Investigating the amount of TFAs, CLAs and $\omega 6/\omega 3$ of various brands of corn oil heated at different time–temperature treatments

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Abstract A qualitative and quantitative analysis of *trans* fatty acids (TFAs), conjugated linoleic acids (CLAs) and linoleic acid/ α -linolenic acid ($\omega 6/\omega 3$) in eleven different brands of fresh and heated corn oil was investigated. Corn oil was subjected to thermal treatment at 180, 210 and 230 °C for 4, 8 and 12 h. The kinds of fatty acids were almost the same in all eleven brands of corn oil, but there were differences in the quantities of TFAs, CLAs and $\omega 6/\omega 3$ among the brands. The formation of TFAs in different brands of corn oil increased slowly at 180 °C and rapidly at 230 °C with the maximum increase of 28 and 374%, respectively. The formation of CLAs also increased during the heating with the amount of 0.00–0.32 g/100 g in fresh corn oil and 0.71–1.12 g/100 g in corn oil heated at 230 °C for 12 h. The value of $\omega 6/\omega 3$ was high in corn oil and increased with heating temperature and time. The largest rise of $\omega 6/\omega 3$ can reach upwards of 239:1. The results showed that temperature control was essential for maintaining the quality and nutritional value of corn oil.

Keywords Corn oil · *Trans* fatty acids · Conjugated linoleic acids · The ratio of linoleic acid to α -linolenic acid · Heating

Introduction

Corn oil plays an important role in our daily diets and is highly recommended as healthy cooking oil by World Health Organization. It contains unsaturated fatty acid up to about 80%. Among them, linoleic acid ($\omega 6$) and α -linolenic acid ($\omega 3$) are essential fatty acids of human body (Gu and Yu 2012). During the refining and deep-fat frying processes, unsaturated fatty acids in corn oil undergoes isomerization leading to the formation of *trans* fatty acids (TFAs) and conjugated linoleic acids (CLAs).

Besides industrial refining process, TFAs are also commonly formed under domestic or commercial cooking conditions, increasing with cooking temperature and time (Tsuzuki et al. 2010). Excessive consumption of TFAs is suggested to increase the incidence of coronary heart disease, cardiovascular disease (Ganguly and Pierce 2012). Due to their detrimental effects, some countries have attempted to increase consumer awareness of TFAs in processed oils by displaying TFAs content on product labels. However, China only requires companies to display TFAs amounts present in food that contains hydrogenated or partially hydrogenated oils or fats, not including vegetable oils (GB 28050 2011), so the amount of TFAs in fresh and heated corn oil on market is unclear and needs to be further investigated.

CLAs are primarily found in meat and dairy products from ruminant mammals, but have also been detected in sunflower, rapeseed and peanut oils (Juaneda et al. 2001). CLAs composed of all-*trans* and *cis/trans* CLA isomers

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have been shown to have prevention of cardiovascular disease effect (Wang et al. 2012). Guo et al. (2015) further confirmed that the CLAs formed from trilinolein at 180 °C were identified as C18:2,9*c*11*t*, C18:2,10*t*12*c* and *t,t*-CLAs (C18:2,9*t*11*t*, C18:2,10*t*12*t*), and that the amount and variety of CLAs formed increased with temperature and time. However, the concentrations and specific identities of CLAs in corn oil have not yet been fully elucidated.

The ratio of $\omega 6/\omega 3$ in edible oils has also gained considerable attention in recent years since increase in $\omega 6/\omega 3$ can result in chronic inflammatory diseases (Patterson et al. 2012). Food and Agriculture Organization of the United Nations recommends that the $\omega 6/\omega 3$ in daily diets should be between 5:1 and 10:1. Vegetable oils in particular serve as one of the main sources of $\omega 6$ and $\omega 3$. Results of these studies emphasize the importance of quantifying $\omega 6/\omega 3$ in both fresh and heated corn oil, which can provide consumers with practical information on healthful eating and provide basic data for manufacturers or researchers developed $\omega 6/\omega 3$ balanced blend oil.

