cis-trans isomerization of unsaturated fatty acids in edible oils to prepare trans fat

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SUMMARY: *Trans* fats, unsaturated fatty acids with at least one double bond in the *trans* configuration, have received a great amount of attention in the field of oleo chemistry and safety. In this work, the *cis-trans* isomerization of unsaturated fatty acids in edible oils has been successfully developed using simple and cheap *p*-toluenesulfinic acid as catalyst. The effects of reaction time, temperature, catalyst loading, and the amounts of water and antioxidants on the *cis-trans* isomerization have been systematically investigated. The results indicate that the amount of water (0–20 wt %) and antioxidants (0–200 mg/kg) had no significant effect on this *cis-trans* isomerization of unsaturated fatty acids in edible oils. The final products (*trans* fats) from the *cis-trans* isomerization reaction were characterized by both GC and React IR. The yield of *trans* double bonds from the isomerized fat can reach 79.6% after heating at 100 °C for 90 min without changing either the location of the double bonds or the degree of unsaturation. In addition, this convenient method has been applied to various vegetable oils (e.g., olive oil, camellia seed oil, corn oil, sesame oil, sunflower oil and soybean oil) and nearly 80.0% yields of TFA were generated, which shows a promising method to provide *trans*-fat products for research related to oleo and food chemistry.

KEYWORDS: cis-trans *Isomerization; Edible fat; p-Toluenesulfinic acid;* trans *Fats;* trans *Fatty acids*

RESUMEN: ***Isomerización* cis-trans *de ácidos grasos insaturados en aceites comestibles para preparar grasas trans.*** Las grasas *trans*, ácidos grasos insaturados con al menos un doble enlace en la configuración *trans*, han recibido muchas atenciones en oleoquímica y seguridad. En este trabajo, se ha llevado a cabo con éxito la isomerización *cis-trans* de ácidos grasos insaturados en aceites comestibles usando mediante un método simple y barato utilizando ácido *p*-toluenosulfínico como catalizador. Los efectos del tiempo de reacción, la temperatura, la carga del catalizador, la cantidad de agua y los antioxidantes en la isomerización *cis-trans* se han investigado sistemáticamente. Los resultados indicaron que la cantidad de agua (0–20% en peso) y antioxidante (0–200 mg/kg) no tuvo un efecto significativo sobre la isomerización *cis-trans*. Los productos finales (grasas *trans*) de la reacción de isomerización *cis-trans* se caracterizaron por GC y React IR. El rendimiento en dobles enlaces *trans* de la manteca isomerizada puede alcanzar el 79,6% tras calentar a 100 ºC durante 90 minutos sin cambiar tanto la posición de los dobles enlaces como el grado de insaturación. Además, este método tan útil se ha aplicado a diferentes aceites vegetales (por ejemplo, oliva, semilla de camelia, maíz, sésamo, girasol y soja) y casi se forma alrededor del 80.0% de ácidos grasos *trans*, lo que demuestra ser un método prometedor para proporcionar productos grasos *trans* para investigaciones relacionadas en la química del aceite y los alimentos.

PALABRAS CLAVE: *Ácido p-toluenosulfínico; Ácidos grasos* trans*; Grasas* trans*; Isomerización* cis-trans*; Manteca comestible*

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1. INTRODUCTION

It is a known fact that fatty acids, which contain saturated fatty acids and unsaturated fatty acids, are one of the most important components of edible oils (Kurt, 2018). The *cis-trans* isomerization of unsaturated fatty acids in edible oils is not expected in most cases because an excessive intake of *trans* fatty acids (TFAs) has been associated with the increased risk of coronary heart disease (CHD), sudden death, diabetes mellitus and increased markers for systematic inflammation (Duffy *et al.*, 2006; Hulshof *et al.*, 1999; Lemaitre *et al.*, 2006). Edible oils consist of triacylglycerides as their main components (> 95%), which differ in their fatty acid compositions to a certain extent (Belitz *et al.*, 1999). Most of the natural unsaturated fatty acids in edible oils are non-conjugated acids with a *cis* structure. Meanwhile, natural TFAs account for only a very small fraction of natural unsaturated fatty acids.

