Comparison of the effect of rapeseed oil or amaranth seed oil supplementation on weight loss, body composition, and changes in the metabolic profile of obese patients following 3-week body mass reduction program: a randomized clinical trial

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Research

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Abstract

Background: Amaranth seed oil (ASO) and rapeseed oil (RSO) are representative functional food with glucose and cholesterol-lowering, antioxidant, and hepatoprotective properties. We aimed to determine whether compared to RSO, ASO supplementation can improve the weight loss and metabolic parameters when consumed as a part of a 3-week weight loss program.

Methods: Eighty-one obese subjects (BMI > 30 kg/m 2) aged 25–70 years enrolled in a 3-week body mass reduction program based on calorie-restricted diet and physical activity. The participants were randomly administered 20 ml/d of ASO (AO group) or 20 ml/d of RSO (RO group), or were assigned to the control (C) group. Anthropometric and metabolic parameters were measured at baseline and at endpoint.

Results: At the end of the study, significant (P < 0.05) decrease in weight, BMI, WC (waist circumference), HC (hip circumference), FM (fat mass), LBM (lean body mass), VFM (visceral fat mass), and TBW% (total body water) were observed in all the studied groups. There were no significant improvements in clinical parameters in the C group, while reduction in fasting insulin (P = 0.001 and P = 0.005) and HOMA-IR (P = 0.02 and P = 0.03) were observed in the RO and AO groups. Compared to the RO group, we observed significant improvement in fasting glucose (P = 0.03), total cholesterol (P = 0.03), non-HDL cholesterol (P = 0.01), TG/HDL ratio (P = 0.03), LDL cholesterol (P = 0.04), and triglycerides (P = 0.000008) in the AO group.

Conclusions: The 3-week body mass reduction intervention resulted in statistically significant reduction in weight, BMI, WC, HC, FM, and VFM in all the studied groups. The fasting insulin level and HOMA-IR improved in both AO and RO groups. In contrast to the RO group, positive changes in glucose and lipid levels were observed in the AO group. Compared to the AO and RO groups, subjects without oil supplementation did not show improvement in clinical parameters. Thus, edible oils may improve metabolic parameters during weight loss programs.

Background

Obesity is a significant public health problem reaching pandemic levels in the developed world [1]. According to data reported by the WHO (World Health Organization), 39% of the population was overweight in 2016 and 650 million (13%) were obese [2]. Lifestyle change focusing on proper nutrition and physical activity is the primary approach in treating obesity [3]. In addition, the use of functional food is another possible method of reducing the prevalence of obesity. Functional food is defined as food fortified with usually scarce nutrients or food without harmful ingredients (e.g. allergens), which provide health benefits. Functional food products deliver additional or enhanced benefits over and above their basic nutritional value, but should not be considered as alternatives to a balanced diet [4, 5]. Amaranth seed oil (ASO) and rapeseed oil (RSO) are functional food products of increasing popularity. The health-promoting properties of both oils are due to their high content of monounsaturated fatty acids (MUFAs) and polyunsaturated fatty acids (PUFAs) or squalene (ASO). Previous studies have indicated that diet

supplemented with ASO regulated lipid levels, improved antioxidant properties, and exhibited anti-inflammatory, hypotensive, and hepatoprotective effects [6]. Furthermore, Kim et al. investigated the effect of amaranth seed and amaranth oil supplementation on blood glucose profile in streptozotocin-induced diabetic rats [7]. The hypoglycemic activity of ASO has not been described in clinical trials so far. RSO possesses similar properties (antioxidant, hypolipemic, anti-inflammatory, and anti-atherogenic properties) but is cheaper and more ubiquitous than ASO [8, 9]. Previous studies have shown that modulation of fatty acid profile via the conversion of fat commonly present in diet such as in RSO positively affects carbohydrate metabolism and reduces the risk of developing breast cancer [9].

However, to the best of our knowledge, studies comparing the effectiveness of ASO and RSO in weight reduction and normalization of metabolic parameters associated with obesity are lacking. It is noteworthy that the fatty acid composition of ASO and RSO differ. RSO contains higher levels of MUFAs and PUFAs than ASO and has more beneficial PUFA/SFA and USFA/SFA ratio than ASO. On the other hand, ASO is rich in squalene. The fatty acid composition of both oils is shown in Table 1.