According to previous investigation and study, cooking and frying temperature are generally between 180 and 230 °C (Liu 1993). The purpose of this study was to analyze changes in the identities of fatty acids found in eleven different brands of fresh and heated corn oil and to evaluate the effect of heating temperature and time on the formation of TFAs and CLAs as well as the changes of $\omega 6/\omega 3$. Together these results may provide important nutritional information and basic data related to corn oil for consumers, manufactures and researchers.

Materials and methods

Materials

Standards for the C18:2 isomers, C18:3 isomers and conjugated linoleic methyl ester mixture (No. O5632) were purchased from Sigma-Aldrich (St. Louis, MO). Mixed standards GLC-674 and undecane acid triglycerides were purchased from NU-CHEK Prep. Isooctane was obtained from Fisher Scientific (Fair Lawn, NJ). The eleven brands of corn oil were purchased from Beijing supermarkets (Ten brands of corn oil were produced in China and brand F was imported from America). All other analytical grade solvents and chemicals were purchased from commercial sources. Silicone oil (viscosity 500 cSt) was obtained from Dinye Industrial Co., Ltd. (Beijing, China).

Thermal processing procedures

Each sample of corn oil (300 mg) was transferred to a 4 mL micro-glass ampoule, which was then sealed in the

presence of air by melting the top with a propane-oxygen flame. Heating experiments were carried out at 180, 210, and 230 °C for 4, 8 and 12 h in micro-glass ampoules. Temperature control of silicone oil in digital constant temperature oil bath pot (HH-S, Changzhou Guohua Electric Co., Ltd., Jiangsu, China) during heating was accurate to ± 2 °C. The unheated corn oil is defined as fresh corn oil. The glass ampoules were removed from the silicone oil at regular time intervals and samples were analyzed after cooling to room temperature.

Preparation of fatty acid methyl esters

The corn oil samples were subjected to derivatization according to the method of our previous study (Guo et al. 2015). Each sample (200 mg) was weighed out in a stoppered centrifuge vial. Then 2 mL of isooctane dissolved undecane acid triglycerides (the internal standard, 4000 ppm, total of 8 mg) was added into the vial, followed by 0.10 mL of 2 mol/L methanolic KOH. The mixture was shaken vigorously for 30 s and then centrifuged at 4000 rpm for 10 min. The supernatant layers were removed and dried over anhydrous magnesium sulfate.

GC-FID analysis

The supernatant layer (20 μ L) of corn oil samples after derivatization was diluted to 1 mL with isooctane and analyzed using a GC-2010 chromatograph (Shimadzu, Kyoto, Japan) equipped with a CP-SIL 88 fused silica capillary column (100 m $\times$ 0.25 mm $\times$ 0.2 μ m) and a flame ionization detector. The initial temperature of 60 °C was maintained for 5 min and then increased to 160 °C at a rate of 25 °C/min. After a time interval of 5 min at 160 °C, the temperature again increased at a rate of 2 °C/min to reach a final temperature of 225 °C. The sample was kept at this final temperature for 16 min. The injection volume was 1 μ L with a split ratio of 1:10. Nitrogen gas (99.999%) was used as the carrier gas with a flow rate of 6.3 mL/min. The detector flow rates for makeup, hydrogen and air are 30, 40 and 400 mL/min, respectively. The injection and detector temperatures were both 250 °C. Fatty acids were identified by comparing their retention time to known standards, using a calculation method from Li et al. (2012). Accurate quantification of the fatty acids concentrations was dependent on the absence of chemical interactions between the molecules.

Statistical analysis

Experiments were performed in triplicate according to a completely randomized design. Sigmaplot 12.0 software (Systat Software Inc., San Jose, CA, USA) was used for all

data plots. Statistically significant differences between samples at different time and temperature were determined as $P < 0.05$ by Duncan's multiple range tests using SPSS (Version 16.0, SPSS Inc., Chicago, IL, USA).

Results and discussion

Fatty acids composition in corn oil

The gas chromatogram of fatty acid methyl esters in fresh and heated corn oil (brand G) is shown in Fig. 1. All the fatty acids detected in the corn oil samples were adequately separated and identified by comparison to the retention time of known standards. Fresh corn oil contained seven saturated fatty acids and twelve unsaturated fatty acid and their contents are shown in Table 1. Three new kind of TFAs (C18:2,9*t*12*t*, C18:3,9*t*12*t*15*c* and C18:3,9*t*12*c*15*t*) and one of CLAs (C18:2,9*c*11*t*) were detected in heated corn oil (Table 2). The formation of new kind of TFAs and CLAs at different heating temperature–time showed that the different brands of corn oil have different isomerization stabilities, especially towards long time at high temperatures.