In terms of chemical structure, TFAs are unsaturated fatty acids with *trans*-non-conjugated carbon-carbon double bonds. Natural TFAs are produced by the bio-hydrogenate unsaturated fatty acids of the feeds in the rumen of ruminants and occur naturally in ruminant meat (beef, lamb and goat) and dairy products at up to about 5% of the total fatty acids (Katherinem *et al.*, 2010; Kuhnt *et al.*, 2015; Trattner *et al.*, 2015; Vahmani *et al.*, 2016). In addition to natural TFAs, TFAs are mainly produced during the industrial processing of oils (e.g., vegetable oils). For example, TFAs are produced from *cis*-unsaturated fatty acids during the heating of oils at high temperatures (> 200 ^{o}C) and the hydrogenation process in the presence of hydrogen and metal-catalysts (e.g., Ni, Cu) (Liu *et al.*, 2017). Hydrogenated vegetable oils have been widely used in the food industry for a long period of time to produce different oil-based foods, such as cakes, cookies, french fries and margarine, because of their longer shelf-life, oxidative stability and other particular physical properties (Cizmeci *et al.*, 2005; García *et al.*, 2017; Iida *et al.*, 2015; Mozaffarian *et al.*, 2006). For example, soybean oil was hydrogenated using Nysosel 222 nickel-based catalysts under constant conditions (165 ^{o}C, 2 bar hydrogen pressure) and the total TFAs were up to 40.5% after 100 min of the hydrogenation process (Kala *et al.*, 2012). The structure of TFAs is more stable than *cis* fatty acids against thermodynamics. In the process of refining and deodorization of vegetable oils, the oils are usually heated to 250 ^{o}C for a long period of time (15–120 min) to eliminate odor components (Li *et al.*, 2012). Furthermore, the deep frying process (160–180 ^{o}C) using unsaturated vegetable oils (e.g., soybean oil, sunflower oil, canola oil) would also lead to an increase in *trans* fatty acids when the operation time was more than 20 h (Farag *et al.*, 2010; Tsuzuki *et al.*, 2010).

Due to the potential risk related to TFAs in food, extensive research has been focused on finding a convenient method for a high conversion of the *cis-trans* isomerization of long-chain unsaturated fatty acids for lipid analysis and other scientific proposes (Ferreri *et al.*, 2001; Geißler *et al.*, 2003; Tzeng *et al.*, 2014). Many types of catalysts, such as nitrous acid and selenium, have been developed for the synthesis of the *trans* fatty acids through a corresponding *cis-trans* isomerization reaction (Snyder *et al.*, 1982). However, these catalysts had some disadvantages, such as toxicity, higher reaction temperature, side reactions and production of impurities, *etc*. There are reports that *p*-toluenesulfinic acid is an ideal catalyst with the advantages of being fast and efficient to accomplish the *cis-trans* isomerization of pure unsaturated fatty acids methyl esters (Gibson *et al.*, 1976). Up to now, reports on a fast and efficient method to promote the *cis-trans* isomerization of fatty acids in edible oils to prepare *trans* lipids are rare due to the fact that lipids are more complicated than pure fatty acid methyl esters, and the minor components in lipids will have an unfavorable effect on the *cis-trans* isomerization of fatty acids to prepare *trans* fats (Akin *et al.*, 2018; Elbadawi *et al.*, 2017).

In this paper, the *cis-trans* isomerization of unsaturated fatty acids in edible oils has been successfully performed to prepare *trans* lipids using *p*-toluenesulfinic acid as catalyst. The unsaturation and location of the carbon-carbon double bonds of the fatty acids remain unchanged with this simple method. With this simple method, prepared *trans* lipids can be applied in food chemistry research and used as lipid research standards.

