View Article Online
View Journal

Food & Function

Linking the chemistry and physics of food with health and nutrition

Accepted Manuscript

This article can be cited before page numbers have been issued, to do this please use: C. Chen, P. Wang, Z. Zhang, Y. Ye, S. Zhuo, Q. Zhou, Y. M. Chen, Y. Su and B. Zhang, *Food Funct.*, 2020, DOI: 10.1039/D0FO00875C.

This is an Accepted Manuscript, which has been through the Royal Society of Chemistry peer review process and has been accepted for publication.

Accepted Manuscripts are published online shortly after acceptance, before technical editing, formatting and proof reading. Using this free service, authors can make their results available to the community, in citable form, before we publish the edited article. We will replace this Accepted Manuscript with the edited and formatted Advance Article as soon as it is available.

You can find more information about Accepted Manuscripts in the Information for Authors.

Please note that technical editing may introduce minor changes to the text and/or graphics, which may alter content. The journal's standard Terms & Conditions and the Ethical guidelines still apply. In no event shall the Royal Society of Chemistry be held responsible for any errors or omissions in this Accepted Manuscript or any consequences arising from the use of any information it contains.

ROYAL SOCIETY OF CHEMISTRY

rsc.li/food-function

View Article Online
DOI: 10.1039/D0FO00875C

Effects of plant oils with different fatty acid composition on cardiovascular risk factors in moderately hypercholesteremic Chinese adults: a randomized, double-blinded, parallel-designed trial

Chao-Gang Chen MD [a]; Ping Wang PhD [b]; Zhe-Qing Zhang PhD [c]; Yan-Bin Ye MD, PhD [d]; Shu-Yu Zhuo MD [d]; Quan Zhou PhD [e]; Yu-Ming Chen PhD [f]; Yi-Xiang Su MD [g]; Bo Zhang PhD [h]

[a] Department of Clinical Nutrition, Sun Yat-sen Memorial Hospital, Sun Yat-sen University, Guangzhou, 510012, P. R. China

[b] Guangdong Provincial Institute of Public Health, Guangzhou 511430, P. R. China

[c] Department of Nutrition and Food Hygiene, Guangdong Provincial Key Laboratory of Tropical Disease Research, School of Public Health, Southern Medical University, Guangzhou 510515, P. R. China

[d] Department of Clinical Nutrition, the First Affiliated Hospital of Sun Yat-sen University, Guangzhou510080，P. R.China

[e] Department of Nutrition and Food Hygiene, School of Public Health Guangzhou Medical University Guangzhou 510182, P. R. China

[f] Department Epidemiology, School of Public Health, Sun Yat-sen University, Guangzhou, 510080, P.R. China

[g] Department of Nutrition, Guangdong Provincial Key Laboratory of Food, School of Public Health, Sun Yat-Sen University, Guangzhou 510080, P. R. China

View Article Online
DOI: 10.1039/D0FO00875C

[h] Food Safety and Health Research Center, Guangdong Provincial Key Laboratory of Tropical Disease Research, School of Public Health, Southern Medical University，Guangzhou 510515, P. R. China

Correspondence Information

Address correspondence to:

Yi-Xiang Su, Department of Nutrition, Guangdong Provincial Key Laboratory of Food, School of Public Health, Sun Yat-Sen University, Guangzhou 510080, P. R. China

Email: suyx@mail.sysu.edu.cn

Bo Zhang, Food Safety and Health Research Center, Guangdong Provincial Key Laboratory of Tropical Disease Research, School of Public Health, Southern Medical University，Guangzhou 510515, P. R. China;

Email: cnzhangbo@126.com.

View Article Online
DOI: 10.1039/D0FO00875C

Abbreviations:

ALA, α-Linoleic acid;

AA, Arachidonic acid;

BMI, Body mass index;

hsCRP, high sensitivity C-reactive protein;

CVD, Cardiovascular disease;

DHA, Docosahexaenoic acid;

EPA, Eicosapentaenoic acid;

HOMA-IR, Homeostasis model assessment insulin resistance index;

LA, Linoleic acid;

MUFAs, Monounsaturated fatty acids;

PUFAs, Polyunsaturated fatty acids;

SFAs, Saturated fatty acids.

View Article Online
DOI: 10.1039/D0FO00875C

Abstract

Objectives: Plant oil for cooking typically provides 40% to 50% of dietary fat，65% of linoleic acid，44% of α-linolenic acid and 41% of oleic acid in the Chinese diet. However, the comparative effects of fatty acids derived from plant oil on cardiovascular risk factors in Chinese are still inconclusive. Hence, the aim of this study was to investigate whether cardiovascular risk factors are altered depending on various types of plant oil such as peanut oil rich in oleic acid, corn oil rich in linoleic acid, and blend oil fortified by α-linolenic acid.

Design: A randomized, double-blinded, parallel-designed trial.

Setting: The First and the Second Affiliated Hospital of Sun Yat-sen University Guangzhou, China.

Participants: A total of 251 volunteers with fasting blood total cholesterol between 5.13 and 8.00 mmol/L were enrolled.

Intervention: Volunteers received peanut oil, corn oil or blend oil to use for cooking for one year.

Main outcome measures: The erythrocyte membrane fatty acid composition, fasting plasma lipids, glucose and insulin concentrations and high sensitivity C-reactive protein (hsCRP) levels were measured before, during and after the intervention. The level of α-linolenic acid in erythrocyte membrane was significantly increased in blend oil group after the intervention ($P < 0.001$). The level of other fatty acids did not show any statistically significant differences between the three groups. No significant differences were observed in the concentrations of fasting plasma lipids, hsCRP, glucose, and

View Article Online
DOI: 10.1039/D0FO00875C

insulin among the three groups using different types of plant oil.

Conclusions: The results suggest that although ingesting cooking oil with different fatty acid composition for one year could change erythrocyte membrane fatty acid compositions, it did not significantly modify cardiovascular risk factors in moderately hypercholesteremic people.

Key words:

plant oil, randomized double-blinded parallel-designed trial, cardiovascular risk factors, fatty acids

Strength and limitations of this study:

- This is a one-year, randomized, double-blinded, and parallel-designed trial to explore the effects of plant oil on cardiovascular risk factors in moderately hypercholesteremic Chinese adults.
- This trial could provide some clues for further long-term interventions using plant oil on CVD risk factors in the real world.
- Total dietary fatty acids, especially fatty acids derived from meat and other fat-rich food were not accurately assessed in the observed participants.

View Article Online
DOI: 10.1039/D0FO00875C

1. Introduction

Cardiovascular diseases (CVDs) are the leading cause of death worldwide. The global mortality number attributed to CVDs was over 17.6 million in 2016 [1]. Among them, approximately 10 million deaths were attributed to 16 dietary risk factors such as diets high in red meat that are rich in saturated fatty acids (SFAs), diets low in polyunsaturated fatty acids (PUFAs), and diets low in seafood n-3 fatty acids, etc. [2]. In order to prevent CVDs, many dietary guidelines recommend reducing the intake of total fat and replacing SFAs with unsaturated fats – preferentially polyunsaturated fats as the beneficial effects of monounsaturated fat on CVDs are of less paucity of evidence [3-5]. However, it is unclear which unsaturated fatty acids (UFAs) are preferred and where the best UFAs could be obtained from. Furthermore, it is also debatable whether the recommendations based on findings mainly from the developed countries could be applicable to the developing countries such as China, where both dietary and disease patterns have undergone rapid changes in the past several decades.

In China, the overall mortality attributed to CVDs increased from 2.6 million in 1990 to 3.7 million in 2013[6]. Meanwhile, the energy contribution from fat intake increased from 12.0% in 1982 to 32.3% in 2012. Specifically, SFAs intake increased by 4.1% and PUFAs increased by 5.7% in total daily energy intake. [7]. Although some obvious improvements of several dietary factors in China have been observed in the past few decades, current dietary fat intake remain suboptimal, and poor diet quality is estimated to be responsible for a substantial proportion of CVD deaths in Chinese population.