Therefore, the aim of this study was to compare the effect of ASO and RSO supplementation on anthropometric parameters (body mass, body mass index (BMI), waist circumference (WC), hip circumference (HC), waist/hip ratio (WHR), and body composition) and selected biochemical parameters (fasting serum glucose and insulin levels, homeostatic model assessment of IR (HOMA-IR), total cholesterol (TC), high-density lipoprotein (HDL), low-density lipoprotein (LDL), triglycerides (TG), and non-HDL levels, and TG/HDL ratio in adult obese patients following a 3-week strictly-controlled weight loss program.

Methods

The study was designed as a randomized, double-bind, controlled trial with three parallel groups and was performed in the Department of Gastroenterology, Internal Diseases and Dietetics from July 2014 to March 2016. The study protocol was approved by the Research Ethics Committee of the Poznan University of Medical Sciences, Poland (approval 333/14) and was performed in accordance with the Declaration of Helsinki. All the patients provided signed informed consent before participation in the study. The study was retrospectively registered in the Deutsches Register Klinischer Studein under the number DRKS00017708.

The inclusion criteria were BMI $\geq$ 30 kg/m^2, stable body weight (< 3 kg self-reported change during the previous 3 months), and age of 18–70 years. Patients with chronic diseases related to metabolism (e.g. chronic liver, kidney, pancreas diseases, inborn metabolic diseases, autoimmune diseases, inflammatory bowel diseases, coeliac disease), diabetes mellitus type 1 or uncontrolled diabetes mellitus type 2, and uncontrolled disorders of lipid metabolism, or on vegetarian or any another alternative diet, and with a history of use of any dietary supplements within the 3 months prior to the study or eating disorders were excluded from the study.

One hundred and six adult Polish patients with obesity were enrolled. Prior to randomization, nine subjects were excluded because of the exclusion criteria and two subjects withdrew consent. These 95 patients were randomized and participated in the intervention. After the 3-week period, 14 patients failed to complete the study: 4 from C, 5 from AO, and 5 from RO. Finally, the data of 81 participants was analyzed. Among the analyzed patients, 49 had hypertension, 27 had type 2 diabetes, and 35 had hyperlipidemia. To minimize the impact of comorbidities and pharmacotherapy on the results of the study, the patients in whom the above-mentioned diseases were diagnosed in less than 2 years before the study or in whom the mode of treatment during the last 2 years was changed were excluded.

The study population was randomly assigned to three groups which received 20 ml ASO (AO group) or 20 ml RSO (RO group), or did not receive any supplementation (control or C group). The randomization list and group allocation was blinded for participants and investigators during the entire study. Patients from all groups underwent a 3-week body mass reduction program under controlled conditions (3-week hospitalization) (Fig. 1).

During the 3-week body mass reduction program, each subject received daily aerobic physical training from the physical therapist (30 min of breathing exercises, 60 min twice a day of cardio, and 30 min of resistance exercises) and hypocaloric diet (70–75% of the total daily energy expenditure (TDEE)). TDEE was calculated using the Harris-Benedict formula and the physical activity level (PAL) index. Subjects received the same type of diet prepared by dietetic food catering. Each patient received diet with identical composition of macronutrients (20% protein, 25–30% fat, and 50–55% carbohydrates) derived from the same products. The diets were supplemented with 20 ml ASO (AO group) or 20 ml RSO per day (RO group) instead of 20 g fat from the diet. One meal (breakfast) was supplemented with one dose of oils for the patients. ASO “Ol'Amar” produced by “Szarłat” (Lomza, Poland) and RSO “Ol’Vita (Marcinowice, Poland) were used.

For each of the patients at baseline and at an endpoint, the anthropometric parameters were assessed. WC (in cm) was measured at the midpoint between the lower margin of the least palpable rib and the top of the iliac crest, and HC was measured around the widest portion of the buttocks with the tape parallel to the floor. Both measurements were performed with the use of stretch-resistant medical tape (Seco) and were repeated twice to obtain a certain result. Height was measured to the nearest centimeter using a stadiometer. Weight and body composition were assessed using bioelectrical impedance, Tanita MC 980 MA (Tanita, Tokyo, Japan). The body composition analysis was performed in accordance with the European Society for Clinical Nutrition and Metabolism (ESPEN) recommendation [10]. BMI (kg/m^2) was defined as the individual’s body mass divided by the square of their height. WHR was the ratio of WC to the HC.

