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ASSESSMENT OF *TRANS* FATTY ACID LEVELS IN REFINED PALM-BASED OILS AND COMMERCIAL VEGETABLE OILS IN THE MALAYSIAN MARKET

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ABSTRACT

Trans *fats consumption is a major concern worldwide due to the deleterious effects associated with increased risks of coronary heart disease. The* trans *fatty acid (TFA) content of 104 refinery and commercial vegetable oils in the Malaysian market were analysed by gas chromatography. TFA levels in 29 samples of refined, bleached and deodourised palm oil, palm olein, palm stearin and palm kernel olein from palm oil refineries ranged from 0.12 ± 0.00 to 0.84 ± 0.01 g/100 g. Commercially packaged vegetable oils namely palm olein, sunflower, corn, coconut, rice bran, peanut, olive and sesame oils contained less than 1 g TFA/100 g while higher TFA levels ranging from 1 to 3 g/100 g were detected in canola oil, soybean oil and canola-based oil blend samples. Amongst the premium oils, cold pressed unrefined almond and walnut oils were found to contain TFA levels exceeding 2 g/100 g while other oils in this category contained TFA less than 1 g/100 g. All retail palm-based vegetable oils and palm-based vegetable fat shortenings except for three samples conformed to the conditions for nutrition claims of low TFA of 1.5 g/100 g and 0.75 g/100 mL in both solids and liquids, respectively, as regulated in the Malaysian Food Act 1983.*

Keywords: palm oil, *trans* fatty acids, vegetable oils.

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INTRODUCTION

Trans fatty acids (TFA) are defined as unsaturated fatty acids possessing at least one double bond in the *trans* configuration. TFA are derived primarily from two sources; (1) ruminant *trans* fats which occur naturally in dairy products and meat from ruminant animals; and (2) industrial *trans* fats which are produced from the partial hydrogenation of vegetable oils (Mozaffarian *et al.*, 2006). Industrial *trans* fats or more commonly known as partially hydrogenated vegetable oils (PHO) are found in a myriad of bakery, frozen and fast food products, margarines and shortenings, packaged snacks and biscuits. In the past, food manufacturers preferred using industrial *trans* fats as an ingredient in their food formulations as the partial hydrogenation process increases the solidity and reduces rancidity of the oil. This resulted in improved stability and shelf-life of food products containing industrial *trans* fats (Nishida and Uauy, 2009).

In the last three decades, there has been a growing body of convincing scientific evidence on the health-damaging effects of TFA. Worldwide consumption of *trans* fats has been strongly associated with an elevated risk of coronary heart disease (CHD) and death from CHD, systemic inflammation, diabetes and cancer (De Souza *et al.*, 2015; Islam *et al.*, 2019; Mozaffarian *et al.*, 2009). Both industrial and ruminant TFAs have been shown to equally raise low-density lipoprotein (LDL) and lower high-density lipoprotein (HDL) cholesterols,

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although controlled human studies on the latter are rather limited (Brouwer *et al.*, 2010; World Health Organization and Brouwer, 2016). Recognising the growing epidemic of cardiovascular diseases worldwide, the World Health Organization (WHO) in 2003 recommended limiting the daily intake of TFA to less than 1% of total energy intake (Nishida *et al.*, 2004).

Since then, countries such as Denmark, USA and Canada initiated the reduction and elimination of *trans* fats in food through legislative initiatives involving the implementation of regulations setting maximum limits of *trans* fat or mandated labelling of *trans* fats which was subsequently instigated in more than 30 countries (Hendry *et al.*, 2015; Zuchowska-Grzywacz and Kowalska, 2019). The United States Food and Drug Administration (USFDA) revoked the Generally Recognised as Safe (GRAS) status of PHO and banned PHO usage in human food effective June 2018 (USFDA, 2015). The European Parliament adopted a resolution the following year to limit PHO in foods and to establish legal limits for TFAs in food by 2018 (EP, 2016). Starting from 1 April 2021, the European Commission will impose a maximum limit of 2 g TFA per 100 g fat in food products intended for the final consumer and food intended for supply to retail, which excludes those naturally occurring *trans* fat in animal fat (European Commission, 2019).