View Article Online
DOI: 10.1039/D0FO00875C

In the Chinese diet 40-50% dietary fat is obtained from plant cooking oils. The average intake of plant oil per capita has increased from 9.6 g per day in 1982 to 33.8 g per day in 2012 [7]. Plant oil provides 33% of SFAs, 65% of linoleic acid (LA), 44% of α-linolenic acid (ALA), and 41% of oleic acid in daily diets according to the China Health and Nutrition Survey in 2011 [8]. The fatty acid proportions of plant oils vary greatly, which potentially impacts on CVD risk. The long-term relationships between dietary fat intake and risk of CVDs could be explained–at least partly–by the roles of dietary fatty acids in the development of CVDs [9]. It is well known that the biological reactivity of fatty acids is determined both by the length of the carbon chain, as well as the number and position of double bonds. SFAs are believed to increase low-density lipoprotein cholesterol (LDL-c), which is a strong risk factor for CVDs [10]. From a combined result of different meta-analyses Schwingshackl et al. reported that there was a beneficial effect from the diets rich in monounsaturated fatty acids (MUFAs) on systolic and diastolic blood pressure as well as parameters of glycemic control, however the impact of MUFAs on blood lipids is still controversial [11]. Plant-derived PUFAs are primarily LA, which is much prevalent than ALA in plant oils. Both ALA and LA lower LDL-c when replacing saturated fats. However, unlike LA, ALA may decrease high-density lipoprotein cholesterol (HDL-c) concentrations [12]. A meta-analysis summarizing the results of randomized controlled trials (RCTs) indicated that increasing plant-derived n-6 PUFAs intake slightly reduced total cholesterol (TC) and probably decreased triglycerides (TG), with no obvious effects on HDL-c or LDL-c [13]. There is compelling evidence suggesting certain types of fatty acids are related to CVD

risk, however, the cardiovascular effects from plant-sourced cooking oils with different fatty acid profiles are still unclear.

Corn oil, containing 55% LA and 28% oleic acid, is viewed as "healthy" oil as it is rich in n-6 PUFA. Peanut oil, having 43% oleic acid and 34% LA, is the most popular plant oil in the Chinese diet for its special flavor. In addition, one type of blend oil contains extra 7% ALA by slightly replacing SFAs for balancing n-6 and n-3 fatty acid, which has similar fatty acid profile with peanut oil except for ALA. To date there is no consensus on the relationships of plant oils with different fatty acid composition and CVD risk. In this study, we conducted a one-year randomized, double-blinded, and parallel-designed trial to compare the effects from daily intake of these three plant oils with different ratios of SFA, MUFA, and PUFA (peanut oil *vs* corn oil), as well as different ratios of LA and ALA (peanut oil *vs* blend oil) on a series of risk factors of CVD among free living Chinese adults with moderate hypercholesterolemia [14]. The change in blood total cholesterol (TC) is the primary outcome and the secondary outcomes include change in low- and high-density lipoprotein cholesterol (LDL-c and HDL-c), change in weight, body mass index (BMI), waist circumference, systolic and diastolic blood pressure, fasting plasma glucose, insulin and high sensitivity C-reactive protein (hsCRP). The fatty acid composition of erythrocyte membrane was analyzed to assess the participants' compliance, and also to serve as biomarkers to explore the effects of long-term interventions of plant oils on the body's fatty acid composition.

2. Experimental Procedures

View Article Online
DOI: 10.1039/D0FO00875C

2.1 Subjects

Subjects aged from 40 to 65 years were recruited by sending invitation letters to residential buildings, posting advertisements on bulletin board, giving health talks in communities, and contacting patients in the nutrition clinic of the first and the second affiliated hospital of Sun Yat-sen university, Guangzhou, Guangdong province of China from December 2005 to April 2006. The subjects with a plasma total cholesterol (TC) concentration between 5.13 and 8.00 mmol/L and a fasting plasma glucose below 6.11 mmol/L were included. Subjects with evidence of CVDs, diabetes mellitus, liver or other metabolic dysfunction, and mental disability were excluded. In addition, subjects taking any drugs known to affect plasma lipids in the past three months were also excluded. Among 739 original participants, a total of 251 subjects were finally enrolled. Of the total 155 were females and 96 were males. All participants signed the written informed consent prior to the enrollment. The study protocol was approved by the Medical Ethics Committee of School of Public Health, Sun Yat-sen University.

2.2 Study design

This was a randomized, double-blinded and parallel-designed trial. Subjects were asked to replace their accustomed oil with one of three tested oils (peanut oil, blend oil, and corn oil) for a one-year period. Table 1 shows the fatty acid compositions of the three types of oil. The recommended oil usage was 25 g/day (approximate 28 mL/day). A 50-mL cylindrical glass was supplied as a measuring tool for all participants. All subjects were asked to record their dietary intake of oil per meal in the first month of

View Article Online
DOI: 10.1039/D0FO00875C

the trial, as well as to reduce the frequency of eating out (less than two times per week). At the beginning of the trial, all subjects received the dietary guidelines for Chinese residents, which are proposed by the Chinese Nutrition Society.

All subjects were asked to visit the nutrition clinic regularly (about once per month) to take two bottles of the tested oil and return the empty bottles. According to the record, the subjects daily consumed 30 mL cooking oil on average (approximately 27 g which was 2 g more than the planned dosage) .

The subjects' characteristics and demographic data were recorded when they were enrolled into study. Anthropometric, physical and blood pressure measurements were also performed. A 20 mL fasting blood sample was collected at month 0 (trial start time), month 3, month 6, and month 12 (trial end time). The blood samples were sent to the laboratory at room temperature on the same day for sample processing, analysis and storage. A food frequency questionnaire (FFQ) was completed at start and end time of the trial. The details of the protocols were described in our previous publication [15].

2.3 **Randomization and blinding**

When the baseline tests were completed, subjects were randomly assigned to one of the three groups in random blocks of 15. A list of randomization numbers was computer-generated by a person who was not involved in the trial. Each randomization number corresponded to one intervention. Randomization numbers were assigned to the subjects in the order of enrollment. The taste and packaging of the three types of oil were identical. In order to ensure the efficacy of blinding, the participants were asked

View Article Online
DOI: 10.1039/D0FO00875C

which group they thought they were assigned to at the end of intervention. The proportions of the correct estimation for the peanut oil, blend oil and corn oil were 7%, 36% and 11%, respectively($P < 0.001$).

2.4 Erythrocyte membrane fatty acids

To assess compliance of the participants in the trial, and also to explore the effects of long-term interventions of plant oils on the fatty acid composition of the body, the erythrocyte membrane fatty acid compositions were analyzed. The venous blood samples of each subjects were taken in the vacutainer tubes containing EDTA-K3 (≤2 mg/ml of blood) and they were centrifuged at 900 rpm for 15 min at room temperature. After isolation of plasma, the white blood cells, platelets, and erythrocytes were washed three times with an equal volume of saline solution in order to eliminate the residual plasma and buffy coat. After another centrifugation at 3,000 rpm for 10 min (hematocrit = 98%), several aliquots of 500 µl of packed RBC with 2% butylated hydroxytoluene (BHT) in methanol (0.1 mg/ml of packed RBC) and N_2 were immediately frozen in 2-ml plastic microtubes at -80°C until assay.

Erythrocytes were thawed and hemolyzed in hypotonic Tris-HCl buffer, then lipids were extracted by chloroform/methanol (2:1, v/v) supplemented with 0.005% BHT. The extract was dried in N_2. Fatty acids methyl esters (FAMES) were obtained by incubating with 14% boron trifluoride ether/methanol (1:3, v/v) solution at 100°C, and were analyzed by gas chromatography as described in our previous articles [16, 17].

Individual fatty acid was identified by comparison with the standards (Sigma-

View Article Online
DOI: 10.1039/D0FO00875C

Aldrich Inc., St. Louis, MO, USA) and expressed as a percentage of total fatty acids quantified from peak areas. Of 32 fatty acids identified in erythrocyte membranes, 19 fatty acids demonstrating meaningful concentrations (mean concentration > 0.10 %) were reported here, which together accounted for 96.9% of total identified fatty acids.