2. EXPERIMENTAL PROCEDURES

2.1. Materials

Edible fat (I.V.=54 g I$_2$/100 g) was purchased from Jiuyuan Oils & Fats Co., Ltd. (Tianjin, China). Olive oil (I.V.=80 g I$_2$/100 g) was purchased from Sinograin Oils Co., Ltd. (Tianjin, China). Sunflower oil 1# (I.V.=131 g I$_2$/100 g) was purchased from Sinograin Oils Co., Ltd. (Tianjin, China). Sunflower oil 2# (I.V.=132 g I$_2$/100 g) was purchased from Standard Food Co., Ltd. (Shanghai, China). Camellia seed oil (I.V.=85 g I$_2$/100 g) was purchased from COFCO Co., Ltd. (Xinjiang, China). Corn oil (I.V.=120 g I$_2$/100 g) was purchased from Xiwang Food Co., Ltd. (Shandong, China). Soybean oil 1# (I.V.=127 g I$_2$/100 g) and soybean oil 2# (I.V.=128 g I$_2$/100 g) were purchased from Jiusan group soybean Technology Co., Ltd. (Tianjin, China) and Wilmar International Limited, respectively. Sesame oil (I.V.=107 g I$_2$/100 g) was obtained from a local market. Petroleum ether (99%, 60–90 ^{o}C) was obtained from Precision Chemical Reagent Factory

(Tianjin, China). Sodium sulfate anhydrous (> 99%), methanol (HPLC grade) and *n*-hexane (HPLC grade) were purchased from Kemiou Chemical Reagent Co., Ltd. (Tianjin, China). Sodium (> 99.5%) was obtained from Kelong Chemical Reagent Factory (Chengdu, China). 1,4-dioxane (99%) was acquired from Fuyu Fine Chemical Co., Ltd. (Tianjin, China). Hydrochloric acid (99%) was obtained from Chemical Reagent Factory (Luoyang, China). Sodium hydroxide (99%) was obtained from Yongda Chemical Reagent Co., Ltd. (Tianjin, China). Butyl-hydroxyanisol (BHA, 98%), butyl-hydroxytoluene (BHT, > 99%), *t*-butyl-hydroquinone (TBHQ, 98%) and sodium *p*-toluenesulfinate (anhydrous, 98%) were obtained from Aladdin Bio-Chem Tenchnology Co., Ltd. (Shanghai, China). All materials were used as received without further treatment.

2.2. Catalyst preparation

p-Toluenesulfinic acid was prepared by the acidification of sodium *p*-toluenesulfinate (Snyder *et al.*, 1982). Sodium *p*-toluenesulfinate was dissolved in a small amount of water and *p*-toluenesulfinic acid was precipitated by the addition of the calculated amount of 6 mol/L hydrochloric acid (HCl) to this solution. The precipitated acid was filtered off and washed rapidly several times with ice-cold distilled water. Finally, *p*-toluenesulfinic acid was thoroughly dried for 24 h at 40 °C under vacuum.

2.3. Preparation process for *trans*-lipids

In the *cis-trans* isomerization experiments, 250 mg edible fat, 10 mL 1,4-dioxane and a certain amount of *p*-toluenesulfinic acid were added to the reactor and the resulting mixture was heated for a certain period of time under a nitrogen atmosphere. After cooling to room temperature, the solution was diluted with 25 mL of a 1 mol/L NaOH solution and then extracted with petroleum ether. The obtained organic layer was washed three times with a saturated sodium chloride solution and then the solvent was removed by a rotary evaporator under vacuum, which afforded the desired *trans*-lipid product.

2.4. Characterization methods

The isomerized fat was treated by methyl esterification before the gas chromatography analysis. In detail, 2–3 drops of isomerized fat and 2 mL of *n*-hexane were mixed in a glass tube, and then 3 mL of 0.5 mol/L sodium methylate were added into the tube. The mixture was rigorously vibrated for 5–7 min and the mixture was then centrifuged to obtain the supernatant. The supernatant was dried by sodium sulfate anhydrous prior to the gas