With the implementation of these government legislations and mandated regulations, worldwide TFA consumption has seen a tremendous decline in the past two decades with an average global *trans* fat intake lower than the 2003 WHO recommendation of a daily TFA intake limit of 1% total energy (Craig-Schimdt and Rong, 2009; Li *et al.*, 2019; Wanders *et al.*, 2017). The WHO in 2018 launched the REPLACE action package which serves to support governments to eliminate industrially produced TFA from the global food supply by 2023 and replacement of TFA with healthier oils and fats through six strategic actions, namely Review, Promote, Legislate, Assess, Create and Enforce (Ghebreyesus and Frieden, 2018). As of 2018, mandatory TFA limits are in effect in 34 countries and passed in 24 additional countries (World Health Organization, 2019). Amongst the Southeast Asian countries, Thailand and Singapore have banned PHO in their food supply while Indonesia has implemented a national policy commitment to eliminate TFA from their food products (Non-Communicable Diseases Alliance, 2019). In Malaysia, mandatory declaration of TFA and/or the setting of maximum limits of TFA in the food supply are still not in place; however, conditions for nutrient contents for use in nutrition claims are stipulated in the Malaysian Food Act 1983. For food claiming to be low in TFA, the maximum allowable limits are 1.5 g/100 g and 0.75 g/100 mL in both solids and liquids, respectively, while a product claiming to be TFA-free must contain no more than 0.1% TFA in both solids and liquids (Legal Research Board, 2015).

Palm oil products have long been regarded as excellent *trans*-fat replacement ingredients as they do not require hydrogenation due to the inherent saturated fatty acid components which provide structure to solid fats (Parveez *et al.*, 2020). To date, there are very few studies which have examined TFA levels in commercial food products available in the Malaysian market. One of the earliest studies by Tang (2002) investigated the TFA levels of various palm-based and non-palm-based vegetable oils from local manufacturers and retailers in Malaysia. The author found that the TFA content of palm-based products ranged between 0.25% and 0.67% while those of non-palm-based cooking oils were present at a higher range of 0.45% to 3.85%. Many authors have reported that the major sources of industrial TFA in the Malaysian diet are semi-solid fats and cooking oils, fast foods, bakery products, breakfast cereals, snacks, dairy products and fried foods (Akmar *et al.*, 2013; Azimah *et al.*, 2013; Nurshahbani and Azrina, 2014). The TFA contents of biscuits in the Malaysian market have also been reported in two separate studies by Neo *et al.* (2007); Norhayati *et al.* (2011). These studies reported that locally-made Malaysian biscuits possessed low TFA levels below 1% as a result of using palm oil in the ingredients whereas imported biscuits were found to contain higher levels of TFA between 0.03 and 3.09 g/100 g of total fatty acids. Karupaiah *et al.* (2014) examined the TFA content of 158 Malaysian supermarket food samples comprising fats and oils, dairy products, snacks, soups, confectionery, meat and meat products. Five products within the chocolate, ghee and butter products contained high TFA contents exceeding the 1.5 g/kg solids level indicated in the Malaysian Food Standard for a TFA nutrient label claiming a product as low *trans*.

Realising the need for an updated assessment of TFA levels in commercial cooking oils and fats, the aims of this study were to analyse the current levels of TFA in vegetable oils in the Malaysian market and to investigate the relationship between the levels of TFA and the contents of different fatty acid groups within the oils. It is hoped that this study would establish the present levels of TFA from retail cooking oils and fats which could contribute to the current TFA intake in the Malaysian population. This would provide authorities with an indication on TFA levels in vegetable oil products as a result of changes in refining and processing practices and further support the implementation of a national commitment for the elimination of TFA from food products on the Malaysian market.

MATERIALS AND METHODS

Materials

A total of 104 samples of vegetable oils were sampled in this study. The oils included refined, bleached and deodourised (RBD) palm-based oils and fats obtained from palm oil refineries throughout Malaysia and commercial vegetable oils and fats bought from major supermarkets as well as small sundry shops in the state of Selangor, Malaysia. The samples were collected between 2017 and 2019, and analysed within the same year. All samples were stored at 4°C and thoroughly homogenised prior to fatty acid composition analysis.

