oil types with mean concentration values of 1.671±0.196 and 1.498±0.341 g/100 g of oil, respectively. The TFA content in Chongqing corn oil at 1.932±0.072 g/100 g of oil ranked highest among all Chongqing oil samples. The TFA content in Lanzhou lard at 1.671±0.196 g/100 g

Table 1. TFA contents in oil samples

(unit: g/100 g of oil)

	9t C16:1	<i>trans</i> C18:1	9t 12t C18:2	Total <i>trans</i>
Rapeseed oil (RSO)				
Lanzhou	ND ¹⁾	0.123±0.099	0.012±0.010	0.135±0.109
Chongqing	0.002±0.001 ²⁾	0.118±0.044	0.007±0.001	0.127±0.050
Guangzhou	ND	0.079±0.016	0.010±0.004	0.088±0.014
Nanjing	ND	0.185±0.059	0.008±0.001	0.193±0.055
Tea oil (TO)				
Lanzhou	ND	0.098±0.041	0.008±0.001	0.106±0.041
Shijiazhuang	ND	0.670±0.056	0.017±0.002	0.687±0.058
Guangzhou	ND	0.511±0.046	0.009±0.001	0.520±0.657
Nanjing	0.015±0.013	1.176±0.349	0.116±0.095	1.307±1.203
Soybean oil (SBO)				
Harbin	ND	0.073±0.006	0.002±0.001	0.075±0.011
Lanzhou	ND	0.073±0.008	0.008±0.003	0.081±0.011
Chongqing	ND	0.497±0.726	0.069±0.101	0.567±0.827
Wuhan	ND	0.127±0.023	0.041±0.042	0.169±0.037
Shijiazhuang	ND	1.986±0.706	0.257±0.065	2.243±0.770
Guangzhou	ND	0.091±0.014	0.004±0.003	0.095±0.011
Nanjing	ND	0.675±0.989	0.097±0.121	0.772±1.110
Peanut oil (PNO)				
Harbin	ND	0.093±0.019	0.003±0.006	0.096±0.025
Lanzhou	ND	0.116±0.027	0.009±0.004	0.126±0.028
Chongqing	ND	0.083±0.043	ND	0.083±0.043
Wuhan	ND	0.122±0.050	0.017±0.007	0.139±0.048
Shijiazhuang	ND	1.507±1.419	0.125±0.122	1.632±1.541
Guangzhou	ND	0.094±0.003	0.008±0.002	0.103±0.005
Nanjing	0.029±0.051	0.861±1.108	0.073±0.081	0.964±1.163
Salad oil (SO)				
Harbin	ND	0.091±0.021	0.007±0.002	0.097±0.020
Lanzhou	ND	0.077±0.015	0.007±0.001	0.084±0.014
Chongqing	ND	0.472±0.689	0.060±0.09	0.532±0.778
Shijiazhuang	ND	0.200±0.07	0.028±0.002	0.228±0.072
Guangzhou	ND	0.116±0.008	0.017±0.003	0.133±0.058
Nanjing	ND	0.497±0.181	0.046±0.020	0.542±0.199
Corn oil (CO)				
Harbin	ND	0.120±0.042	0.032±0.022	0.152±0.063
Lanzhou	ND	0.149±0.076	0.041±0.010	0.190±0.085
Chongqing	ND	1.720±0.017	0.212±0.011	1.932±0.072
Wuhan	ND	0.664±0.936	0.098±0.105	0.762±1.040
Shijiazhuang	0.020±0.008	1.315±1.237	0.173±0.129	1.508±1.339
Guangzhou	ND	0.108±0.003	0.021±0.002	0.129±0.031
Nanjing	0.010±0.008	0.852±0.691	0.177±0.039	1.039±0.722
Lard (L)				
Harbin	0.064±0.009	1.849±0.258	0.076±0.017	1.989±0.279
Lanzhou	0.060±0.021	1.536±0.165	0.075±0.022	1.671±0.196
Chongqing	0.030±0.017	0.573±0.429	0.019±0.014	0.622±0.460
Wuhan	0.010±0.006	0.126±0.077	0.005±0.004	0.141±0.086
Shijiazhuang	0.098±0.085	0.942±0.437	0.023±0.003	1.063±0.507
Guangzhou	0.107±0.037	2.037±0.339	0.084±0.016	2.227±0.391
Nanjing	0.069±0.03	0.953±0.237	0.021±0.019	1.043±0.248
Palm oil (PO)				
Harbin	ND	1.562±0.032	0.056±0.002	1.617±0.033
Lanzhou	ND	1.459±0.334	0.039±0.012	1.498±0.341
Chongqing	ND	0.534±0.763	0.022±0.034	0.556±0.797
Wuhan	ND	0.098±0.013	0.005±0.001	0.103±0.019
Shijiazhuang	0.250±0.039	0.461±0.020	0.030±0.003	0.741±0.062
Guangzhou	ND	0.854±1.184	0.032±0.055	0.886±1.239