Quantitative analysis of TFAs in corn oil

Quantitative analysis of TFAs in fresh corn oil

As shown in Fig. 2a, the amount of TFAs was different while the average concentration of TFAs was 1.47 g/100 g in the eleven brands of fresh corn oil. These results were consistent with Ferrari et al. (1996), who reported that the TFAs content in refined corn oil comprised 1.5% of the total fatty acids content. The average levels of *trans* 18:1, *trans* 18:2 and *trans* 18:3 fatty acids in fresh corn oil were 0.02 g/100 g, 0.92 g/100 g, and 0.62 g/100 g, respectively. These results indicate that *trans* C18:2 fatty acids are the main *trans* isomers formed in corn oil, which agrees with the results of Hou et al. (2012).

The concentration of TFAs in brand I (2.21 g/100 g) was the highest amongst all the fresh corn oil tested, exceeding the limit (2.00 g/100 g) imposed by some European countries. The second highest concentration of TFAs was found in brands C and G, followed by, in order of decreasing concentration, brand J, brands A and H, brand E, brands F and K and brands B and D. The lowest TFAs concentrations found in brands B and D were 0.84 g/100 g and 0.82 g/100 g, respectively. The differences of

Fig. 1 Gas chromatogram of fatty acids methyl esters in fresh and heated corn oil (brand G)

Table 1 The content of fatty acids in eleven brands of fresh corn oil (g/100 g)