Fatty Acid Composition Analysis

The fatty acid composition was analysed according to the American Oil Chemists' Society (AOCS) Official Method Ce 1f-96 (AOCS, 2009). Methyl esters of fatty acids were analysed using an Agilent 6890 Series gas chromatography (GC) system (J&W Scientific, Folsom, USA) equipped with a flame ionisation detector (FID) (Agilent Technologies, Wilmington, USA) on a fused silica capillary column (BPX-70, 60 m length × 0.25 mm i.d., film thickness 0.25 µm, SGE Inc., Austin, TX). The column temperature was set at 192°C while injector (with split ratio 100:1) and detector temperatures were both set at 250°C. Helium (purity 99.999%) flowrate was set at 0.8 mL min^{-1}. FAME were identified based on the retention times of FAME mix standards, namely Grain FAME Mix (Supelco, Bellefonte, USA), rapeseed oil reference mixture (AOCS, Urbana, USA), linoleic acid methyl ester isomer mix (Supelco, Bellefonte, USA) and comparisons with earlier literature. Analyses were carried out in duplicate and reported as mean ± standard deviation (SD). All oil samples analysed in this study were categorised as refined oils and fats, hence the TFA content using the abovementioned procedure was defined as the sum of C18:1*t*, C18:2*t* and C18:3*t* components relative to the total fatty acids present in the oil sample. Results are reported in g per 100 g fat.

Statistical Analysis

One-way analysis of variance (ANOVA) was performed to evaluate significant differences between results using Tukey's test at a confidence level of 95% ($p<0.05$). Pearson's correlation coefficient was used to determine the relationship between TFA and selected fatty acid parameters, *i.e.*, saturated fatty acids (SFA), monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA). All statistical analyses were conducted using Minitab software (Minitab 16, Minitab Inc., State College, USA).

RESULTS AND DISCUSSION

Distribution of *Trans* Fatty Acids Content in RBD Palm-based Oils and Fats from Malaysian Refineries

The compositions of TFA, TFA isomers, SFA, MUFA and PUFA groups for RBD palm-based samples from Malaysian refineries are presented in *Table 1*. TFA was detected in all RBD palm-based samples with TFA concentrations varying from 0.12 ± 0.00 g/100 g to 0.84 ± 0.01 g/100 g. These results agree with Tang (2002) who demonstrated that small amounts of TFA present in refined palm oils are a result of thermal isomerisation due to the relatively high temperatures of up to 260°C employed during deodourisation. There was a significant difference between the TFA levels in RBD palm olein and RBD palm kernel olein. Higher TFA levels in RBD palm olein samples compared to that of RBD palm kernel olein can be attributed to higher deodourisation temperatures used during palm oil refining and higher content of PUFA in RBD palm olein compared to RBD palm kernel olein. This is supported by

TABLE 1. COMPOSITION OF TFA, TFA ISOMERS AND FATTY ACID GROUPS OF RBD PALM OIL AND PALM KERNEL OIL PRODUCTS FROM MALAYSIAN PALM OIL REFINERIES

RBD palm oil fractions	SFA (g/100 g)	MUFA (g/100 g)	PUFA (g/100 g)	C18:1*t* (g/100 g)	C18:2*t* (g/100 g)	C18:3*t* (g/100 g)	TFA (g/100 g)	Average TFA (g/100 g)
Palm oil (*n*=18)	50.38 ± 0.62	39.27 ± 1.19	9.99 ± 0.61	0.05 ± 0.01	0.34 ± 0.13	0.09 ± 0.03	0.24 – 0.67	0.48 ± 0.16
Palm olein (*n*=7)	44.62 ± 1.33	43.94 ± 0.92	10.99 ± 0.58	0.07 ± 0.02	0.45 ± 0.14	0.11 ± 0.02	0.39 – 0.84	0.62 ± 0.15
Palm stearin (*n*=3)	67.67 ± 0.22	25.92 ± 0.26	6.09 ± 0.06	0.06 ± 0.03	0.22 ± 0.01	0.06 ± 0.01	0.32 – 0.38	0.34 ± 0.03
Palm kernel olein (*n*=1)	74.08	22.09	3.75	0.04	0.08	ND	-	0.12

Note: Values expressed as mean ± standard deviation. The number of products (*n*) is descripted within parentheses.
SFA - saturated fatty acid; MUFA - monounsaturated fatty acid; PUFA - polyunsaturated fatty acids; TFA - *trans* fatty acids; ND - not detected.

a previous study by Tasan *et al.* (2011) which showed that PUFA such as linoleic acid (C18:2) and linolenic acid (C18:3) are more prone to geometrical isomerisation during deodourisation. Furthermore, the considerably lower TFA observed in palm kernel fractions can also be ascribed to the milder deodourisation temperatures of 240°C and below used during palm kernel oil refining (Tang, 2002).