Biochemical and anthropometric measurements were made at the baseline and at the endpoint. Fasting venous blood samples (10 mL) were collected at the beginning and at the end of the program. Serum glucose, TC, HDL, and TG levels were analyzed using the fully automated Modular P-800 Roche (Diamondd Dagnostics, Budapest, Hungary). LDL was measured indirectly using the Friedewald equation.

Fasting insulin level was determined using the microparticle enzyme immunoassay (Abbot, Abbot Park, IL, USA). The HOMA-IR was calculated according to the formula: fasting insulin (microU/L) · fasting glucose (nmol/L)/22.5.

Statistical analyses were performed using the Statistica 10.0 (StatSoft) program and MetaboAnalyst 3.0. server (www.metaboanalyst.ca). The normal distribution was checked using the Shapiro-Wilk test. Differences between the three groups were determined using the analysis of variance (ANOVA) Kruskal–Wallis test, followed by Dunn's multiple comparison post-test or the Mann–Whitney test for comparison of two groups. The normal distributed data are presented as mean ± SD and the skewed data are shown as median (interquartile range). To determine if the body mass reduction program affected the metabolic and anthropometric profile, the Wilcoxon signed-rank test or paired Student's t-test was used. Correlations between data are expressed as Spearman's coefficient. Results were considered statistically significantly different when $P < 0.05$ [11].

Results

Eight-one patients with obesity (mean BMI: 39.6 ± 7.4 kg/m^2) were enrolled in the study. The baseline anthropometric and biochemical characteristics of the AO, RO, and C groups are presented in Table 2 and Table 3. There were no significant between-group differences in metabolic and anthropometric variables at baseline.

After the 3-week body mass reduction program, statistically significant ($P < 0.05$) decrease in body weight, BMI, WC, HC, FM, LBM, VFM, and TBW% were observed in all the studied groups. There were no significant differences in anthropometric variables between the RO, AO, and C groups at the end of the study (Table 4). The most significant reduction in parameters such as weight, BMI, HC, and WC was observed in the AO group. Compared to RO and AO, subjects without oil supplementation showed more changes in FM%, VF, and LBM.

At the end of study, there were no significant improvements in clinical parameters in the C group, while reduction in fasting insulin and HOMA-IR were observed in RO and AO groups. Significant reduction in fasting glucose levels were noted only in the AO group.

Similarly, only in the AO group, improvements in lipid parameters (TC, non-HDL, LDL, and TG) were observed. The increase in HDL% was observed in AO and RO groups. Small significant differences in HOMA-IR and HDL were observed between the RO, AO, and C groups at the end of the study (Table 5).

Discussion

To the best of our knowledge, this is the first study in which direct comparison of the effect of RSO or ASO supplementation on weight loss, and anthropometric and metabolic parameters was performed in a weight loss program in patients with obesity. In contrast to studies based on long-term body mass

reduction protocols, we evaluated whether the short-time weight loss program can induce satisfactory anthropometric and metabolic changes in adult patients with obesity.

No significant difference in weight loss or other anthropometric parameters were observed between the analyzed groups. Both oils showed favorable effect on carbohydrate and lipids profiles. However, the beneficial effects of ASO exceeded that of RSO in terms of lipid profile.

At the end of study, significant reduction in weight, BMI, WC, HC, and FM and were observed in the AO, RO, and C groups. The weight loss and improvement in body composition observed in this study is comparable with those observed in other studies [12, 13]. It is noteworthy that the most significant reduction in FM and VFM was observed in patients without oil supplementation, although this did not affect the improvement in metabolic parameters.

After the 3-weeks weight loss program, significant reductions in fasting serum insulin level and HOMA-IR were noted in the AO and RO groups, but not in the C group. Statistically significant reduction in fasting glucose level was observed only in the AO group.

In our study, we observed improvement in TC, non-HDL, TG/HDL, LDL, and TG levels in response to weight loss; however, the changes were significant only in the AO group. In both AO and RO groups, the significant increase in percentage HDL was observed at the end of the study.