Blinded (indistinguishable from other samples) duplicate samples (n = 40) were analyzed throughout the study. The range of coefficients of variation (CVs) for these samples was 5.2–36.8%. The CVs for the most abundant fatty acids were 5.2% for palmitic acid (16:0), 10.5% for stearic acid (18:0), 8.1% for oleic acid (18:1n-9), 11.5% for α-linolenic acid (18:3n-3), 8.5% for linoleic acid (18:2n-6), 15.2% for eicosapentaenoic acid (EPA; 20:5n-3) and 9.5% for docosahexaenoic acid (DHA; 22:6n-3).

2.5 Diet assessments

Dietary intakes of energy and nutrients were assessed at the beginning and at the end of the study using the quantitative food frequency questionnaire (FFQ).It is a comprehensive questionnaire containing 119 items of food or food groups that was validated to estimate the intake of fatty acids among Chinese adults in South China [16]. The food intake frequency contains four categories: times per day, week, month or year. The questionnaires were completed through a face-to-face interview by trained staff. For each food item of FFQ, participants were asked to recall how often and how much on average they consumed over the preceding year.

2.6 Plasma lipids and glucose

View Article Online
DOI: 10.1039/D0FO00875C

Plasma was separated and stored at -80°C until it was tested. All samples were analyzed in a single batch within 5 days to minimize laboratory variability. Plasma lipids profiles were detected at month0, 3, 6 and 12 of the trial. TC, HDL-c, LDL-c, TG, ApoA1 and ApoB were measured with colorimetric methods using commercial kits (Biosino Biotechnology Company Ltd, Beijing, China) by an automated analyzer (A25 Biosystem, Barcelona, Spain). Fasting glucose concentration was measured by using the glucose oxidase method (Roche, Basel, Swiss). The CVs for lipid and glucose measurements were described previously[15, 17].

Plasma hsCRP was measured by the Hitachi 7170A automatic analyzer in the clinical biochemistry laboratory at the First Affiliated Hospital of Sun Yat-Sen University. The CVs were 6.51% at 0.44 mg/dL and 2.06% at 3.06 mg/dL.

Plasma insulin was measured by radioimmunoassay (Beijing North Institute of Biotechnology Co. Ltd.). The HOMA-IR indices were calculated to evaluate insulin sensitivity. The calculation formula is as follows: HOMA-IR = [fasting plasma insulin (mIU/L)] X [fasting plasma glucose (mmol/L)]/22.5.

2.7 Statistical analysis

Of the 251 enrolled participants eight participants were excluded from the intention-to-treat analysis because they received medical treatment during the intervention period though they all completed one-year follow-up. For the 24 participants who lost to the follow-up, the last-observation-carried-forward method was used. Per-protocol analysis restricted to the 219 participants who completed the one-year intervention was also

View Article Online
DOI: 10.1039/D0FO00875C

performed as a sensitivity analysis.

All results are expressed as mean ± SD. The absolute change and its 95% confidence interval (95% CI) in BMI, systolic blood pressure (SBP), diastolic blood pressure (DBP), lipids, glucose, high sensitivity C-reactive protein (hsCRP), and erythrocyte membrane fatty acid levels from baseline to 12 months or six months were calculated by subtracting the baseline value from the 12-month or six-month value. Analysis of variance (ANOVA) was performed to evaluate the absolute treatment effects among the three groups. Differences between groups were estimated and tested using Bonferroni pairwise comparisons within each outcome if significant difference was observed among the three groups. All analyses were conducted with SPSS for Windows (version 21.0, SPSS, Inc., Chicago, IL). $P < 0.05$ was considered as statistically significant.

3. Results

A total of 739 volunteers were screened for eligibility, among whom 446 subjects were excluded. Reasons for exclusion were mainly based on predefined inclusion and exclusion criteria. Forty-two females were also excluded as their husbands were included. For the final 251 recruited participants, eight were removed from the intention-to-treat analysis because they had seen the doctor at least once during the one-year trial for the reasons that might affect the outcomes. Twenty-four participants who were lost to follow-up were further excluded in per-protocol analysis (**Figure 1**).

The descriptive characteristics of 151 females an 92 males in the intention-to-treat

View Article Online
DOI: 10.1039/D0FO00875C

analysis were shown in table 2. The mean (SD) age of females and males was 54.2 ± 5.2 years and 57.2 ± 7.2 years, respectively (P = 0.017). Only one woman was a current-smoker, while 50% of men were current-smokers. The education levels were similar between men and women (P > 0.05). The baseline characteristics were similar across the three groups (data not shown).

3.1 Dietary intake and fatty acid composition of erythrocyte membrane

Table 3 presents the dietary intakes of energy and nutrients in each group. The average of energy intakes in the peanut, blend and corn oil group were 2309.9 ± 572.4, 2333.1 ± 588.1, and 2312.6 ± 559.7 kcal/day at baseline and reduced to 2161.4 ± 495.1, 2248.2 ± 593.2, and 2072.3 ± 425.1 kcal/day at month 12, respectively. The percentage of dietary fat that contributed to total energy reduced significantly by 4.1%, 2.5%, and 3.1% in the peanut, blend and corn oil group respectively, but the changes had no significant difference among the groups (P = 0.331). In the context of reduced intake of dietary fat, the intakes of SFA, MUFA, and PUFA of all participants also decreased during the intervention period. As cooking oil is the main source of dietary unsaturated fatty acids, the intake of n-6 PUFA increased dramatically in the corn oil group, and the intake of n-3 PUFA increased greatly in the blend oil group. The differences among the three groups are statistically significant (all P < 0.001).

The changes of the fatty acid composition in the erythrocyte membrane are shown in Table 4. Consumption of the ALA-rich blend oil for one year increased the content of ALA in the erythrocyte membrane from 0.099 ± 0.039% to 0.125 ± 0.029% (net

View Article Online
DOI: 10.1039/D0FO00875C

difference: +0.027%; 95% CI: 0.013%, 0.041%). In contrast, subjects who consumed corn oil experienced a significant decrease of ALA content from 0.118 ± 0.059% to 0.100 ± 0.029% (net difference: -0.018%; 95% CI: -0.034%, -0.003%). (P ＜0.001). The proportions of SFA, MUFA, and eicosapentaenoic acid (EPA) in the erythrocyte membrane decreased significantly, while the proportions of PUFA, n-6 PUFA, LA, and arachidonic acid (AA) significantly increased. However, these changes showed no significant difference among three groups (all P ＞ 0.05, Table 4).

3.2. Effects on the outcome parameters

The effects of different types of plant oil on BMI, blood pressure, serum glucose, lipid profiles, insulin and hsCRP are shown in Table 5. After one-year intervention the subjects' BMI, systolic blood pressure, diastolic blood pressure, total cholesterol, LDL-cholesterol, triglyceride, ApoA1, and ApoB have improved in all participants, but with no statistically significant difference among the three groups .

Per-protocol analysis did not change the results essentially (data not shown).

Discussion

In the present study, we aimed to determine whether the use of three plant oils with different fatty acid compositions would result in different effects on the established risk factors of CVD in moderately hypercholesteremic individuals. Our data showed that fatty acid composition of the erythrocyte membrane was significantly affected. However, there were no significant differences in the cardiovascular risk factors among

View Article Online
DOI: 10.1039/D0FO00875C

the three groups.

It is well established that replacement of SFAs with LA could decrease LDL-c [18, 19]. Additionally, increased dietary LA intake may improve insulin resistance [20]. A recent meta-analysis of RCTs suggested n-6 PUFA, mainly LA, significantly improved insulin secretion capacity when replacing SFA [21] . The effects of oleic acid and LA on CVD risk factors were seldom compared directly. Previous studies showed that both oleic acid and LA raised HDL-c, slightly lowered LDL-c and lowered TG when substituting for carbohydrate [22]. Our study is consistent with the previous statement. Our results indicated that peanut oil rich in oleic acid (43% of total fatty acids） had similar effects on CVD risk factors as corn oil which contained 55% LA.