The average TFA content of RBD palm-based samples in the present study were found to be slightly higher compared to the average TFA for similar sample groups in the study by Tang (2002). The author reported average TFA levels for RBD palm oil, RBD palm olein, RBD palm stearin and RBD palm kernel olein at 0.32 ± 0.16%, 0.30 ± 0.17%, 0.26 ± 0.13% and 0.03 ± 0.03%, respectively. The higher TFA values observed in this study suggest that there may be differences in refining practices employed by the Malaysian palm oil industry within the last two decades, in particular during the deodourisation step. Wolff (1993) previously showed that TFA formation strongly depends on heating time and deodourisation temperature, thus, prolonged deodourisation time at higher temperatures may increase TFA content of refined oils. Thus, it is possible that the use of higher deodourisation temperatures in the past few decades may have contributed to the rise in TFA levels in the current RBD palm-based samples in this study. All RBD palm-based samples in this study conformed to the condition for nutrition claims of low TFA levels in the Malaysian Food Act 1983 of 0.75 g per 100 mL liquid. Only one RBD palm olein sample with TFA level of 0.84 ± 0.01 g/100 g was found to exceed this limit.

Distribution of *Trans* Fatty Acids Content in Commercial Cooking Oils and Fats from Malaysian Supermarkets and Sundry Shops

Table 2 summarises the composition of TFA, TFA isomers and fatty acid groups of selected commercial cooking oils purchased in their final packaging form from supermarkets and sundry shops in Malaysia. The commercial cooking oil samples were grouped into different oil types, namely palm olein, canola oil, sunflower oil, soybean oil, corn oil, coconut oil, sesame oil, olive oil, peanut oil, rice bran oil, palm-based oil blend, canola-based oil blend, vegetable shortenings and premium oils. The premium oils category comprised of various cold pressed oils, specifically avocado oil, apricot kernel oil, almond oil, organic flaxseed (linseed) oil, unrefined pumpkin oil and safflower oil. The category also included macadamia oil, walnut oil, grapeseed oil, black seed oil and black seed and olive oil blend. TFA was detected in all the commercial cooking oil samples analysed in this study with the exception of cold pressed virgin coconut oil.

TABLE 2. COMPOSITION OF TFA, TFA ISOMERS AND FATTY ACID GROUPS OF COMMERCIAL VEGETABLE OILS IN MALAYSIA

Category	SFA (g/100 g)	MUFA (g/100 g)	PUFA (g/100 g)	C18:1*t* (g/100 g)	C18:2*t* (g/100 g)	C18:3*t* (g/100 g)	TFA Range (g/100 g)	TFA (g/100 g)
Palm olein (*n*=14)	43.65 ± 1.79	44.31 ± 1.28	11.79 ± 0.75	0.04 ± 0.01	0.26 ± 0.18	0.07 ± 0.04	0.04 – 0.86	0.37 ± 0.22
Canola oil (*n*=4)	7.51 ± 0.71	61.48 ± 3.57	30.79 ± 2.92	0.04 ± 0.01	0.28 ± 0.17	1.62 ± 0.54	1.43 – 2.96	1.94 ± 0.70
Sunflower oil (*n*=4)	9.18 ± 2.41	56.43 ± 33.53	34.24 ± 31.08	0.03 ± 0.02	0.16 ± 0.15	0.06 ± 0.03	0.10 – 0.47	0.24 ± 0.16
Soybean oil (*n*=2)	15.90 ± 0.25	24.49 ± 1.29	59.33 ± 1.34	0.08 ± 0.01	0.49 ± 0.23	1.06 ± 0.52	1.10 – 2.15	1.63 ± 0.74
Corn oil (*n*=4)	14.51 ± 0.37	32.04 ± 2.08	53.15 ± 2.31	0.05 ± 0.03	0.45 ± 0.23	0.14 ± 0.06	0.25 – 0.97	0.64 ± 0.30
Coconut oil (*n*=3)	92.23 ± 2.17	6.24 ± 1.40	1.52 ± 0.75	0.04 ± 0.01	0.03 ± 0.01	0.05 ± 0.01	0.00 – 0.14	0.06 ± 0.07
Sesame oil (*n*=5)	16.10 ± 0.58	41.68 ± 1.30	41.59 ± 1.55	0.18 ± 0.12	0.27 ± 0.15	0.33 ± 0.00	0.10 – 0.76	0.52 ± 0.27
Olive oil (*n*=8)	15.62 ± 0.95	74.49 ± 2.96	9.66 ± 2.21	0.07 ± 0.07	0.07 ± 0.04	0.07 ± 0.04	0.04 – 0.45	0.19 ± 0.14
Palm-based oil blend (*n*=6)	36.69 ± 6.35	41.45 ± 3.42	21.54 ± 9.63	0.05 ± 0.02	0.43 ± 0.25	0.20 ± 0.18	0.32 – 1.04	0.67 ± 0.33
Canola-based oil blend (*n*=6)	10.53 ± 3.71	54.21 ± 8.46	34.99 ± 7.97	0.03 ± 0.02	0.23 ± 0.19	1.13 ± 0.32	1.00 – 2.06	1.38 ± 0.39
Premium oils (*n*=11)	12.22 ± 3.78	45.72 ± 26.13	41.66 ± 27.81	0.04 ± 0.03	0.37 ± 0.62	0.37 ± 0.76	0.01 – 2.64	0.64 ± 0.93
Vegetable fat shortenings (*n*=5)	51.62 ± 13.79	31.42 ± 6.34	16.70 ± 19.28	0.06 ± 0.02	0.40 ± 0.20	0.26 ± 0.36	0.34 – 1.37	0.71 ± 0.44
Peanut oil (*n*=1)	16.69	61.65	21.42	0.04	0.19	0.09	0.32	0.32
Rice bran oil (*n*=1)	23.88	41.89	34.17	0.13	0.18	0.07	0.39	0.39