The differences observed between the groups in the effectiveness of improving metabolic parameters may be due to the differences in the fatty acid composition of ASO and RSO. ASO contains lower amount of MUFAs (~ 24% vs. ~59%) and LC n-3 PUFAs (~ 1% vs. ~11%) and has poorer PUFA/SFA and USFA/SFA ratio than RSO. Furthermore, ASO was less beneficial as its n-3/n-6 ratio was lower than that of RSO [14]. In contrast, ASO is one of the oils with highest squalene content. Strong anticancer, antioxidant, drug carrier, detoxifier, skin hydrating, and emollient activities of squalene have been reported both in animal models and in vitro environments [15].

A previous study showed that replacement of usual edible oils with oils rich in unsaturated fatty acids [USFA] such as ASO and RSO resulted in lipid-modulating, anti-atherogenic, antioxidative, anti-inflammatory, hepatoprotective, and hypotensive effects [8–9]. The quality of dietary fat modulated the development of obesity by interacting with genes involved in fatty acid metabolism, adipogenesis, and endocannabinoid system [16].

Evidence from animal studies suggested that LC n-3 PUFAs may protect against weight gain, raising the possibility that LCn-3 PUFA facilitates weight loss or differential changes in body composition when incorporated into weight-loss programs [17]. Furthermore, Borsonelo et al. [18] demonstrated anxiolytic-like effect of a diet enriched with PUFAs in an animal model of anxiety. A time-dependent effect of LC n-3 PUFAs on weight loss was also established in humans [19, 20]. Certain studies showed that compared to PUFAs, MUFAs affect weight loss better, as MUFAs induce more energy expenditure, diet-induced thermogenesis, and fat oxidation than PUFA diet [21, 22]. In our study, there were no significant

differences in the effectiveness of weight loss between patients in the RO, AO, and C groups. However, weight, BMI, WC, HC, and FM in the AO group tended to decrease more than in the RO group. On the other hand, important changes in FM% and VFM were observed in the C group, although this did not affect the clinical parameters.

Numerous studies have indicated that consumption of high levels of MUFAs and PUFAs improves glucose metabolism and lipid profile compared to consumption of fats containing higher levels of SFAs. However, whether metabolic parameters will improve more when the dietary SFAs are replaced by higher concentrations of MUFAs or of PUFAs is still unclear [23, 24]. The meta-analysis conducted by Qian et al. [25] provided evidence that compared to consumption of high-PUFA diets, consumption of MUFA-rich diets resulted in significant reduction in fasting plasma glucose and a nonsignificant reduction in fasting insulin, TG, and LDL levels [25]. In contrast, Miller et al. [24] showed that substitution of SFA with PUFAs in patients with metabolic syndrome was associated with higher reductions in TG and improvement in endothelial function than MUFAs.

Previous studies have suggested that RSO can be used in glucose profile normalization in humans [26–38]. The study conducted in a Canadian academic center on patients with type 2 diabetes treated with an oral antihyperglycemic agent showed that consumption of canola oil-enriched low-GL diet for 3 months improved glycemic control [26]. The effect of ASO on glucose metabolism was less clear. Kim et al. [7] showed that 3 weeks of ASO supplementation (100 mg/kg) significantly reduced the serum glucose level in streptozocin-induced diabetic rats. The beneficial effect of ASO in patients with diabetes mellitus type 2 has also been confirmed by Miroshnichenko et al. [29]. In this study, improvements in fasting glucose and insulin levels, and insulin sensitivity were also observed in the AO and RO groups, although these changes were higher in subjects supplemented with ASO [30].

The effect of RSO on circulatory cholesterol level has been observed in most short-term interventions. Lin et al. [9] showed that diet rich in RSO resulted in substantial reductions in TC (12.2–12.5%) and LDL levels (17%); however, changes in HDL and TG levels with canola oil are inconsistent. Furthermore, previous studies [31–33] have reported that compared to consumption of high-SFA diets, consumption of diet enriched with RSO resulted in 8–10% reduction in HDL concentrations. Our data showed that calorie-restricted RSO-supplemented diet did not significantly affect TC and TG levels. We observed slight increase in HDL concentration and improvement in non-HDL and TG/HDL ratio, although these changes were not statistically significant.