Fatty acids	Brand A	Brand B	Brand C	Brand D	Brand E	Brand F	Brand G	Brand H	Brand I	Brand J	Brand K	Average content
Cl4:0	ND	0.02 ± 0.00	ND	0.01 ± 0.00	ND	0.01 ± 0.00	ND	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.02 ± 0.00	0.01 ± 0.00
Cl6:0	11.99 ± 0.43	14.49 ± 0.23	11.84 ± 0.30	12.06 ± 0.17	11.94 ± 0.89	11.44 ± 0.43	12.13 ± 0.11	13.50 ± 0.25	12.84 ± 0.10	12.56 ± 0.12	13.96 ± 0.21	12.69 ± 0.92
Cl6:1–9c	0.08 ± 0.00	0.10 ± 0.00	0.09 ± 0.01	0.08 ± 0.00	0.08 ± 0.00	0.10 ± 0.00	0.08 ± 0.00	0.09 ± 0.00	0.09 ± 0.00	0.10 ± 0.00	0.10 ± 0.00	0.09 ± 0.01
Cl7:0	0.10 ± 0.00	0.10 ± 0.00	0.09 ± 0.01	0.10 ± 0.00	0.10 ± 0.00	0.10 ± 0.00	0.11 ± 0.00	0.10 ± 0.00	0.10 ± 0.00	0.10 ± 0.00	0.10 ± 0.00	0.10 ± 0.00
Cl8:0	0.82 ± 0.02	0.97 ± 0.02	0.82 ± 0.02	0.77 ± 0.01	0.75 ± 0.06	0.94 ± 0.03	0.71 ± 0.01	0.93 ± 0.04	0.85 ± 0.00	0.75 ± 0.00	0.97 ± 0.02	0.82 ± 0.09
Cl8:1–9t	ND	ND	0.03 ± 0.00	ND	ND	ND	0.01 ± 0.00	ND	0.02 ± 0.00	ND	ND	0.02 ± 0.00
Cl8:1–9c	29.60 ± 0.89	36.58 ± 0.70	30.53 ± 1.07	27.03 ± 0.55	25.66 ± 2.04	30.41 ± 1.17	26.86 ± 0.38	35.32 ± 1.10	31.14 ± 0.01	28.69 ± 0.03	35.00 ± 0.81	30.11 ± 3.93
Cl8:1–11c	0.15 ± 0.00	0.16 ± 0.00	0.13 ± 0.00	0.15 ± 0.00	0.58 ± 0.00	0.16 ± 0.01	0.15 ± 0.00	0.15 ± 0.00	0.14 ± 0.00	0.15 ± 0.00	0.16 ± 0.00	0.20 ± 0.14
Cl8:2–9c,12t	0.49 ± 0.01	0.29 ± 0.00	0.67 ± 0.01	0.30 ± 0.01	0.38 ± 0.01	0.26 ± 0.01	0.67 ± 0.01	0.48 ± 0.01	0.75 ± 0.00	0.61 ± 0.00	0.31 ± 0.00	0.50 ± 0.16
Cl8:2–9t,12c	0.45 ± 0.01	0.26 ± 0.00	0.64 ± 0.00	0.26 ± 0.00	0.36 ± 0.02	0.22 ± 0.00	0.65 ± 0.01	0.45 ± 0.02	0.75 ± 0.00	0.57 ± 0.00	0.28 ± 0.00	0.47 ± 0.17
Cl8:2–9c,12c	44.96 ± 1.36	52.25 ± 0.82	42.83 ± 0.74	48.14 ± 1.10	52.27 ± 4.09	49.79 ± 1.86	48.94 ± 0.53	48.00 ± 1.62	49.40 ± 0.00	48.47 ± 0.08	51.31 ± 1.19	49.05 ± 2.62
C20:0	0.44 ± 0.01	0.51 ± 0.00	0.42 ± 0.00	0.41 ± 0.01	0.43 ± 0.03	0.44 ± 0.00	0.41 ± 0.01	0.48 ± 0.02	0.45 ± 0.00	0.43 ± 0.00	0.50 ± 0.00	0.44 ± 0.03
Cl8:3–9c,12c,15t	0.25 ± 0.01	ND	0.25 ± 0.00	ND	0.21 ± 0.01	0.20 ± 0.00	0.27 ± 0.00	0.26 ± 0.00	0.29 ± 0.00	0.27 ± 0.00	0.18 ± 0.00	0.26 ± 0.03
Cl8:3–9c,12t,15c	0.26 ± 0.01	0.29 ± 0.00	0.25 ± 0.00	0.26 ± 0.01	0.25 ± 0.00	0.27 ± 0.01	0.26 ± 0.00	0.28 ± 0.01	0.27 ± 0.01	0.26 ± 0.00	0.30 ± 0.00	0.27 ± 0.01
Cl8:3–9t,12c,15c	0.11 ± 0.00	ND	0.12 ± 0.00	ND	0.09 ± 0.00	0.10 ± 0.00	0.12 ± 0.00	0.12 ± 0.00	0.14 ± 0.02	0.12 ± 0.00	ND	0.12 ± 0.01
Cl8:3–9c,12c,15c	0.51 ± 0.01	0.70 ± 0.01	0.41 ± 0.01	0.79 ± 0.02	0.67 ± 0.05	1.22 ± 0.04	0.46 ± 0.00	0.65 ± 0.04	0.48 ± 0.00	0.50 ± 0.00	0.90 ± 0.02	0.60 ± 0.12
<i>t, t</i> -CLA _s	0.21 ± 0.00	ND	0.27 ± 0.00	0.16 ± 0.01	0.16 ± 0.01	0.09 ± 0.00	0.32 ± 0.02	0.17 ± 0.00	0.32 ± 0.01	0.25 ± 0.00	0.10 ± 0.01	0.23 ± 0.07
C22:0	0.07 ± 0.00	0.08 ± 0.00	0.07 ± 0.00	0.08 ± 0.00	0.07 ± 0.00	0.09 ± 0.00	0.07 ± 0.00	0.08 ± 0.00	0.08 ± 0.00	0.07 ± 0.00	0.10 ± 0.00	0.07 ± 0.00
C24:0	0.08 ± 0.00	0.10 ± 0.00	0.08 ± 0.00	0.08 ± 0.00	0.08 ± 0.00	0.09 ± 0.00	0.08 ± 0.00	0.09 ± 0.00	0.08 ± 0.00	0.08 ± 0.00	0.10 ± 0.00	0.08 ± 0.01