Note: Values are expressed as mean ± standard deviation. The number of products (*n*) is descripted within parentheses.
SFA - saturated fatty acid; MUFA - monounsaturated fatty acid; PUFA - polyunsaturated fatty acids; TFA - *trans* fatty acids.

Among the 75 commercial cooking oils analysed, the highest TFA levels were found in canola oil, followed by soybean oil and canola-based oil blends. This can be attributed to significantly higher contents of C18:3*t* in these three oil categories compared to all other oils. High TFA contents in soybean and canola oils are primarily caused by the geometrical isomerisation of their inherently high PUFA contents during deodourisation at temperatures above 200°C (Ceriani and Meirelles, 2007; Wolff, 1992). Higher concentrations of α-linolenic acid are present in canola oils and their bonds are more labile compared to that of linoleic acid, resulting in higher isomerisation degrees of α-linolenic acid (Kemény *et al.*, 2001). Hénon *et al.* (1999) reported that linolenic acid isomerisation in canola oil increases greatly beyond deodourisation temperatures of 220°C-230°C. Similar TFA levels were observed in US canola oils (TFA range 0.73-4.16 g/100 g) as reported by O'Keefe *et al.* (1994). The TFA of soybean oil in this study were comparable to values reported earlier by Tang (2002) (TFA range 1.63-3.83 g/100 g), Martin *et al.* (2008) for Brazilian soybean oils (TFA range 0.83-2.58 g/100 g) and Hou *et al.* (2012) for soybean oil from China (TFA range 0.23-3.11 g/100 g). However, the values were lower than those observed by Wolff (1993) for soybean oil from Great Britain (TFA range 1.73-2.52 g/100 g) and those by Akmar *et al.* (2013); Azimah *et al.* (2013), both reporting a mean TFA of 5.79 g/100 g for one soybean oil sample in Malaysia. This could be due to the wide variation in processing conditions by refiners which give rise to varying TFA levels in different soybean oil brands in Malaysia.

Commercial vegetable oils which showed TFA below 0.5 g/100 g include rice bran oil, palm olein, peanut oil, sunflower oil and coconut oil in descending order. The lowest TFA level amongst all commercial oils analysed was detected in coconut oil. The coconut oils in this study contained a significantly higher content of SFA (more than 90%) and relatively low amount of PUFA (less than 3%) compared to all other commercial oils. This was expected since coconut oil is well-known for its high saturated fatty acid content, comprising mainly medium-chain SFA such as lauric acid and myristic acid which give the oil higher thermal resistance. As a consequence, coconut oil requires deodourisation at lower temperatures between 240°C-250°C (Withana-Gamage *et al.*, 2005). The coconut oil category in this study included one cold pressed virgin coconut oil sample where TFA was not detected. This can be explained through the nature by which virgin coconut oil is obtained from fresh, mature kernel of the coconut by mechanical or natural means, with or without the application of heat and which does not result in the alteration of the nature of the oil (Phillipines National Standard, 2007). The TFA in coconut oils in our study agreed with those reported by Dayrit *et al.* (2011) for coconut oils from Phillipines and Marina *et al.* (2009) for Malaysian and Indonesian coconut oils.