Gonor et al. [34] investigated the beneficial effect of diet supplemented with squalene (600 ml/d) from amaranth oil (18 ml/d) on TC and TG concentration and composition of fatty acids of erythrocytes in patients with ischemic heart disease and hyper lipoproteinemia. Similarly, Martirosyan et al. [35] showed that 3 weeks of low-sodium/low-fat diet containing ASO (3, 6, 12, or 18 ml/d) promoted positive dose-dependent changes in the serum TC, LDL, and TG levels among obese patients with coronary heart disease and hypertension. In our study, we observed that 3-week intervention with ASO supplementation (20 ml/d) lead to significant reduction in TC, %HDL, LDL, and TG levels and slight non-significant

increase in HDL level. Statistically significant improvement in the non-HDL and TG/HDL levels were also observed in the AO group. Although, ASO contains lower amounts of MUFA and LC n-3 PUFA than RSO, our study demonstrated that ASO is more effective in improving lipid profiles than RSO. Although further investigations are required for understanding the underlying reason for this observation, our results suggest that incorporation of moderate amounts of dietary squalene in a weight loss program that includes consumption of an equivalent amount of high MUFA and LC n-3 PUFA oils improves the metabolic profile of obese patients.

The major limitations of this trial are the small sample size and relatively short time of intervention. The main reason for this was the inability to interrupt professional and family duties for 3 weeks. However, it is noteworthy that this is one of the few studies conducted under specific and strictly controlled conditions, which is rare in nutritional interventions. Patients who participated in the study received the same type of hypocaloric diet prepared by the dietetic food catering and underwent the same physical activity program with the physical therapist. The 3-week hospitalization of the study population allowed control of their involvement in the intervention. Although dual energy X-ray absorptiometry (DXA) is the gold standard for the assessment of body composition, the bioimpedance method (BIA) was used in the study due to non-invasiveness, lower cost, and widespread use.

Conclusions

In conclusion, the results of this study showed that the 3-week diet and physical activity program significantly reduced the weight, BMI, WC, HC, FM and VFM in the AO, RO, and C groups. However, the effectiveness of the changes in clinical parameters was affected by the fatty acid profile in the diet during intervention. Although we did not observe significant differences in the effectiveness of weight loss and body composition improvement between the RO, AO, and C groups, we observed that oil supplementation is beneficial for changes in clinical parameters. Furthermore, compared to RSO supplementation, ASO supplementation in 3-week weight loss program improved metabolic measurements.

Compared to the AO and RO groups, subjects without oil supplementation did not show significant improvement in glucose and lipid profiles. At the end of the study, significant improvement in fasting glucose and insulin levels and insulin sensitivity were observed in patients of the AO and RO groups. We also noticed the positive effect of ASO-supplemented or RSO-supplemented weight loss programs on lipid profiles; however, these changes were statistically significant only in the AO group. Subjects receiving ASO during intervention showed significant improvement in TC, TG, LDL, %HDL, and non-HDL levels.

Although we did not understand why ASO affects glucose and lipid metabolism more in humans, our observations supported the results of other studies regarding the use of ASO and RSO in the treatment of obesity-related disorders. This study also highlighted that not only optimal amount of fat, but also dietary sources of fat (especially fatty acid composition) may provide additional health benefits in weight-loss diets.

Abbreviations

ASO: amaranth seed oil; BMI: body mass index; C: control group; ECW: extracellular water; FM: fat mass; HC: hip circumference; HDL: high-density lipoprotein; HOMA-IR: homeostatic model assessment of IR; ICW: intracellular water; LBM: lean body mass; LC n-3 PUFAs: long chain polyunsaturated fatty acids; LDL: low-density lipoprotein; MUFA: monounsaturated fatty acids; AO: amaranth seed oil group; RO: rapeseed oil group; PAL: physical activity level index; PUFA: polyunsaturated fatty acids; RSO: rapeseed oil; SFA: saturated fatty acids; TBW: total body water; TC: total cholesterol; TDEE: total daily energy expenditure; TG: triglycerides; USFA: unsaturated fatty acids; VFM: visceral fat mass; WC: waist circumference; WHO: World Health Organization, WHR: waist to hip ratio

Declarations

Ethics approval and consent to participate: Consent was obtained from each participant included in the study. The study was approved by the Bioethics Committee at Poznan University of Medical Sciences (No. 333/14) and was performed in accordance with the Declaration of Helsinki.