chromatography analysis. Analysis of the isomerized fat was performed on a Agilent Technologies 6890N gas chromatography (GC) using a 30.0 m×250 µm×0.25 µm BPX-70 capillary column and detected using a flame ionization detector (FID). The carrier was nitrogen with a flow of 1.0 mL/min. The oven was programmed from the set temperature of 170 °C to 210 °C at 2 °C/min. Injection volumes were 1 µL with the inlet set to split mode and the split ratio was 50:1. The GC injection temperature was 250 °C and the detector temperature was 300 °C. The yield of *trans* double bonds in the isomerized oil samples was calculated from the capillary GC data. Furthermore, the experimental results were mainly determined by the yield of total *trans* double bonds. The yield of total *trans* double bonds was calculated using Eq. (1):

$$\text{Yield of total } trans \text{ double bonds}(\%) = \frac{\text{Total } trans \text{ double bonds}}{\text{Total double bonds}} \times 100\%$$

Where total *trans* double bonds are the double bonds of the elaidic acid, *trans* linoleic acid and *trans* linolenic acid; total double bonds are the double bonds of the oleic acid, linoleic acid and linolenic acid.

3. RESULTS AND DISCUSSION

3.1. General consideration

The proposed mechanism for *trans* carbon-carbon double bond formation in edible oils using *p*-toluenesulfinic acid as catalyst is presented in Scheme 1. According to the previously proposed mechanism (Gibson *et al.*, 1976), the *p*-toluenesulfinic acid catalyst would produce an arylthiyl radical when *p*-toluenesulfinic acid was heated in the reaction system. All of the radicals would promote *cis-trans* isomerization. Hence, the reaction heating temperature and antioxidant compounds in edible oils would both affect the isomerization reaction.

As we know, edible oils, mainly vegetable oils, contain natural antioxidants and synthetic antioxidants which would inhibit the lipid peroxidation and other radical reactions. Thus, edible oil without any antioxidants is an ideal candidate for the *cis-trans* isomerization reaction through a radical process. Therefore, edible fat
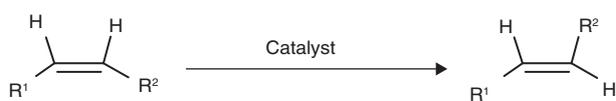
SCHEME 1. Reaction scheme for the *cis-trans* isomerization reaction in lipids.

without any antioxidants was selected as the model lipid for the isomerization reaction because the content of natural antioxidants in edible fat is scarce. In addition, the fatty acid composition of the edible fat used in this work showed that the content of unsaturated fatty acids in edible fat is about 50.0%, which includes 36.8% oleic acid and 13.1% linoleic acid. Refined edible fat was suitable to study this free radical-like *cis-trans* isomerization of unsaturated carbon-carbon double bonds of fatty acids to prepare *trans*-lipid.

3.2. Effect of reaction time on the isomerization of the edible fat

Firstly, the reaction time was one of the key factors for isomerization because the radical intermediates generated by the *p*-toluenesulfinic acid are responsible for the fat isomerization. The effect of reaction time on the isomerization of edible fat is shown in Table 1. The isomerization was performed at 120 °C under a nitrogen atmosphere using *p*-toluenesulfinic acid as catalyst (oil/catalyst=250:20) to investigate the effect of reaction times (10 min, 20 min, 30 min, 60 min, 90 min and 120 min) on the isomerization process. Obviously, the generation of radical intermediates required a certain period of time and a much lower yield of TFAs (2.8%) was generated after heating for only 10 min. When the reaction time was increased to 20 min, the yield of TFAs in the fat was increased rapidly and a 72.5% yield of TFAs was detected. Prolonging the reaction time (30–90 min) led to a slight increment in TFA and a 79.2% yield of TFAs was produced in fat after heating for 90 min. Continuing to increase the reaction time (120 min) resulted in no significant changes in the yield of *trans* double bonds. Therefore, an operation reaction time of 90 min was chosen in the following experiments.

3.3. Effect of reaction temperature on the isomerization of edible fat

The effect of reaction temperature on the isomerization of edible fat was investigated and shown in Table 2. The experiments were performed under a nitrogen atmosphere using *p*-toluenesulfinic acid (250:20 edible fat to catalyst) as catalyst to investigate the effect of different reaction temperatures (60 °C, 80 °C, 100 °C, 120 °C and 140 °C) on the isomerization process. Based on the reaction mechanism, the generation of the free radical catalyst from *p*-toluenesulfinic acid required a definite temperature.