Palm olein, rice bran and peanut oils contained similar TFA levels, however, the SFA content in palm olein was higher compared to the latter two. There were no significant differences between the MUFA and PUFA levels among the three oil categories with palm olein containing much lower PUFA levels compared to the other two oils. The major TFA isomer contributing to total TFA in all three oil types was C18:2*t*. As there was only one sample each for rice bran and peanut oils, there was insufficient data to draw a conclusion from these oils. However, results from this study were similar to that of Huang *et al.* (2016) who reported TFA levels ranging from 0.10-1.62 g/100 g and 0.1-1.63 g/100 g for palm oils and peanut oils in China, respectively.

A substantial reduction in the mean TFA was observed in sunflower oils to below 0.3 g/100 g in this study in comparison to the TFA levels for sunflower oils in Malaysia reported by Tang (2002) which exceeded 1%, and that of French sunflower oils (mean 0.5 g/100 g) in the study by Vingering *et al.* (2010). It is worth noting that the sunflower oil samples analysed in this study included conventional as well as high oleic sunflower oils which contained approximately 27% and 85% MUFA on average, respectively. The major TFA isomer in sunflower oil samples were those of C18:2*t*. The TFA observed in sunflower oils in this study could be attributed to the various sunflower oil species and possibly different refining methods used for the oils. High oleic sunflower oil predominantly contains oleic acid which is less prone to isomerisation compared to PUFA (Martinčič *et al.*, 2008). Tasan and Demirci (2003) demonstrated that physically refined sunflower oils contained a higher level of TFA (2.56 $\pm$ 0.25 g/100 g) compared to chemically refined sunflower oils (0.76 $\pm$ 0.27 g/100 g) due to the high temperature applied in the last stage of physical refining. The C18:3*t* range in sunflower oil samples was observed to be significantly lower compared to that of canola and soybean oils and equivalent to that of palm olein. Optimisation of processing conditions during the deacidification step of physical refining of sunflower oil, through the application of lower deodourisation temperatures and shorter heating times could minimise the degree of isomerisation of PUFA in sunflower oils (Ceriani *et al.*, 2008) and this may explain the reduced TFA levels of sunflower oils in this study.

A very low TFA level averaging at 0.19 g/100 g was found for the olive oil category and this could be due to the significantly higher MUFA content (more than 70%) compared to other commercial oils. The olive oils in this study included extra virgin olive oil, virgin + refined olive oil and olive pomace oil based on the labels provided on the packaging. Virgin olive

oils are obtained from the fruit of the olive tree solely by mechanical or other physical means, particularly thermal conditions that do not lead to alterations in the oil and have not undergone any treatment other than washing, decanting, centrifuging and filtration (Codex Alimentarius, 2015). On the other hand, olive pomace oil is obtained by treating olive pomace with solvents other than halogenated solvents or by other physical treatments, to the exclusion of oils obtained by re-esterification processes and of any mixture with oils of other kinds. The production of olive pomace oil also involves a drying step using hot drying gases normally within a temperature range of between 400°C and 800°C (Sánchez Moral and Ruiz Méndez, 2006). Amongst the olive oils sampled, extra virgin olive oils (n=3) contained the lowest levels of TFA (less than 0.1 g/100 g), while virgin olive oils (n=3) showed TFA levels less than 0.3 g/100 g. The highest level of TFA was observed in olive pomace oil (n=1) at 0.45 g/100 g oil. The varying TFA levels within the different types of olive oils are indicative of the different extraction processes and whether the oils had undergone any thermal treatment. TFA levels of all olive oils in this study were lower than that reported by Azimah *et al.* (2013) and Akmar *et al.* (2013) at 0.79 g/100 g and fell within the TFA ranges specified in the Codex Standard for Olive Oils and Olive Pomace Oils (Codex Alimentarius, 2015).