Consent for publication: Not applicable.

Availability of data and material: The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests: The authors declare that they have no competing interests.

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Authors' contributions: MM, AZ, and MG conceived the concept of the study. MM, AZ, and MG contributed to the design of the research. MM, AZ, and AJ were involved in data collection and statistical analysis. MM, AZ, and PB contributed to data interpretation and drafting of the article. MG and PB coordinated the project tasks. All authors edited, revised, and approved the final version of the manuscript.

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References

1. Baboota RKB, Bishnoi M, Ambalam P, Kondepudi KK, Sarma SM, Boparai RK, et al. Functional food ingredients for the management of obesity and associated co-morbidities – A review. J Funct Foods. 2013;5:997-1012.
2. https://www.who.int/en/news-room/fact-sheets/detail/obesity-and-overweight. Accessed 10.11.2019

3. Rodriguez JE, Campbell KM. Past, Present and future of pharmacologic therapy in obesity. Prim Care. 2016;43:61-7.
4. Martirosyan DM, Singh J. A new definition of functional food by FFC: what makes a new definition unique? Funct Food Health Dis. 2015;5:209-23.
5. Grajeta H. Functional foods in prevention of cardiovascular disease. Adv Clin Exp Med. 2004;13:503-10.
6. Moszak M, Zawada A, Grzymisławski M. The properties and the use of rapeseed oil and amaranth oil in the treatment of metabolic disorders related to obesity. Forum Zaburzeń Metabolicznych. 2018;9:53-64.
7. Kim HK, Kim MJ, Cho HY, Kim E-K, Shin DH. Antioxidative and anti-diabetic effects of amaranth (Amaranthusesculantus) in streptozotocin-induced diabetic rats. Cell Biochem Funct. 2006, 24: 195-9.
8. Maniak B, Zdybel B, Bogdanowicz M. Ocena wybranych właściwości fizykochemicznych tradycyjnych olejów roślinnych produkowanych na ziemi lubelskiej. Agric Eng. 2012;3:101-7.
9. Lin L, Allemekinders H, Dansby A, Campbell L, Durance-Todd S, Berger A, et al. Evidence of health benefits of canola oil. Nutr Rev.2013;71:370-85.
10. Kyle UG, Bosaeus I, De Lorenzo AD, Deurenerg P, Elia M, Gomez JM, et al. Bioelectrical impedance analysis-part II: utilization in clinical practice. Clin Nutr. 2014;23:1430-53.
11. Munro Hazard B. Statistical methods for health care research. Lippincot Williams & Wilkins; 2005.
12. Perez-Cornago A, Brennan L, Ibero-Baraibar I, Hermsdorff HHM, O'Gormann A, Zulet MA, et al. Metabolomics identifies changes in fatty acid and amino acid profiles in serum of overweight older adults following a weight loss intervention. J Physiol Biochem. 2014;70:593-602.
13. Sartorio A, Agosti F, Resnik M, Lafortuna CL. Effects of a 3-week integrated body weight reduction program on leptin levels and body composition in severe obese subjects. J Endocrinol Invest. 2003;26:250-6.
14. Rathod KJ, Jadeja BA, Jadav JK, Golakiya BA. Physico-chemical characterization and fatty acid profiling of seed oils of grain amaranthus cultivars of India–a nutritional perspective. Int J Pure App Biosci. 2017;5:1424-32.
15. Kim SK, Karadeniz F. Biological importance and applications of squalene and squalane. Adv Food Nutr Res. 2012;65:223-33.
16. Hammad SS, Jones PJ. Dietary fatty acid composition modulates obesity and interacts with obesity-related genes. 2017;52:803-22.
17. Norris LE, Collene AL, Asp ML, Hsu JC, Liu L-F, Richardson JR, et al. Comparison of dietary conjugated linoleic acid with safflower oil on body composition in obese postmenopausal women with type 2 diabetes mellitus. Am J Clin Nutr. 2009;90:468-76.
18. Borsonelo EC, Vieira L, Galduróz JC. The influence of the polyunsaturated fatty acids on body weight and anxiolytic-like behavior in female rats. Nutr Neurosci. 2013;16:2-5.