There is a long-standing concern about the side effects of dietary LA on the inflammatory measures because LA is the precursor of arachidonic acid (AA), which is the substrate for the synthesis of a variety of pro-inflammatory molecules. Hence the health effects of ALA and LA have been widely compared for their potential antagonistic effects. Table S1 summarizes the characteristics and major findings from nine RCTs. Three of nine trials that performed in healthy subjects with normal blood lipids did not find any significantly different effects between the ALA and LA group [23-26]. However, among another six trials in subjects with different types of dyslipidemia [27-35], four studies demonstrated that ALA and LA had different effects, especially on inflammatory markers and blood lipid profiles [27, 31-34, 36]. Based on these combined data, the potential different effects of ALA and LA might be more marked in subjects with high risk of CVDs. However, our study that performed in moderately

View Article Online
DOI: 10.1039/D0FO00875C

hypercholesteremic adults did not observe any significantly different effects between the peanut oil (LA)and blend oil (ALA) groups. The most important factor attributed to these discrepancies may be the amount of ALA intake per day. The net difference of ALA intake between the ALA group and the LA group is a minimum of 0.8 g/day [26] and a maximum of 10 g/day [36] in the above-mentioned nine trials. ALA intake per day is greater than 5.0 g/day in eight of the nine trials. In contrast, the net difference of the present study was 1.7 g/day (1.9 g/day in blend oil *vs* 0.2 g/day in corn oil). In the previous studies, only Kaul et al. used such a low dosage [26]. Consistently, they also failed to observe any significant effects on lipid profile, LDL oxidation or platelet aggregation over a 12-week intervention in healthy participants. Moreover, Kaul et al. also reported that supplementation with flaxseed oil (50% ALA and 14% LA) resulted in a significant but modest increase in plasma ALA. It is also consistent with our study. We showed that consumption of the ALA-rich blend oil for one year significantly increased the content of ALA in erythrocyte membrane.

There is compelling evidence suggesting that increased consumption of EPA and docosahexaenoic acid (DHA) from fish could reduce risk of CVDs and all-cause mortality [4]. However, data on the effects of ALA on CVD outcomes are limited and of poor quality[37, 38]. ALA is considered the precursor of EPA and DHA. Therefore, ALA EPA, and DHA should have similar physical effects on CVD risk when the amount of intake is biologically equivalent. In the present study, after a one year intervention, the percentages of EPA and DHA in erythrocyte membrane were not significantly different among the three groups. This suggested that ALA supplementation did not induce an

View Article Online
DOI: 10.1039/D0FO00875C

increase of EPA and DHA *in vivo*. In the study by Bemelmans et al. the subjects are given 6.3 g/day and 1.0 g/day ALA intakes in the ALA and LA groups for 2 years, respectively. They observed a significant difference in the changes of EPA and AA composition in the serum cholesteryl ester, which is consistent with their finding that the ALA group has a lower HDL-c, higher serum triacylglycerol and lower plasma fibrinogen [27].

It is important to emphasize that we do not negate the potential healthy significance of ALA as an essential fatty acid on the cardiovascular system. Other than the relatively low intake of ALA, choosing LA but not animal fat rich in SFA as a control might be another factor contributing to the nonsignificant associations. We prefer to conclude that ALA was a fatty acid as "good" as LA, and the replacement of LA with ALA might have an equal effect on the risk of CVD development.

Our investigation benefited from a relatively large sample size and longer period of intervention than most of the previous trials. Our study provided evidence for the real-world interventions using plant oils. Potential limitations should also be considered. Firstly, although plant oil is the maximum dietary source of oleic (41%), linoleic (65%), and α-linolenic acid (44%), the fatty acids derived from meat and meat products as well as other fat-rich food were not accurately assessed . Secondly, it is hard to estimate the actual consumption of plant oil for each subject during the one-year period although we provided measuring cylinder and collected empty bottles. Thirdly, we did not collect the information on the cooking styles when they used the plant oils, which may modify the health effects of plant oil. Finally, these results can only be generalized to the

View Article Online
DOI: 10.1039/D0FO00875C

specific study population enrolled in this study and it might not be applicable to other individuals such as those with different metabolic profiles, other race/ethnic populations, etc.

In summary, our study showed that using either peanut oil, blend oil, or corn oil with different fatty acid compositions had no impact on plasma lipids, glucose, and insulin after one-year intervention in moderately hypercholesteremic Chinese adults.

View Article Online
DOI: 10.1039/D0FO00875C

Acknowledgements

The authors wish to thank Dr. Michael Routledge (University of Leeds, UK) and Dr. Jinhui Li (The University of Hong Kong, China)for their kind help with the English language.

Competing interests

The authors report no conflicts of interest and all are alone responsible for the content and writing of the paper.

Ethics approval and consent to participate

Ethics approval for the study was obtained from the School of Public Health, Sun Yat-sen University and informed consent was obtained from each participant.

Consent for publication

Not applicable.

Funding

National Natural Science Foundation of China (30872102)

Availability of data and materials

The datasets for the current study are available from the corresponding author on reasonable request.

Authors' contributions

CCG, WP, YYB, ZSY, ZQ and ZB contributed to the data collection and analysis and the manuscript preparation. ZZQ contributed to manuscript preparation. CYM contributed to study design and statistical analysis. SYX and ZB were responsible for the conception and design of the study and critical revision of the manuscript.

View Article Online
DOI: 10.1039/D0FO00875C

1. GBD 2016 Causes of Death Collaborators. Global, regional, and national age-sex specific mortality for 264 causes of death, 1980-2016: a systematic analysis for the Global Burden of Disease Study 2016, *Lancet (London, England)*, 2017, **390**, 1151-1210.
2. GBD 2017 Diet Collaborators. Health effects of dietary risks in 195 countries, 1990-2017: a systematic analysis for the Global Burden of Disease Study 2017, *Lancet (London, England)*, 2019, **393**, 1958-1972.
3. Central Committee for Medical and Community Program of the American Heart Association. Dietary fat and its relation to heart attacks and strokes, *Jama*, 1961, **175**, 389-391.
4. F. M. Sacks, A. H. Lichtenstein, J. H. Y. Wu, L. J. Appel, M. A. Creager, P. M. Kris-Etherton, M. Miller, E. B. Rimm, L. L. Rudel, J. G. Robinson, N. J. Stone and L. V. Van Horn, Dietary Fats and Cardiovascular Disease: A Presidential Advisory From the American Heart Association, *Circulation*, 2017, **136**, e1-e23.
5. *Scientific Report of the 2015 Dietary Guidelines Advisory Committee. Washington, DC: US Department of Agriculture; 2015.*
6. M. Zhou, H. Wang, J. Zhu, W. Chen, L. Wang, S. Liu, Y. Li, L. Wang, Y. Liu, P. Yin, J. Liu, S. Yu, F. Tan, R. M. Barber, M. M. Coates, D. Dicker, M. Fraser, D. Gonzalez-Medina, H. Hamavid, Y. Hao, G. Hu, G. Jiang, H. Kan, A. D. Lopez, M. R. Phillips, J. She, T. Vos, X. Wan, G. Xu, L. L. Yan, C. Yu, Y. Zhao, Y. Zheng, X. Zou, M. Naghavi, Y. Wang, C. J. Murray, G. Yang and X. Liang, Cause-specific mortality for 240 causes in China during 1990-2013: a systematic subnational analysis for the Global Burden of Disease Study 2013, *Lancet (London, England)*, 2016, **387**, 251-272.
7. Y. He, Y. Li, X. Yang, E. C. Hemler, Y. Fang, L. Zhao, J. Zhang, Z. Yang, Z. Wang, L. He, J. Sun, D. D. Wang, J. Wang, J. Piao, X. Liang, G. Ding and F. B. Hu, The dietary transition and its association with cardiometabolic mortality among Chinese adults, 1982-2012: a cross-sectional population-based study, *The lancet. Diabetes & endocrinology*, 2019, **7**, 540-548.
8. X. Shen, A. Fang, J. He, Z. Liu, M. Guo, R. Gao and K. Li, Trends in dietary fat and fatty acid intakes and related food sources among Chinese adults: a longitudinal study from the China Health and Nutrition Survey (1997-2011), *Public health nutrition*, 2017, **20**, 2927-2936.
9. L. Schwingshackl, B. Bogensberger, A. Bencic, S. Knuppel, H. Boeing and G. Hoffmann, Effects of oils and solid fats on blood lipids: a systematic review and network meta-analysis, *Journal of lipid research*, 2018, **59**, 1771-1782.
10. R. P. Mensink, *Effects of saturated fatty acids on serum lipids and lipoproteins: a systematic review and regression analysis*, World Health Organization, Geneva, Switzerland, 2016.
11. L. Schwingshackl and G. Hoffmann, Monounsaturated fatty acids and risk of cardiovascular disease: synopsis of the evidence available from systematic reviews and meta-analyses, *Nutrients*, 2012, **4**, 1989-2007.
12. G. C. Burdge and P. C. Calder, Dietary alpha-linolenic acid and health-related outcomes: a metabolic perspective, *Nutrition research reviews*, 2006, **19**, 26-52.
13. A. S. Abdelhamid, N. Martin, C. Bridges, J. S. Brainard, X. Wang, T. J. Brown, S. Hanson, O. F. Jimoh, S. M. Ajabnoor, K. H. Deane, F. Song and L. Hooper, Polyunsaturated fatty acids for the primary and secondary prevention of cardiovascular disease, *The Cochrane database of systematic reviews*, 2018, **11**, Cd012345.