From the 14 commercial vegetable oil categories, five oil categories were found to contain TFA levels between 0.5-1.0 g/100 g. These included vegetable fat shortenings, palm-based oil blends, corn oil, premium oils and sesame oil in descending order. There were no significant differences (p<0.05) between the TFA levels of these oil categories, however, vegetable shortenings contained a significantly higher SFA content followed by palm-based blended cooking oils. This can be explained by the presence of palm-based solid fraction with 50%-60% SFA content as one of the solid fat ingredients used in four out of five of the vegetable shortenings samples (individual results not shown). Only one vegetable shortening sample contained fully hydrogenated palm oil and soybean oil as indicated in its ingredients list with over 50% PUFA. This consequently gave the highest TFA level of 1.37 g/100 g within this oil category. It is important to note that this study only considered shortenings derived from vegetable oils and fats in order to avoid the naturally occurring ruminant TFA that are usually present in dairy products.

TFA levels above 2 g/100 g were found in two out of the 13 premium oil samples (individual results not shown in *Table 2*), specifically cold pressed unrefined almond oil (2.18 g/100 g) and walnut oil (2.64 g/100 g). As the almond oil was cold pressed and unrefined, one would expect a significantly low TFA value for the almond oil as TFA levels below 0.3 g/100 g was detected in all the other cold pressed oils, *i.e.*, avocado, apricot, flaxseed, pumpkin seed and safflower oils. A possible explanation for the presence of TFA in cold pressed oils can be a result from mixing oils that have been deodourised under different conditions in the same tank or may be due to their storage in unswept tanks (Wolff, 1993).

The TFA of walnut oil in our study was higher than those reported by Wolff (1993) (range 0.84-1.83 g/100 g) for German and French walnut oils and Vingering *et al.* (2010) (range 0.9-1.7 g/100 g oil) for French walnut oil. The walnut oil sample in this study contained about 73% PUFA and the TFA value was mainly contributed by C18:3*t*. TFA was present at an average of less than 1 g/100 g in all other oils in the premium cooking oil category. The large variation in TFA values between commercial oil samples in this study may be influenced by the differences in oil species, processing conditions prior to packaging as well as any additional ingredients such as anti-oxidants or anti-clouding agents used in the oils (Azimah *et al.*, 2013). The nutrient conditions for claiming low TFA is met in all retail cooking oils and fats with the exception of soybean oils, canola oils, canola-based blended oils and one sample of palm olein blend, walnut oil, cold pressed unrefined almond oil and vegetable shortening containing soybean oil.

Relationship of TFA with Different Fatty Acid Groups

In this study, Pearson correlation analysis was carried out to determine the relationship between TFA with fatty acid groups SFA, MUFA, PUFA, as well as selected PUFA, namely C18:1, C18:2 and C18:3. The strength of the relationship between variables tested is expressed as Pearson correlation coefficient (r). Correlation between variables were defined as follows: very weak (0.0<r<0.3), weak (0.3<r<0.5), moderate (0.5<r<0.7), strong (0.7<r<0.9) and very strong (r>0.9) (Zady, 2000). The relationships were considered significant if p-value <0.05.

TABLE 3. PEARSON CORRELATIONS BETWEEN TFA AND DIFFERENT FATTY ACID GROUPS AND UNSATURATED FATTY ACIDS IN RBD PALM-BASED PRODUCTS FROM MALAYSIAN PALM OIL REFINERIES

Parameters	r	p-value
SFA	-0.549	0.002
MUFA	0.511	0.005
PUFA	0.587	0.001
C18:1	0.509	0.005
C18:2	0.581	0.001
C18:3	-0.117	0.546

Note: TFA - *trans* fatty acids.

Table 3 tabulates results from the Pearson correlation analyses between the levels of TFA and SFA, MUFA, PUFA, C18:1, C18:2 and C18:3 for all samples of RBD palm-based oils from Malaysian palm oil refineries. MUFA and PUFA showed significant moderate positive correlations with TFA (r=0.511 and r=0.587, respectively) while SFA displayed a significant moderate inverse correlation (r=-0.549), all showing p-value <0.05. The levels of C18:1 and C18:2 fatty acids both exhibited moderate positive correlations with TFA (r=0.509 and r=0.581, respectively) and the correlations were significant (p-value <0.05). On the other hand, C18:3 showed a very weak inverse correlation (r=-0.117) with TFA and the correlation was insignificant. It is worth noting that the levels of C18:3 present in the RBD palm-based samples were very low, ranging on average between 0.00 to 0.17 g/100 g total fat.