It could be observed in the results that no generation of *trans* double bonds was observed when the reaction was performed below 100 °C (60 °C and 80 °C). When the experiment was carried out at 100 °C for 90 min, the yield of *trans* double bonds in the fat could reach 79.6%. Further increasing the reaction temperature (120–140 °C) had almost no effect on the yield of *trans* double bonds in the fat. This is probably because the temperature was not the rate-determining step in this *cis-trans* isomerization reaction. In other words, it was impossible to increase the yield of *trans* double bonds through increasing the reaction temperature. Therefore, 100 °C was chosen as the optimum reaction temperature.

3.4. Effect of amount of catalyst on the isomerization of the edible fat

The catalyst amount had a certain impact on the *cis-trans* isomerization of the edible fat. The effect of the amount of catalyst in terms of different fat/catalyst mass ratios (250:5, 250:10, 250:20 and 250:40) was also investigated and the results are listed in Table 3. Heating the fat at 100 °C without any catalyst did not lead to any production of TFAs after heating for 90 min. The use of less catalyst (250:5) was not conducive to the production of *trans*-fat. The ratio of 250:20 led to a higher conversion

TABLE 1. Effect of reaction time on the isomerization of edible fat

Reaction time	Final isomer composition (%)		Yield of total *trans* double bonds (%)
	Elaidic acid	*Trans*-linoleic acid	
10 min	3.0	2.3	2.8
20 min	70.8	65.7	72.5±1.6
30 min	77.3	74.7	75.4±1.8
60 min	77.6	75.4	76.2±1.3
90 min	79.5	78.8	79.2±0.5
120 min	77.6	78.9	79.1±0.7

Each value in the table represents the mean and mean ± standard deviation of triplicate analyses, respectively. Reaction conditions: reaction temperature 120 °C, ratio of edible fat to catalyst was 250 to 20 (w/w), N_2.

TABLE 2. Effect of reaction temperature on the isomerization of edible fat

Reaction temperature	Final isomer composition (%)		Yield of total *trans* double bonds (%)
	Elaidic acid	*Trans*-linoleic acid	
60 °C	/	/	/
80 °C	/	/	/
100 °C	79.7	79.3	79.6±0.2
120 °C	79.5	78.8	79.2±0.5
140 °C	78.7	78.1	78.4±0.1

Each value in the table represents the mean and mean ± standard deviation of triplicate analyses, respectively. Reaction conditions: reaction time 90 min, ratio of edible fat to catalyst was 250 to 20 (w/w), N_2.

TABLE 3. Effect of amount of catalyst on the isomerization of edible fat

Ratio of edible fat and catalyst (w/w)	Final isomer composition (%)		Yield of total *trans* double bonds (%)
	Elaidic acid	*Trans*-linoleic acid	
250:0	0	0	0
250:5	31.5	30.4	31.9
250:10	60.4	58.0	59.3±0.8
250:20	79.7	79.3	79.6±0.2
250:40	79.9	80.0	80.0±2.6

Each value in the table represents the mean and mean ± standard deviation of triplicate analyses, respectively. Reaction conditions: reaction temperature 100 $^{\circ}$C, reaction time 90 min, N$_2$.

TABLE 4. Effect of water on the isomerization of edible fat

Water addition	Final isomer composition (%)		Yield of total *trans* double bonds (%)
	Elaidic acid	*Trans*-linoleic acid	
0	79.7	79.3	79.6±0.2
5%	79.9	79.8	79.9±0.4
10%	79.9	80.5	80.2±0.1
20%	79.8	79.5	79.7±0.6

Each value in the table represents the mean and mean ± standard deviation of triplicate analyses, respectively. Reaction conditions: reaction temperature 100 $^{\circ}$C, reaction time 90 min, ratio of edible fat to catalyst was 250 to 20 (w/w), N$_2$. The added water was the weight percentage of the edible fat.

of TFAs (79.6%) in the fat. Further increasing the catalyst amount (250:40) showed no improvement in the yield of *trans* double bonds in the fat product. Therefore, 250:20 was selected as the optimum mass ratio of fat and catalyst.