Each value in the table represents the mean ± SD from triplicate analyses

ND not detected

Table 2 Newly formed fatty acids in heated corn oil of different brands

Fatty acids	Brands		Heating condition
	Detected	Not detected	
C18:1,9 <i>t</i>	A, B, C, G, I, K	D, E, F, H, J	210 °C, 8 h
	A, B, C, E, F, G, I, J, K	D, H	230 °C, 8 h
	A–K	–	230 °C, 12 h
C18:2,9 <i>t</i> 12 <i>t</i>	C, G, I, K	A, B, D, E, F, H, J	210 °C, 8 h
	A–K	–	230 °C, 8 h
C18:3,9 <i>t</i> 12 <i>t</i> 15 <i>c</i>	A, B, C, D, F, G, H, I, J, K	E	230 °C, 8 h
	A–K	–	230 °C, 12 h
C18:3,9 <i>t</i> 12 <i>c</i> 15 <i>t</i>	A, B, C, D, F, G, H, I, J, K	E	230 °C, 8 h
	A–K	–	230 °C, 12 h
C18:2,9 <i>c</i> 11 <i>t</i>	G, I	A, B, C, D, E, F, H, J, K	230 °C, 8 h
	A, D, E, G, I, J, K	B, C, F, H	230 °C, 12 h

Fig. 2 The amounts of TFAs in eleven brands of fresh (Fig. 2a) and heated corn oil (Fig. 2b–d). Vertical error bars represent the standard deviation of the mean. Duncan's multiple range tests at $P = 0.05$ was calculated to compare the differences between means

TFAs among the brands may result from variation in raw materials quality, processing technique, and storage conditions of each corn oil. Ceriani and Meirellers (2007) showed that the process of deodorization was responsible for generating a significant portion of TFAs found in corn oil. However, there are no standards currently in China to limit the amount of TFAs in edible oil.

Thus, we suggest that the TFAs content in fresh corn oil should be displayed on nutrition labels and the standards should be set in order to limit the amount of TFAs in oils.

Quantitative analysis of TFAs in heated corn oil

The concentration of TFAs in the eleven brands of corn oil heated at 180 °C for 4, 8 and 12 h ranged from 0.82 g/100 g (brand B) to 2.21 g/100 g (brand I), 0.81 g/100 g (brand B) to 2.19 g/100 g (brand I) and 1.04 g/100 g (brand B) to 2.20 g/100 g (brand I), respectively (Fig. 2b). The TFAs content in corn oil heated at 210 °C for 4, 8 and 12 h ranged from 1.16 g/100 g (brand B) to 2.18 g/100 g (brand I), 1.18 g/100 g (brand B) to 2.16 g/100 g (brand I) and 1.39 g/100 g (brand B) to 2.66 g/100 g (brand I), respectively (Fig. 2c). In addition, the concentration of TFAs heated at 230 °C for 4, 8 and 12 h ranged from 1.69 g/100 g (brand D) to 2.95 g/100 g (brand I), 2.48 g/100 g (brand E) to 4.19 g/100 g (brand I) and 3.29 g/100 g (brand E) to 4.94 g/100 g (brand A), respectively (Fig. 2d). These results suggest that the amount of TFAs in the eleven brands of corn oil increases with the heating temperature and time.

Consistent with the order of fresh corn oil (Fig. 2a), the order of the heated corn oil brands from the highest to the lowest, TFAs content was brand I > brands C and G > brand J > brands A and H > brand E > brands F and K > brands D and B. However, the order of the corn oil heated at 230 °C for 12 h was brand A > brand I > brands K, G and C > brand J > brands H, F and B > brands D and E. The results indicated that the order of most but not all of the brands of corn oil containing TFAs remained the same at higher temperatures. Brands with lower levels of TFAs found in the fresh corn oil samples showed lower levels of TFAs after heating as well. Therefore, the order of the brands from the highest to the lowest, TFAs content was roughly the same when heated at different temperatures for different lengths of time, which further emphasized the importance of displaying TFAs content in corn oil on nutrition labels.