There were large variations in the TFA content found in the palm-based samples from Malaysian refineries produced by different manufacturers, presumably using dissimilar processing conditions. According to Gibon (2012), palm oils which undergo physical refining are more prone to form TFA compared to the chemical route due to the more severe thermal treatments applied during physical refining. Chemical refining involves the application of milder temperatures of between 220°C and 240°C compared to physical refining and Gibon *et al.* (2007) reported that a typical mean value of 0.6 g/100 g TFA was found in commercial palm oil products refined at 260°C-275°C with short residence times of 45-90 min. TFA formation can significantly accelerate if higher temperatures and longer residence times are employed. This was further demonstrated by Siew and Mohammad (1989) for palm olein and palm mid fraction which showed TFA values as high as 2.1 g/100 g and 1.5 g/100 g, respectively, when processed at 280°C.

In the case of commercial cooking oils, Pearson correlation coefficients between TFA and different fatty acid groups as well C18:1, C18:2 and C18:3 for all commercial vegetable oil samples are shown in *Table 4*. SFA yielded a weak negative correlation with TFA (r=-0.329) while PUFA, C18:2 and C18:3 displayed weak positive correlations (r=0.405; r=0.321; r=0.240, respectively) with TFA, and all these correlations were significant (p<0.05). This indicates that commercial vegetable oils with higher SFA tend to have lower TFA content and *vice versa* for oils containing higher PUFA concentration. These observations are in agreement with the study by Akmar *et al.* (2013) on the TFA content of selected foods in Malaysia. The authors concluded that high TFA prevailed in oils with low SFA content. Furthermore, it was observed that the TFA in all commercial vegetable oil samples were not associated with MUFA (r=-0.079) and C18:1 (r=-0.074). It is important to note that the majority of commercial vegetable oil samples in this study consisted primarily of refined oils. This observation appears to be consistent with Djikstra (2008) who reported that the main fatty acid to isomerise during hydrogenation is the monounsaturated oleic acid (C18:1). Previous studies have also shown that *trans* MUFA are generally produced by hydrogenation of vegetable oils or biohydrogenation in ruminants, whereas *trans* PUFA are formed as a result of deodourisation of oils or during frying treatments (Chen *et al.*, 2014; Stender *et al.*, 2008). These results suggest that the TFA present in commercial vegetable oils in this study were mainly associated with the levels of PUFA (C18:2 and C18:3) and not MUFA (C18:1).

TABLE 4. PEARSON CORRELATIONS BETWEEN TFA AND DIFFERENT FATTY ACID GROUPS AND UNSATURATED FATTY ACIDS IN COMMERCIAL VEGETABLE OIL SAMPLES

Parameters	*r*	*p*-value
SFA	-0.329	0.004
MUFA	-0.079	0.501
PUFA	0.405	0.000
C18:1	-0.074	0.529
C18:2	0.321	0.005
C18:3	0.240	0.039

Note: TFA - *trans* fatty acids.

CONCLUSION

The majority of palm-based cooking oils in Malaysia contained TFA below 1 g/100 g and were found to conform to the conditions for nutrition claims of low TFA in solid and liquid products, respectively, as regulated in the Malaysian Food Act 1983. All soybean, canola and canola-based blended oils as well as walnut and cold-pressed almond oils sampled contained TFA levels exceeding 1 g/100 g. In general, PUFA exhibited significant moderate positive correlations with TFA while SFA showed significant moderate inverse correlations with TFA in all oil categories. These findings indicate that the TFA in the oil samples were mostly generated through refining at high deodourisation temperatures and not through partial hydrogenation. Thus, it is imperative that vegetable oil manufacturers reassess the thermal conditions employed during processing in order to minimise the isomerisation of linoleic and linolenic acids. An overview of the overall TFA levels in various vegetable oils in Malaysia is crucial for manufacturers to evaluate current refining practices to meet the recommended TFA levels by WHO. Results evidently show that palm-based

oils and fats continue to be excellent alternative sources to PHO in the global quest to eliminate *trans* fat consumption by 2023. In addition, the findings provide further data in support of the national health authority for the implementation of a national commitment to eliminate TFA from food products on the Malaysian market.

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