3.5. Effect of water on the isomerization of the edible fat

Water exists widely in oil-based food and has some impact on the reactions in food. The effect of water addition on the *cis-trans* isomerization of edible fat is shown in Table 4. It was evident that water addition ranging from 5–20% had no significant impact on the *cis-trans* isomerization of the edible fat. The total *trans* double bonds remained at the same level with increasing the amount of water. Because the small amount of added water probably evaporated into the gaseous state under heating (100 $^{\circ}$C) conditions, this resulted in separating it from the reaction system. These results made this method more convenient to produce *trans*-lipids without extra drying or dehydration of the oil sample before the isomerization reaction.

3.6. Effect of antioxidant on the isomerization of the edible fat

The *cis-trans* isomerization of carbon-carbon double bonds in edible fat was caused by free radicals. During the reaction, *p*-toluenesulfinic acid cleaved thermally to radicals which resulted in the production of *trans* fat. Hence, the antioxidant as free radical quencher would affect the radical reaction. Considering the complexity of natural antioxidants in different edible oils, various commonly used synthetic antioxidants are investigated in the *cis-trans* isomerization of carbon-carbon double bonds in edible fat. BHA (butyl-hydroxyanisol), BHT (butyl-hydroxytoluene) and TBHQ (*t*-butyl-hydroxyquinone) are the most commonly used synthetic antioxidants for delaying the lipid oxidation process. Table 5 shows the effect of different antioxidants on the isomerization of edible fat. The results indicate that introducing 50–200 mg/kg BHA in the reaction system had no significant impact on the isomerization of the edible fat. However, the addition of 200 mg/kg BHT completely inhibited the isomerization of edible fat at 100 $^{\circ}$C and no TFA was detected. Increasing the

TABLE 5. Effect of antioxidant on the isomerization of edible fat

Antioxidant content	Final isomer composition (%)		Yield of total *trans* double bonds (%)	Reaction temperature
	Elaidic acid	*Trans*-linoleic acid		
0	79.7	79.3	79.6±1.0	100 $^{\circ}$C
50 mg/kg BHA	79.9	82.5	81.2±0.8	100 $^{\circ}$C
100 mg/kg BHA	79.8	82.0	80.7±0.7	100 $^{\circ}$C
200 mg/kg BHA	79.8	82.9	81.4±1.2	100 $^{\circ}$C
200 mg/kg BHT	/	/	/	100 $^{\circ}$C
200 mg/kg BHT	79.4	79.2	79.3±0.4	120 $^{\circ}$C
200 mg/kg TBHQ	79.8	83.3	81.1±1.3	100 $^{\circ}$C

Each value in the table represents the mean and mean ± standard deviation of triplicate analyses, respectively. Abbreviations: BHA, butyl-hydroxyanisol; BHT, butyl-hydroxytoluene; TBHQ, *t*-butyl-hydroquinone. Reaction conditions: reaction time 90 min, ratio of edible fat to catalyst was 250 to 20 (w/w), N$_2$.

reaction temperature from 100 °C to 120 °C, the *cis-trans* isomerization took place smoothly with the addition of 200 mg/kg BHT and afforded the TFAs a yield of 79.3%. Because the high radical inhibition activity of BHT was most likely obtained at 100 °C, the isomerization of edible fat with BHT could be implemented by elevating the reaction temperature to 120 °C. Moreover, introducing 200 mg/kg TBHQ into the reaction system had no significant impact on the isomerization of edible fat at 100 °C. Therefore, *cis-trans* isomerization at 100 °C or 120 °C could efficiently take place in edible fat containing no more than 200 mg/kg synthetic antioxidants.