View Article Online
DOI: 10.1039/D0FO00875C

14. H. N. Nguyen, A. Fujiyoshi, R. D. Abbott and K. Miura, Epidemiology of cardiovascular risk factors in Asian countries, *Circulation journal : official journal of the Japanese Circulation Society*, 2013, **77**, 2851-2859.
15. B. Zhang, Y. M. Chen, L. L. Huang, X. X. Zhou, C. G. Chen, Y. B. Ye and Y. X. Su, Greater habitual soyfood consumption is associated with decreased carotid intima-media thickness and better plasma lipids in Chinese middle-aged adults, *Atherosclerosis*, 2008, **198**, 403-411.
16. B. Zhang, P. Wang, C. G. Chen, Q. Q. He, S. Y. Zhuo, Y. M. Chen and Y. X. Su, Validation of an FFQ to estimate the intake of fatty acids using erythrocyte membrane fatty acids and multiple 3d dietary records, *Public health nutrition*, 2010, **13**, 1546-1552.
17. X. W. Dai, B. Zhang, P. Wang, C. G. Chen, Y. M. Chen and Y. X. Su, Erythrocyte membrane n-3 fatty acid levels and carotid atherosclerosis in Chinese men and women, *Atherosclerosis*, 2014, **232**, 79-85.
18. R. P. Mensink and M. B. Katan, Effect of dietary fatty acids on serum lipids and lipoproteins. A meta-analysis of 27 trials, *Arterioscler Thromb*, 1992, **12**, 911-919.
19. W. S. Harris, D. Mozaffarian, E. Rimm, P. Kris-Etherton, L. L. Rudel, L. J. Appel, M. M. Engler, M. B. Engler and F. Sacks, Omega-6 fatty acids and risk for cardiovascular disease: a science advisory from the American Heart Association Nutrition Subcommittee of the Council on Nutrition, Physical Activity, and Metabolism; Council on Cardiovascular Nursing; and Council on Epidemiology and Prevention, *Circulation*, 2009, **119**, 902-907.
20. L. K. Summers, B. A. Fielding, H. A. Bradshaw, V. Ilic, C. Beysen, M. L. Clark, N. R. Moore and K. N. Frayn, Substituting dietary saturated fat with polyunsaturated fat changes abdominal fat distribution and improves insulin sensitivity, *Diabetologia*, 2002, **45**, 369-377.
21. F. Imamura, R. Micha, J. H. Wu, M. C. de Oliveira Otto, F. O. Otite, A. I. Abioye and D. Mozaffarian, Effects of Saturated Fat, Polyunsaturated Fat, Monounsaturated Fat, and Carbohydrate on Glucose-Insulin Homeostasis: A Systematic Review and Meta-analysis of Randomised Controlled Feeding Trials, *PLoS medicine*, 2016, **13**, e1002087.
22. M. B. Katan, P. L. Zock and R. P. Mensink, Effects of fats and fatty acids on blood lipids in humans: an overview, *The American journal of clinical nutrition*, 1994, **60**, 1017s-1022s.
23. D. Pang, M. A. Allman-Farinelli, T. Wong, R. Barnes and K. M. Kingham, Replacement of linoleic acid with alpha-linolenic acid does not alter blood lipids in normolipidaemic men, *Br J Nutr*, 1998, **80**, 163-167.
24. M. A. Allman-Farinelli, D. Hall, K. Kingham, D. Pang, P. Petocz and E. J. Favaloro, Comparison of the effects of two low fat diets with different alpha-linolenic:linoleic acid ratios on coagulation and fibrinolysis, *Atherosclerosis*, 1999, **142**, 159-168.
25. U. S. Schwab, J. C. Callaway, A. T. Erkkila, J. Gynther, M. I. Uusitupa and T. Jarvinen, Effects of hempseed and flaxseed oils on the profile of serum lipids, serum total and lipoprotein lipid concentrations and haemostatic factors, *Eur J Nutr*, 2006, **45**, 470-477.
26. N. Kaul, R. Kreml, J. A. Austria, M. N. Richard, A. L. Edel, E. Dibrov, S. Hirono, M. E. Zettler and G. N. Pierce, A comparison of fish oil, flaxseed oil and hempseed oil supplementation on selected parameters of cardiovascular health in healthy volunteers, *J Am Coll Nutr*, 2008, **27**, 51-58.
27. W. J. Bemelmans, J. Broer, E. J. Feskens, A. J. Smit, F. A. Muskiet, J. D. Lefrandt, V. J. Bom, J. F. May and B. Meyboom-de Jong, Effect of an increased intake of alpha-linolenic acid and group nutritional education on cardiovascular risk factors: the Mediterranean Alpha-linolenic

Enriched Groningen Dietary Intervention (MARGARIN) study, *The American journal of clinical nutrition*, 2002, **75**, 221-227.

28. Y. E. Finnegan, D. Howarth, A. M. Minihane, S. Kew, G. J. Miller, P. C. Calder and C. M. Williams, Plant and marine derived (n-3) polyunsaturated fatty acids do not affect blood coagulation and fibrinolytic factors in moderately hyperlipidemic humans, *Journal of Nutrition*, 2003, **133**, 2210-2213.

29. Y. E. Finnegan, A. M. Minihane, E. C. Leigh-Firbank, K. Kew, G. W. Meijer, R. Muggli, P. C. Calder and C. M. Williams, Plant- and marine-derived n-3 polyunsaturated fatty acids have differential effects on fasting and postprandial blood lipid concentrations and on the susceptibility of LDL to oxidative modification in moderately hyperlipidemic subjects, *American Journal of Clinical Nutrition*, 2003, **77**, 783-795.

30. S. Kew, T. Banerjee, A. M. Minihane, Y. E. Finnegan, R. Muggli, R. Albers, C. M. Williams and P. C. Calder, Lack of effect of foods enriched with plant- or marine-derived n-3 fatty acids on human immune function, *American Journal of Clinical Nutrition*, 2003, **77**, 1287-1295.

31. L. S. Rallidis, G. Paschos, G. K. Liakos, A. H. Velissaridou, G. Anastasiadis and A. Zampelas, Dietary alpha-linolenic acid decreases C-reactive protein, serum amyloid A and interleukin-6 in dyslipidaemic patients, *Atherosclerosis*, 2003, **167**, 237-242.

32. W. J. Bemelmans, J. D. Lefrandt, E. J. Feskens, P. L. van Haelst, J. Broer, B. Meyboom-de Jong, J. F. May, J. W. Tervaert and A. J. Smit, Increased alpha-linolenic acid intake lowers C-reactive protein, but has no effect on markers of atherosclerosis, *European journal of clinical nutrition*, 2004, **58**, 1083-1089.