The amount of TFAs found in corn oil heated at 180 °C for 12 h was higher than that of 4 and 8 h, while no significant differences were observed between the fresh corn oil and the corn oil heated at 180 °C for 4 and 8 h (Fig. 2b). These results indicate that the corn oil samples are quite stable when heated at 180 °C which agrees well with results from Tsuzuki et al. (2010). The level of TFAs

for samples heated at 210 °C for 4, 8 and 12 h rose by 54% (brand D), 59% (brand D) and 73% (brand B), respectively, while the level of TFAs for samples heated at 230 °C for 4, 8 and 12 h rose by 109% (brand B), 264% (brand B) and 374% (brand B), respectively, which was the largest increase in TFAs content observed among the eleven different brands.

These results indicated that the concentration of TFAs increased with heating temperature and time. TFAs content increased more quickly when corn oil is heated at 230 °C compared to that of 180 and 210 °C, suggested that heating temperature was a key factor to influence the formation of TFAs. Thus, it was better to cooking using corn oil at temperature below 180 °C.

Quantitative analysis of CLAs in corn oil

Quantitative analysis of CLAs in fresh corn oil

As shown in Fig. 3a, *t,t*-CLAs were only detected in fresh corn oil samples. The *t,t*-CLAs content in the eleven brands of fresh corn oil ranged from 0.00 g/100 g (brand B) to 0.32 g/100 g (brands G and I) with the average content of *t,t*-CLAs being 0.19 g/100 g. Similar to the order for TFAs content, the order of the eleven corn oil brands from highest to lowest CLAs content was brands I and G > brands C, J and A > brand H > brands D and E > brands K and F > brand B. These results further confirm that the formation of CLAs increases with the increase of TFAs content, consist with the results of Guo et al. (2015).

Quantitative analysis of CLAs in heated corn oil

As shown in Figs. 3b, c, only *t,t*-CLAs were detected in corn oil heated at 180 and 210 °C. The concentration of *t,t*-CLAs in the eleven different brands of corn oil when heated at 180 °C for 4, 8 and 12 h ranged from 0.09 g/100 g (brand F) to 0.31 g/100 g (brand I), 0.12 g/100 g (brand B) to 0.34 g/100 g (brand G), and 0.13 g/100 g (brand B) to 0.35 g/100 g (brand G), respectively (Fig. 3b). When heated at 210 °C for 4, 8 and 12 h, the *t,t*-CLAs content ranged from 0.18 g/100 g (brand B) to 0.39 g/100 g (brand C), 0.20 g/100 g (brand F) to 0.39 g/100 g (brand J), and 0.26 g/100 g (brand F) to 0.48 g/100 g (brand I), respectively (Fig. 3c). The *t,t*-CLAs content of corn oil heated at 230 °C for 4 and 8 h ranged from 0.36 g/100 g (brand B) to 0.62 g/100 g (brand G) and 0.53 g/100 g (brand B) to 0.98 g/100 g (brand G), respectively (Fig. 3d). When heated at 230 °C for 12 h, a new type of CLAs (C18:2,9c11t) was detected in seven brands (brands A, D, E, G, I, J and K) of corn oil. The total CLAs content (*t,t*-CLAs and C18:2,9c11t) in corn oil heated at 230 °C for

Fig. 3 The amounts of CLAs in eleven brands of fresh (Fig. 3a) and heated corn oil (Fig. 3b–d). Vertical error bars represent the standard deviation of the mean. Duncan's multiple range tests at $P = 0.05$ was calculated to compare the differences between means

12 h ranged from 0.71 g/100 g (brand B) to 1.12 g/100 g (brand G). These results indicate that the amount and kind of CLAs in corn oil increase with the heating temperature and time similar to a previous study (Destailats and Angers 2005) that reported CLAs could form from methyl linoleate samples at higher temperatures and longer heating time.

The formation of CLAs at low temperatures increased slowly compared to that of higher temperatures. The increase in the total CLAs content of heated corn oil compared to fresh corn oil was 21, 56 and 62% at 180 °C for 4, 8 and 12 h, respectively, and 149, 171 and 260% at 210 °C for 4, 8 and 12 h, respectively, and 393, 658, and 979% at 230 °C for 4, 8 and 12 h, respectively. These results show that the growth regularity of CLAs in corn oil was consistent with the changes of TFAs content, and the formation rate of CLAs also increased significantly with the heating temperature and time.