3.7. Analysis of the isomerized fat by GC and FT-IR

The results of *cis-trans* isomerized unsaturated fatty acids in edible fat monitored by GC are shown in Figure 1. The A and B diagrams in Figure 1 show the fatty acid compositions by GC before and after the *cis-trans* isomerization, respectively. It was clear that *trans* double bonds were formed. The results were achieved under the optimum conditions which were conducted at 100 °C for 90 min. The fatty acid composition of isomerized edible fat (Table 6) showed that the yields of isomerized double bonds of oleic acid and linoleic acid were 79.7% and 79.3%, respectively. The total yield of *trans* double bonds in the final fat was 79.6% without a change in the location of the double bonds (Snyder *et al.*, 1982).

IR spectroscopy is one of the most efficient tools to directly determine *trans*-double bonds. Therefore, the *cis-trans* isomerization of edible fat was also detected by React IR^{TM} spectroscopy. The React IR^{TM} spectra (Figure 2) clearly showed the generation of *trans*-double bonds. The new bonds, associated with *trans* fat formation, were observed
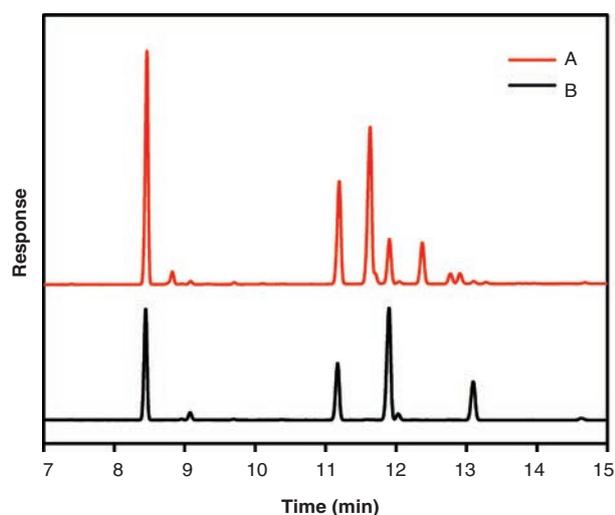
TABLE 6. Fatty acid composition of the isomerized edible fat

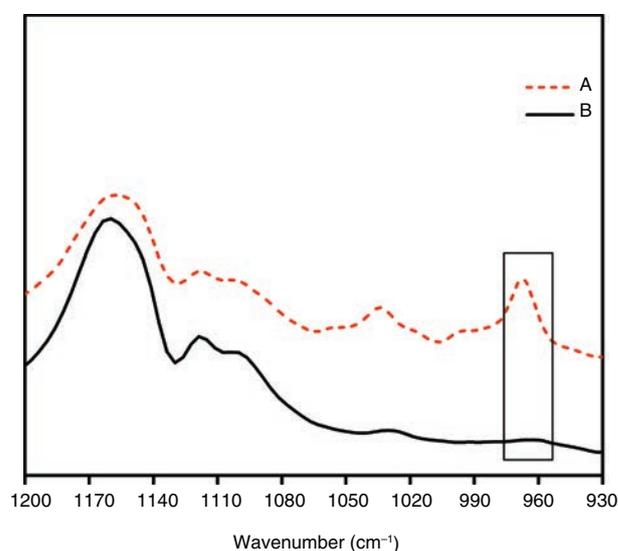| Fatty acid	Content (%)
C16:0	27.96
C18:0	17.40
C18:1 t[a]	29.80
C18:1 c[b]	7.58
C18:2 t, t	7.26
C18:2 t, c	1.84
C18:2 c, t	1.93
C18:2 c, c	0.50

[a] t = *trans*
[b] c = *cis*

FIGURE 2. The FT-IR after (A) and before (B) the *cis-trans* isomerization of fat

at a bond of 966 cm^{-1}. These results indicated that the *cis-trans* isomerization of edible fat was realized. Moreover, React IR was also used to monitor the *cis-trans* isomerization of fat process (Figure 3), and the *trans* fat was generated rapidly.