33. L. S. Rallidis, G. Paschos, M. L. Papaioannou, G. K. Liakos, D. B. Panagiotakos, G. Anastasiadis and A. Zampelas, The effect of diet enriched with alpha-linolenic acid on soluble cellular adhesion molecules in dyslipidaemic patients, *Atherosclerosis*, 2004, **174**, 127-132.

34. G. K. Paschos, F. Magkos, D. B. Panagiotakos, V. Votteas and A. Zampelas, Dietary supplementation with flaxseed oil lowers blood pressure in dyslipidaemic patients, *European journal of clinical nutrition*, 2007, **61**, 1201-1206.

35. G. K. Paschos, A. Zampelas, D. B. Panagiotakos, S. Katsiougiannis, B. A. Griffin, V. Votteas and F. N. Skopouli, Effects of flaxseed oil supplementation on plasma adiponectin levels in dyslipidemic men, *Eur J Nutr*, 2007, **46**, 315-320.

36. G. Zhao, T. D. Etherton, K. R. Martin, S. G. West, P. J. Gillies and P. M. Kris-Etherton, Dietary alpha-linolenic acid reduces inflammatory and lipid cardiovascular risk factors in hypercholesterolemic men and women, *J Nutr*, 2004, **134**, 2991-2997.

37. C. Wang, W. S. Harris, M. Chung, A. H. Lichtenstein, E. M. Balk, B. Kupelnick, H. S. Jordan and J. Lau, n-3 Fatty acids from fish or fish-oil supplements, but not alpha-linolenic acid, benefit cardiovascular disease outcomes in primary- and secondary-prevention studies: a systematic review, *The American journal of clinical nutrition*, 2006, **84**, 5-17.

38. Q. Zhou, Z. Zhang, P. Wang, B. Zhang, C. Chen, C. Zhang and Y. Su, EPA+DHA, but not ALA, Improved Lipids and Inflammation Status in Hypercholesterolemic Adults: A Randomized, Double-Blind, Placebo-Controlled Trial, *Molecular nutrition & food research*, 2019, **63**, e1801157.

View Article Online
DOI: 10.1039/D0FO00875C

Table 1 Fatty acid composition of cooking oil (g per 100 g oil)

Fatty Acids	Peanut Oil	Blend Oil	Corn Oil
Myristic (14:0)	0.036	0.068	0.033
Palmitic (16:0)	10.899	8.375	12.322
Stearic (18:0)	4.023	3.031	1.957
Arachidic (20:0)	1.600	0.538	0.446
Behenic (22:0)	2.535	0.527	0.123
Lignoceric (24:0)	1.051	0.176	0.104
Total saturated Fatty Acids	20.144	12.715	14.985
Palmitoleic (16:1)	0.112	0.200	0.141
Oleic (18:1)	43.129	37.904	28.881
Gadoleic (20:1)	0.813	1.334	0.253
Erucic (22:1)	0.070	2.917	0.054
Total monounsaturated fatty acids	44.124	42.355	29.329
Linoleic (18:2)	34.304	37.241	54.538
α-linolenic (18:3)	1.006	7.461	0.964
Other fatty acids	0.422	0.229	0.184

View Article Online
DOI: 10.1039/D0FO00875C

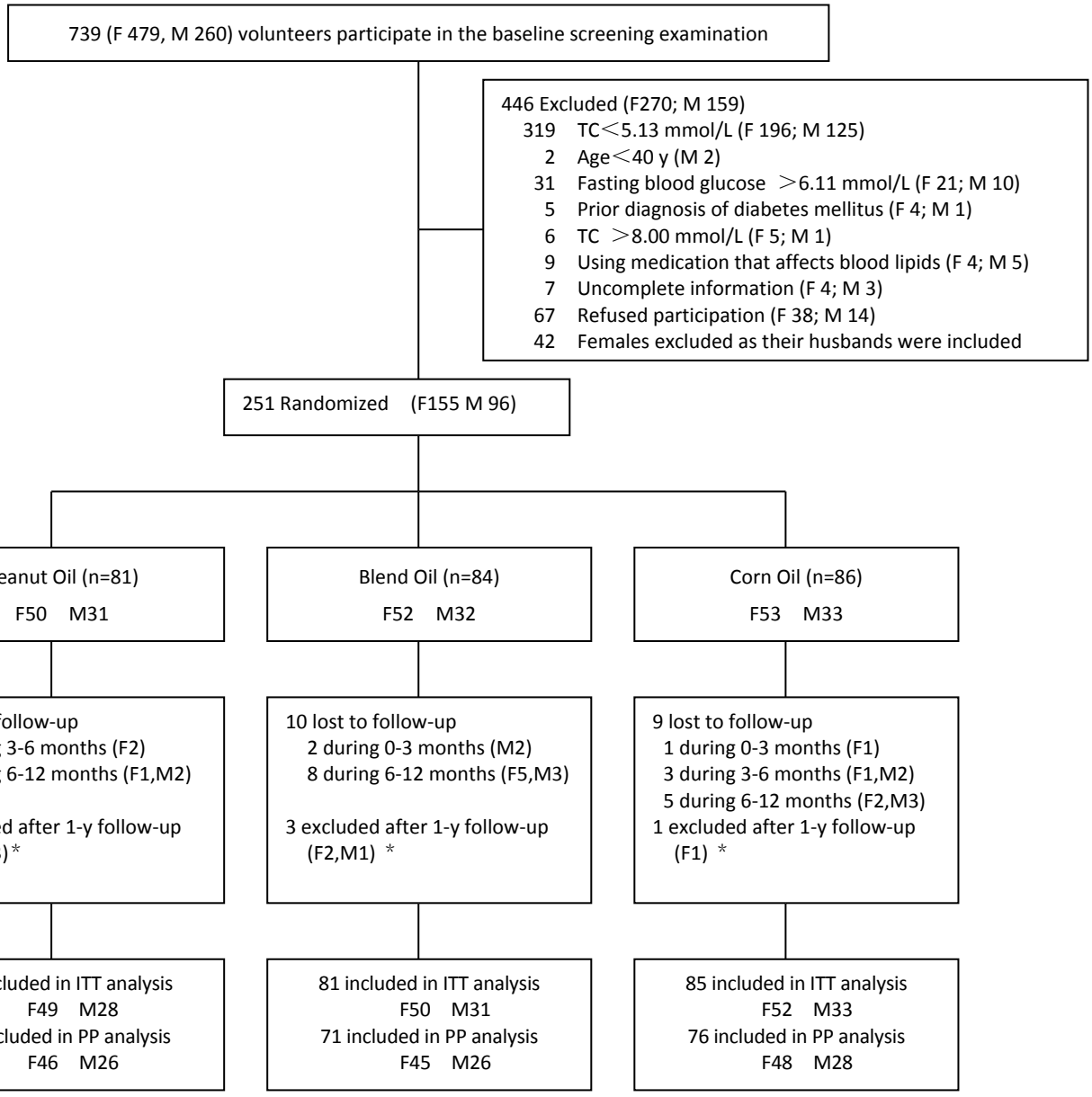

FIGURE 1 Participant flow diagram. *Subjects were excluded because they had seen a doctor at least once during the intervention period for the following reasons: suspicious diabetes (1 in peanut oil group and 2 in blend oil group), stroke (1 in peanut oil group), coronary artery disease(1 in peanut oil group) and dyslipidemia (1 in each group, respectively). ITT analysis, intention-to-treat analysis; PP analysis, per-protocol analysis.