Table 1. Continued

(unit: g/100 g of oil)

	9t C16:1	<i>trans</i> C18:1	9t 12t C18:2	Total <i>trans</i>
Blended oil (BO)				
Harbin	ND	0.101±0.016	0.009±0.002	0.110±0.019
Lanzhou	ND	0.153±0.101	0.022±0.033	0.175±0.134
Chongqing	ND	0.574±0.841	0.050±0.074	0.624±0.915
Wuhan	0.005±0.001	0.158±0.025	0.018±0.009	0.181±0.031
Shijiazhuang	ND	1.779±1.861	0.200±0.221	1.979±2.082
Guangzhou	ND	0.104±0.104	0.010±0.010	0.114±0.021
Nanjing	ND	1.227±0.066	0.148±0.064	1.375±0.109

¹ND, not detected²Means from different cities with a different superscript a, b, c in the same column were significantly different ($p < 0.05$).

Fig. 1. Comparison of TFA contents. (A) Comparison of TFA contents for different cities; (B) Comparison of TFA contents for different oil types. A univariate ANOVA and Tukey's test were used for analysis of significant differences. Different letters or letter combinations on each bar indicate significant differences among different cities (A) or oils (B) ($n=3$, $p < 0.05$).

of oil was significantly ($p < 0.05$) higher than for other Chongqing oils. Generally speaking, lard contained more TFAs, mainly due to techniques of manufacture.

TFA Exposure assessment for edible oils in China Crystal Ball was used for a complete assessment of EDI values of total TFAs in Chinese edible oils.

Probability distribution of total TFA contents in Chinese edible oils A probability distribution of Cf values for TFAs was determined for evaluation of the daily TFAs intake. The results showed that total TFA contents in Chinese edible oils fitted a Gamma distribution with location=0.075, scale=1.340, and shape=0.437.

TFA exposure assessment for Chinese edible oils Determination of

(A) total TFA EDI values based on edible oil consumption followed the Monte Carlo method. The results showed that PIR, ABS, and EF values fitted a constant distribution, Cf fitted a Gamma distribution, ED and AT values fitted a uniform distribution, and CDI fitted a forecast index. An estimate of daily TFAs intake is shown in Fig. 2. The mean EDI value for total TFAs in Chinese edible oils was 2.71×10^{-4} and the median value was 1.25×10^{-4} . EDI values at different percentiles were 2.63×10^{-5} (0%), 3.45×10^{-5} (10%), 4.30×10^{-5} (20%), 6.08×10^{-5} (30%), 8.42×10^{-5} (40%), 1.25×10^{-4} (50%), 1.86×10^{-4} (60%), 2.72×10^{-4} (70%), 4.12×10^{-4} (80%), 7.01×10^{-4} (90%), and 2.86×10^{-3} (100%). Thus, EDI values for TFAs contents in Chinese edible oils were low.

Sensitivity analysis of the assumption Sensitivity analysis is used for estimation of the contribution of factors related to a forecast item on the final assessment. Here, the factors taken into consideration were the exposure concentration (Cf), the exposure duration (ED) and the average year (AT). Crystal Ball was then used for evaluation of the contribution of these factors.

Cf had the highest sensitivity for the CDI value of total TFAs in edible oils, with a ratio of 99.37%, indicating that Cf was the main factor contributing to daily intake of TFAs among Chinese consumers. The exposure duration and the average year had contribution values of 0.27 and 0.36% respectively, indicating that an increase in ED or AT values would generate a slight rise for the EDI value of total TFAs in Chinese edible oils.

TFA risk assessment for Chinese edible oils

TFA hazard identification: TFAs can enter human tissues via the normal fatty acid metabolic pathway and can cause adverse effects on the lipid metabolism, leading to physiologic effects on the human body, including both lipid and non-lipid effects (12). Lipid effects include metabolism disorders of lipid and apolipoprotein, and non-lipid effects include insulin resistance, systemic inflammation, endothelial dysfunction, and adiposity.