3.8. Isomerization of different edible oils

Based on the above results in hand, we investigated the *cis-trans* isomerization of unsaturated fatty acids in other edible oils, mainly vegetable oils (Table 7). It could be seen that the yields of *trans* double bonds in the eight kinds of isomerized edible oils were all close to 80.0%. This is similar to an earlier report employing pure fatty acids as substrates (Snyder *et al.*, 1982). In fact, vegetable oils contain various natural antioxidants with different kinds and concentrations, which are more complicated than edible fat or pure fatty acids. The yields of elaidic

FIGURE 1. Gas chromatogram after (A) and before (B) the *cis-trans* isomerization of fat
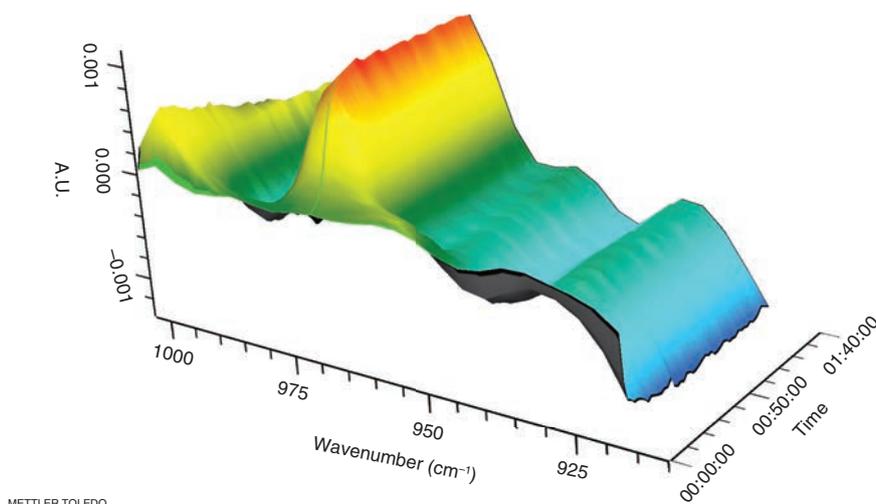
FIGURE 3.   3D-FTIR profiles of the *cis-trans* isomerization of fat, the reaction was monitored by React IR

TABLE 7. *cis-trans* Isomerization of different edible vegetable oils

Edible oils	Final isomer composition (%)			Yield of total *trans* double bonds (%)
	Elaidic acid	*Trans*-linoleic acid	*Trans*-linolenic acid	
Olive oil	79.4	78.8	/	79.2±0.2
Camellia seed oil	79.3	78.0	/	78.8±0.9
Corn oil	79.4	78.5	/	78.7±0.6
Sesame oil	79.7	79.8	/	79.6±0.7
Sunflower oil 1#	79.1	78.7	/	78.9±1.1
Sunflower oil 2#	79.1	78.8	/	79.0±0.8
Soybean oil 1#	79.5	79.6	77.4	79.3±1.3
Soybean oil 2#	79.6	79.8	77.7	79.7±1.0

Each value in the table represents the mean and mean ± standard deviation of triplicate analyses, respectively. 1# and 2# represent the same variety of edible oils from different manufacturers, respectively. Reaction conditions: reaction temperature 100 °C, reaction time 90 min, ratio of edible oil to catalyst was 250 to 20 (w/w), N_2.

acid were all over 79%, and the yields of *trans*-linoleic acid fluctuated between 78.0% and 79.8%. Therefore, nearly 80.0% yields of TFAs generated in various vegetable oils are an acceptable result for the production of *trans*-lipids without changing the degree of unsaturation.

4. CONCLUSIONS

The *cis-trans* isomerization of unsaturated fatty acids in edible oils has been successfully developed using simple and cheap *p*-toluenesulfinic acid as catalyst. The effects of reaction time, temperature, catalyst loading, and the amount of water and antioxidants on isomerization have been investigated systematically. Under the optimal conditions, the yield of *trans* double bonds from isomerized fat could reach 79.6% without changing either the location of the double bonds or the degree of unsaturation. The results indicated that the amount of water (0–20 wt %) and antioxidant (0–200 mg/kg) had no significant effect on the *cis-trans* isomerization of unsaturated fatty acids in edible oils. In addition, this convenient method has been applied to different kinds of vegetable oils and yields of nearly 80.0% of TFAs were generated, which is a promising result for the production of *trans*-fats.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this paper.

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