View Article Online
DOI: 10.1039/D0FO00875C

Table 2 Descriptive characteristics of participants (intention-to-treat analysis)

	Female	Male
n	151	92
Age (year, mean ± SD)	54.2 ± 5.2	56.2 ± 7.0
Weight (cm, mean ± SD)	56.6 ± 8.2	67.2 ± 9.4
Height (kg, mean ± SD)	156.1± 5.9	168.5 ± 5.6
Education (%)		
Primary school or below	26.5	25.6
Junior high school	35.4	38.9
Senior high school	24.5	22.2
College or above	13.6	13.3
Smoking (%)		
Non-smoker	99.3	36.7
Ex-smoker	0	13.3
Current-smoker	0.7	50.0

View Article Online
DOI: 10.1039/D0FO00875C

644
645
646

Table 3 Changes in dietary intakes of nutrients over the course of the study period

	0 mo *	12 mo *	Change(12mo – 0mo) †	*P*
Energy (kcal/day)				
Peanut oil	2309.9±572.4	2161.4±495.1	-148.5±593.0 (-284.0, -13.0)	
Blend oil	2333.1±588.1	2248.2±593.2	-84.9±659.2 (-239.8, 70.0)	0.332
Corn oil	2312.6±559.7	2072.3±425.1	-240.3±6444.4 (-390.6, -89.9)	
Protein (% of energy)				
Peanut oil	14.6±2.6	16.1±2.4	1.5±2.9 (0.8, 2.1)	
Blend oil	15.0±3.2	16.3±2.7	1.3±3.2 (0.5, 2.0)	0.625
Corn oil	14.5±2.7	15.5±2.8	1.0±2.9 (0.3, 1.7)	
Carbohydrate (% of energy)				
Peanut oil	50.8±7.2	53.4±6.7	2.6±6.3 (1.1, 4.0)	
Blend oil	50.8±5.8	52.0±7.1	1.2±6.7 (-0.3, 2.8)	0.493
Corn oil	52.5±6.4	54.6±6.8	2.1±7.9 (0.3, 4.0)	
Fat (% of energy)				
Peanut oil	34.6±6.9	30.5±6.2	-4.1±6.1(-5.5, -2.7)	
Blend oil	34.2±5.4	31.7±6.6	-2.5±6.4 (-4.0, -1.0)	0.331
Corn oil	33.0±5.6	29.8±5.8	-3.1±6.8 (-4.7, -1.6)	
SFA (% of energy)				
Peanut oil	8.6±2.9	7.4±2.2	-1.2±2.9(-1.8, -0.1)	
Blend oil	8.3±2.8	7.7±2.2	-0.6±2.2 (-1.1, 0.0)	0.328
Corn oil	8.0±2.3	7.2±2.3	-0.7±2.9 (-1.4, 0.1)	
MUFA (% of energy)				
Peanut oil	12.3±3.3	11.3±2.8	-0.9±3.2 (-1.6, -0.2)	
Blend oil	12.5±2.8	11.9±2.3	-0.5±3.3 (-1.3, 0.3)	0.001
Corn oil	11.9±2.6	9.4±2.5	-2.5±3.3 (-3.3, -1.7)	
PUFA (% of energy)‡				
Peanut oil	8.2±2.6	6.8±1.9	-1.5±2.6 (-2.1, -0.9)	
Blend oil	8.1±2.2	7.5±2.6	-0.6±2.8 (-1.3, 0.0)	＜0.001
Corn oil	7.8±2.4	8.4±2.1	0.6±2.7 (0.0, 1.2)	
n-6 PUFA(% of energy)‡				

View Article Online
DOI: 10.1039/D0FO00875C

Peanut oil	7.6±2.6	6.3±1.9	-1.3±2.6 (-1.9, -0.7)	
Blend oil	7.5±2.0	7.1±2.5	-0.4±2.8 (-1.0, 0.3)	＜0.001
Corn oil	7.2±2.3	7.8±2.0	0.6±2.6 (-0.1, 1.2)	
n-3 PUFA(% of energy)				
Peanut oil	0.38±0.25	0.21±0.08	-0.2±0.3 (-0.2, -0.1)	
Blend oil	0.38±0.25	1.00±0.43	0.6±0.5 (0.5, 0.7)	＜0.001
Corn oil	0.33±0.23	0.39±0.15	0.1±0.3 (0.0, 0.1)	

* Values are mean±SD

† Values are mean±SD (95% confidence interval)

SFA, Saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; LA, linoleic acid; ALA, α-Linolenic acid; EPA, eicosapentaenoic acid; DHA, docosahexaenoic acid.

View Article Online
DOI: 10.1039/D0FO00875C

Table 4 Changes in fatty acid composition of erythrocyte membrane (% of total fatty acids) over the course of the study period

	0 mo	12 mo	Change (12mo – 0mo)	P^*
SFA				
Peanut oil	40.77±2.82	39.42±1.51	-1.35±3.15(-2.20, -0.50)	
Blend oil	41.10±2.86 †	39.91±2.06	-1.19±3.55 (-2.14, -0.24) ‡	0.749
Corn oil	40.88±2.66	39.99±1.55	-0.89±3.15 (-1.69, -0.09)	
MUFA				
Peanut oil	17.15±1.27	16.43±1.34	-0.72±1.80(-1.21, -0.23)	
Blend oil	17.18±1.47	16.36±1.33	-0.83±1.86 (-1.32, -0.33)	0.626
Corn oil	16.97±1.26	15.95±1.12	-1.02±1.38 (-1.37, -0.67)	
PUFA				
Peanut oil	38.96±2.71	40.83±2.04	1.87±3.24(1.00, 2.75)	
Blend oil	38.57±2.69	40.39±2.56	1.82±3.45 (0.89, 2.74)	0.950
Corn oil	38.91±2.76	40.59±2.40	1.68±3.61 (0.75, 2.60)	
n-3 PUFA				
Peanut oil	11.06±2.95	12.10±2.85	1.04±3.66(0.05, 2.03)	
Blend oil	10.77±2.39	11.30±2.76	0.54±3.59 (-0.43, 1.50)	0.280
Corn oil	11.48±2.59	11.42±2.51	-0.06±3.81 (-1.03, 0.92)	
ALA				
Peanut oil	0.112±0.041	0.121±0.033	0.008±0.045(-0.004, 0.020)	
Blend oil	0.099±0.039	0.125±0.029	0.027±0.051 (0.013, 0.041)	＜0.001
Corn oil	0.118±0.059	0.100±0.029	-0.018±0.061 (-0.034, -0.003)	
EPA				
Peanut oil	0.393±0.175	0.320±0.127	-0.073±0.151(-0.114, -0.033)	
Blend oil	0.406±0.168	0.320±0.155	-0.086±0.209 (-0.142, -0.030)	0.447
Corn oil	0.422±0.208	0.302±0.146	-0.121±0.247 (-0.184, -0.057)	
DHA				
Peanut oil	8.87±2.82	10.31±2.91	1.44±3.68(0.44, 2.43)	
Blend oil	8.58±2.48	9.39±2.81	0.81±3.70 (-0.19, 1.80)	0.306
Corn oil	9.23±2.62	9.59±2.56	0.36±3.90 (-0.64, 1.36)	
n-6 PUFA				
Peanut oil	27.89±2.43	28.73±2.15	0.84±2.87 (0.06, 1.61)	
Blend oil	27.80±2.40	29.09±1.93	1.28±2.62 (0.58, 1.98)	0.223
Corn oil	27.44±2.35	29.18±2.35	1.73±2.82 (1.01, 2.46)	
LA				

View Article Online
DOI: 10.1039/D0FO00875C

Peanut oil	11.33±1.87	11.26±1.52	-0.07±1.72 (-0.54, 0.39)	
Blend oil	10.66±1.51	11.13±1.32	0.47±1.51 (0.06, 0.87)	0.055
Corn oil	10.88±1.42	11.56±1.44	0.68±1.84 (0.21, 1.15)	
AA				
Peanut oil	13.00±1.58	14.01±1.34	1.01±1.59 (0.58, 1.44)	
Blend oil	13.45±1.67	14.39±1.51	0.94±1.74 (0.47, 1.41)	0.903
Corn oil	13.12±1.51	14.00±1.40	0.87±1.52 (0.48, 1.26)	
n-6:n-3				
Peanut oil	2.71±0.80	2.59±0.78	-0.16±0.98 (-0.43, 0.10)	
Blend oil	2.72±0.69	2.74±0.76	0.02±0.99 (-0.24, 0.28)	0.169
Corn oil	2.52±0.65	2.70±0.72	0.18±0.98 (-0.07, 0.43)	
P:S				
Peanut oil	0.964±0.127	1.039±0.084	0.07±0.15 (0.03, 0.11)	
Blend oil	0.946±0.120	1.017±0.106	0.07±0.16 (0.03, 0.11)	0.842
Corn oil	0.960±0.125	1.018±0.094	0.06±0.16 (0.02, 0.10)	

* *P* value for the effect of treatment, ANOVA for change (12mo – 0mo)

† mean±SD, all such values.