Quantitative analysis of the ratio of linoleic acid ($\omega 6$) to α -linolenic acid ($\omega 3$) in corn oil

Quantitative analysis of $\omega 6/\omega 3$ in fresh corn oil

Figure 4a showed that the $\omega 6/\omega 3$ in the eleven different brands of fresh corn oil ranged from 41:1 (brand F) to 106:1 (brand G), which was consistent with the results of Yang et al. (2011) who reported a $\omega 6/\omega 3$ of 62:1 and was higher than the recommendation. Several studies have focused on the content of $\omega 6$ and $\omega 3$ in fresh edible oils (Wang et al. 2011). However, little information is currently available on changes in the $\omega 6/\omega 3$ of corn oil during heating.

Quantitative analysis of $\omega 6/\omega 3$ in heated corn oil

Linoleic acid ($\omega 6$) and α -linolenic acid ($\omega 3$), unsaturated fatty acids, were easily to oxidize, decompose, polymerize

Fig. 4 The ratios of $\omega 6/\omega 3$ in eleven brands of fresh (Fig. 4a) and heated corn oil (Fig. 4b–d). Vertical error bars represent the standard deviation of the mean. Duncan's multiple range tests at $P = 0.05$ was calculated to compare the differences between means

or isomerize under heating processing. Moreover, as the positions of double bonds in fatty acids of $\omega 6$ and $\omega 3$ were different, they have different thermal stabilities. Therefore, the changes of $\omega 6$ and $\omega 3$ fatty acids, namely $\omega 6/\omega 3$, occurred when heated at 180, 210 and 230 °C for 4, 8 and 12 h. At 180 °C, there was barely any increase observed in the value of $\omega 6/\omega 3$ (Fig. 4b). However, there was a substantial increase observed for $\omega 6/\omega 3$ in corn oil heated at 210 and 230 °C (Fig. 4c, d). The ratio of $\omega 6/\omega 3$ for corn oil heated at 180 °C ranged from 40:1 (brand F) to 108:1 (brand G). The $\omega 6/\omega 3$ ratio of corn oil heated at 210 °C for 4, 8 and 12 h ranged from 42:1 (brand F) to 110:1 (brand G), 45:1 (brand F) to 117:1 (brand G), and 48:1 (brand F) to 129:1 (brand I), respectively. At 210 °C, significant differences were observed among the heating time of 4, 8 and 12 h for all of the corn oil brands. At 230 °C, the $\omega 6/\omega 3$

ratio increased much faster compared to 180 and 210 °C for the same heating times. After heating for 4, 8 and 12 h, the value of $\omega 6/\omega 3$ ranged from 52:1 (brand F) to 137:1 (brand I), 67:1 (brand F) to 192:1 (brand I), and 84:1 (brand F) to 239:1 (brand J), respectively. These results showed that the ratio of $\omega 6/\omega 3$ in corn oil increased with the heating temperatures and time, especially for the heating temperatures greater than 230 °C. This suggested that the $\omega 6$ was more stable than $\omega 3$.

The FAO has suggested that individuals with $\omega 6/\omega 3$ higher than 10:1 should increase consumption of $\omega 3$ -rich foods such as green leafy vegetables, legumes, fish and other seafood (FAO and WHO 1994). Healthier alternatives could involve corn oil blended with edible oil rich in $\omega 3$ on the basis of the research results and cooked below a temperature of 230 °C.

Conclusion

The composition of fatty acids is almost identical among the eleven different brands of corn oil, while the quantities of TFAs, CLAs and $\omega 6/\omega 3$ were different. The amounts of TFAs, CLAs and the values of $\omega 6/\omega 3$ in corn oil increased with the heating temperature and time. The results suggested that the heating temperature was the main factor to influenced the generation of TFAs, CLAs and the ratio of $\omega 6/\omega 3$ compared to that of heating time. Thus, it was suggested to keep cooking and frying temperatures below 180 °C in order to ensure both the quality and nutritional value of corn oil. The TFAs content in corn oil must be displayed on nutrition labels with limits indicating acceptable quantities of TFAs for the information of consumers.

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