TFAs can increase serum LDL-C and decrease HDL-C levels (12), thereby increasing the ratio of LDL-C to HDL-C, which is associated with an increased risk of cardiovascular disease (CVD). A previous

Fig. 2. EDI forecast of total TFAs in Chinese edible oils

Fig. 3. HQ forecast of total TFAs in Chinese edible oils

study (13) with 140,000 participants showed that for every 2% increase in TFAs intake, a 23% increase in the incidence of myocardial infarction and CVD death results. Additionally, an increasing amount of evidence suggests that TFAs intake can cause weight gain and fat accumulation, particularly visceral fat. On an isocaloric basis (11), weight gain caused by TFAs consumption was approximately 3-4x more than weight gain caused by saturated fatty acid consumption, and 7x more than weight gain caused by total fat consumption. Evidence from clinical research has proved an association of type 2 diabetes incidence with TFAs consumption (1,4). TFAs probably interfere with cell membrane functions and there are reasons to believe that high levels of TFAs intake can affect insulin sensitivity and, consequently, increase the diabetes risk (13). Christiansen *et al.* (14) reported that, compared with monounsaturated fatty acids, dietary TFAs intake caused a significantly elevated postprandial insulin response.

The main factors that cause higher TFAs levels in edible oils are: 1) edible oil refining, 2) hydrogenation of vegetable oils, and 3) inappropriate cooking methods. A number of substances, such as free fatty acids, phospholipids, carbohydrates, and proteins, that are present in natural vegetable oils, can cause changes in color, aroma, and taste of oils, which restrict oil applications and reduce product shelf-life. Therefore, oils should be refined to remove these substances.

Generally speaking, oil refining includes degumming, neutralization, bleaching, and deodorization steps. Oils are usually heated to temperatures between 60 to 100°C before deodorization, then the temperature is increased to 180-270°C in a deodorization step, which leads to formation of TFAs (15). Tasan and Demirci (16) reported that TFA contents in oils increased 13.8x after refining.

Hydrogenated oil, due to a good consistency and melting in the mouth, has been frequently used in the food industry. Hydrogenation is based on reaction of unsaturated fatty acids of vegetable oil in the presence of a catalyst. High selectivity hydrogenation can cause a reduction in formation of saturated fatty acids. Therefore, a low hydrogen pressure, a moderate stirring speed, and a high temperature

are often used in the hydrogenation process that, in turn, leads to formation of TFAs (15). Chinese traditional cooking methods usually include sautéing and frying. However, high temperature processes increase TFA contents in oils and foods. Therefore, original TFA contents in edible oils should be controlled to a low level.

TFA dose-response assessment in Chinese edible oils: TFA intake can affect the ratio of LDL/HDL in the human body (17) and a dose-dependent response exists between the percentage of TFA intake and the LDL/HDL ratio. Increased consumption of TFAs caused the LDL to HDL ratio to increase (16).

Hazard quotient assessment of TFAs in Chinese edible oils: Assessment of the hazard quotient (HQ) was based on the Monte Carlo method. The mean HQ value for total TFAs in Chinese edible oils was 0.14, the median was 0.07, and HQ values at different percentiles were 0.01 (0%), 0.02 (10%), 0.02 (20%), 0.03 (30%), 0.04 (40%), 0.06 (50%), 0.09 (60%), 0.13 (70%), 0.21 (80%), 0.34 (90%), and 1.35 (100%) (Fig. 3). At percentiles ranging from 0% to 90%, forecast HQ values were all <1, indicating a low risk for TFAs consumption in Chinese edible oils.

Uncertainty analysis of TFA risk assessment in Chinese edible oils: Uncertainty of TFA risk assessment in Chinese edible oils was due to different factors. Differences between human populations may not have been considered. Reference RfD dosage values used for assessment should be current, but values used in this study needed to be updated. Hence, this risk assessment study of TFAs in Chinese edible oils should be considered as a reference point for current TFA distributions and as a forecast of TFA risks in Chinese edible oils.

TFA contents in 165 edible oil samples from 7 cites in China were evaluated in this study. Total TFA concentrations varied from 0.075 ± 0.011 to 2.243 ± 0.770 g/100 g of oil with a mean content of 0.66 g/100 g of oil. Only 2 oil samples contained more than 2 g of TFA/100 g of oil. Generally speaking, lard contained more TFAs than other oils. Exposure assessment showed that the mean EDI value for total TFAs in Chinese edible oils was low at 2.71×10^{-4} . Among all factors considered in evaluation of EDI values of total TFAs in edible oils, the exposure concentration (Cf) had the strongest contribution.

In addition, risk assessment demonstrated that there was a low risk for TFA consumption in Chinese edible oils.

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