‡ mean±SD (95%CIs), all such values.

SFA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; LA, linoleic acid; ALA, α-Linolenic acid; EPA, eicosapentaenoic acid; DHA, docosahexaenoic acid; AA, arachidonic acid; P:S, polyunsaturated fatty acids: saturated fatty acids

Table 5 Changes in main parameters over the course of the study period

	0 mo Baseline	3 mo	6 mo	12 mo	Change (Final visit – baseline)	*P**
Body Mass Index (kg/m^2)						
Peanut oil	23.20±2.60	22.78±2.54	22.57±2.42	22.82±2.67	-0.38±1.03 (-0.62, -0.15)	
Blend oil	23.23±2.86 ‡	23.02±3.40	22.71±3.13	22.80±2.98	-0.43±0.90 (-0.63, -0.23) §	0.490
Corn oil	23.63±3.19	23.34±3.23	23.13±3.27	23.38±3.34	-0.24±0.87 (-0.43, -0.05)	
Waist-to-hip Ratio						
Peanut oil	0.86±0.06	0.85±0.09	0.85±0.06	0.84±0.09	-0.016±0.080 (-0.034, 0.002)	
Blend oil	0.86±0.06	0.86±0.06	0.87±0.06	0.86±0.06	-0.001±0.039 (-0.009, 0.008)	0.289
Corn oil	0.86±0.06	0.87±0.06	0.87±0.06	0.85±0.06	-0.009±0.038 (-0.017, -0.001)	
Systolic Blood Pressure (mmHg)						
Peanut oil	120.5±17.6	119.5±16.3	115.2±15.9	113.1±13.6	-7.33±15.75 (-10.91, -3.76)	
Blend oil	126.4±17.4	122.4±19.6	118.4±18.9	116.3±19.0	-10.08±16.84 (-13.82, -6.32)	0.205
Corn oil	122.7±17.2	118.2±15.9	114.0±18.8	115.3±19.0	-8.02±17.64 (-11.88, -4.17)	
Diastolic Blood Pressure (mmHg)						
Peanut oil	78.8±9.19	77.2±9.8	78.7±10.6	76.3±9.3	-2.40±9.44 (-4.55, -0.26)	
Blend oil	83.4±10.9	79.7±10.5	80.9±11.9	79.0±11.1	-4.43±9.92 (-6.63, -2.21)	0.119
Corn oil	81.7±10.7	78.6±10.2	79.1±12.1	78.7±10.7	-3.01±10.34 (-5.27, -0.75)	
Total cholesterol (mmol/L)						
Peanut oil	6.13±0.70	5.62±1.01	5.61±0.78	5.37±0.96	-0.76±0.86 (-0.95, -0.55)	

Blend oil	6.03±0.65	5.50±0.87	5.49±0.82	5.39±0.82	-0.64±0.83 (-0.82, -0.46)	0.571
Corn oil	6.09±0.73	5.69±0.89	5.56±0.90	5.46±0.90	-0.64±0.90 (-0.83, -0.43)	
LDL-cholesterol (mmol/L)						
Peanut oil	4.27±0.95	3.70±1.02	3.86±0.97	3.59±0.76	-0.68±1.07 (-0.93, -0.44)	
Blend oil	4.25±1.01	3.46±0.96	3.59±1.00	3.69±0.86	-0.56±1.07 (-0.80, -0.32)	0.606
Corn oil	4.26±0.94	3.53±0.97	3.82±1.00	3.72±0.83	-0.54±1.02 (-0.76, -0.32)	
HDL-cholesterol (mmol/L)						
Peanut oil	1.75±0.30	1.51±0.29	1.49±0.29	1.71±0.35	-0.04±0.40 (-0.13, 0.05)	
Blend oil	1.71±0.51	1.49±0.24	1.55±0.32	1.72±0.31	0.01±0.58 (-0.12, 0.14)	0.753
Corn oil	1.78±0.50	1.53±0.26	1.57±0.29	1.69±0.38	-0.09±0.54 (-0.21, 0.03)	
Triacylglycerols (mmol/L)[†]						
Peanut oil	2.42±1.53	1.78±1.06	1.83±0.97	1.28±0.75	-1.14±1.63 (-1.51, -0.77)	
Blend oil	2.48±1.48	2.01±1.43	2.05±1.32	1.54±0.88	-0.76±1.65 (-1.13, -0.40)	0.231
Corn oil	2.56±1.97	1.96±1.33	2.01±1.10	1.42±0.83	-1.16±1.82 (-1.55, -0.76)	
ApoA1(g/L)						
Peanut oil	1.59±0.28		1.51±0.29	1.49±0.26	-0.12±0.29 (-0.18, -0.05)	
Blend oil	1.56±0.29	—	1.51±0.27	1.49±0.27	-0.06±0.20 (-0.10, 0.01)	0.960
Corn oil	1.58±0.29	—	1.54±0.28	1.49±0.28	-0.09±0.23 (-0.14, -0.04)	
ApoB (g/L)						
Peanut oil	1.35±0.28		1.19±0.23	1.45±0.36	0.09±0.33 (0.02, 0.17)	
Blend oil	1.33±0.25	—	1.14±0.28	1.42±0.34	0.09±0.28 (0.03, 0.16)	0.644
Corn oil	1.36±0.29	—	1.15±0.27	1.45±0.30	0.09±0.33 (0.01, 0.16)	
Glucose (mmol/L)						

Peanut oil	4.61±0.83		4.43±0.64		0.18±0.80 (-0.02, 0.38)
Blend oil	4.72±0.65	—	4.62±0.65	—	0.10±0.67 (-0.07, 0.27)
Corn oil	4.54±0.62	—	4.44±0.72	—	0.11±0.74 (-0.07, 0.29)
Insulin (μU/ml)					
Peanut oil	7.72±3.23		6.94±3.94		-0.78±3.63 (-1.69, 0.12)
Blend oil	7.73±3.88	—	7.44±4.34	—	-0.29±4.26 (-1.36, 0.78)
Corn oil	8.35±3.42	—	7.46±4.05	—	-0.89±3.63 (-1.77, 0.02)
HOMA-IR					
Peanut oil	1.53±0.71		1.45±0.77		-0.08±0.84 (-0.29, 0.13)
Blend oil	1.59±0.88	—	1.57±0.96	—	-0.02±0.96 (-0.26, 0.22)
Corn oil	1.67±0.80	—	1.56±0.90	—	-0.11±0.87 (-0.32, 0.10)
hsCRP (mg/L)					
Peanut oil	1.54±0.64		1.48±0.61		-0.60±0.59 (-0.21, 0.09)
Blend oil	1.71±0.69	—	1.65±0.72	—	0.06±0.46 (-0.18, 0.06)
Corn oil	1.68±0.77	—	1.62±0.80	—	-0.06±0.42 (-0.16, 0.04)

* *P* value for the effect of treatment, ANOVA for change (12mo − 0mo)

† log transformed before statistical analysis.

‡ mean±SD, all such values.

§ mean±SD (95% CIs), all such values.

‖ not analyzed.

717 SFA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; LA, linoleic acid; ALA, α-Linolenic acid; EPA, eicosapentaenoic acid; DHA, docosahexaenoic
718 acid; AA, arachidonic acid; P:S, polyunsaturated fatty acids: saturated fatty acids; IMT, intima-media thickness; HOMA-IR, homeostasis model assessment insulin resistance index; hsCRP, high
719 sensitivity C-reactive protein.
720
721
722
723
724
725
726
727
728
729
730
731
732
733