19. Munro IA, Garg ML. Prior supplementation with long chain omega-3 polyunsaturated fatty acids promotes weight loss in obese adults: a double-blinded randomized controlled trial. Food Funct. 2013;4:650-8.
20. Riserus U, Berglund L, Vessby B. Conjugated linoleic acid (CLA) reduced abdominal adipose tissue in obese middle-aged men with signs of the metabolic syndrome: a randomized controlled trail. Int J Obes Metab Disord. 2001;25:1129-1135.
21. Kaippert VC, Santos Lopes MC,Carvalho PD, Rosaldo DE. Effects of unsaturated fatty acids on weight loss, body composition and obesity related biomarkers. Diabetol Metab Syndr. 2015; 7: A139.
22. Krishnan S, Cooper JA. Effect of dietary fatty acid composition on substrate utilization and body weight maintenance in humans.Eur J Nutr. 2014; 53: 691-710.
23. González-Muniesa P, Mártinez-González MA, Hu FB, et al. Obesity Nat Rev Dis Prim. 2017; 3:17034.
24. Miller M, Sorkin JD, Mastella L, et al. Poly is more effective than monounsaturated fat for dietary management in the metabolic syndrome: The muffin study. J Clin Lipidol. 2016; 10: 996-1003.
25. Qian F, Korat AA, Malik V, Hu FB. Metabolic Effects of Monounsaturated Fatty Acid-Enriched Diets Compared With Carbohydrate or Polyunsaturated Fatty Acid-Enriched Diets in Patients With Type 2 Diabetes: A Systematic Review and Meta-analysis of Randomized Controlled Trials. Diabetes Care. 2016; 39: 1448-1457.
26. Jenkins DJ, Kendall CW, Vuksan V, et al. Effect of lowering the glycemic load with canola oil on glycemic control and cardiovascular risk factors: a randomized controlled trial. Diabetes Care.2014; 37: 1806-14.
27. Uusitupa M, Schwab U, Mäkimattila S, et al. Effects of two high-fat diets with different fatty acid compositions on glucose and lipid metabolism in healthy young women. Am J ClinNutr. 1994; 59: 1310-1316.
28. Södergren E, Gustafsson IB, Basu S, et al. A diet containing rapeseed oil-based fats does not increase lipid peroxidation in humans when compared to a diet rich in saturated fatty acids. Eur J Clin Nutr. 2001; 55: 922-931.
29. Miroshnichenko LA, Zoloedov VI, Volynkina AP, Kulakova SN. Influence with amaranth and sunflower oils used in dietary therapy of patients with diabetes mellitus 2 types on parameters of carbohydrate and lipid metabolism.2008; 77: 53-57.
30. Gillingham LG, Gustafson JA, Han SY,et al. High-oleic rapeseed (canola) and flaxseed oils modulate serum lipids and inflammatory biomarkers in hypercholesterolaemic subjects. Br J Nutr.2011; 105: 417-427.
31. Gustafsson IB, Vessby B, Ohrvall M, Nydahl M. A diet rich in monounsaturated rapeseed oil reduces the lipoprotein cholesterol concentration and increases the relative content of n-3 fatty acids in serum in hyperlipidemic subjects. Am J Clin Nutr. 1994; 59: 667-674.
32. Lichtenstein AH, Ausman LM, Carrasco W, et al. Effects of canola, corn, and olive oils on fasting and postprandial plasma lipoproteins in humans as part of a national cholesterol education program step 2 diet. Arterioscler Thromb. 1993; 13: 1533-1542.

33. McDonald B, Gerrard J, Bruce V, Corner EJ. Comparison of the effect of canola oil and sunflower oil on plasma lipids and lipoproteins and on in vivo thromboxane A2 and prostacyclin production in healthy young men. Am J Clin Nutr. 1989; 50: 1382-1388.
34. Gonor KV, Pogozheva AV, Kulakova SN, et al. The influence of diet with including amaranth oil on lipid metabolism in patients with ischemic heart disease and hyperlipoproteidemia. Vopr Pitan.2006; 75: 17-21.
35. Martirosyan DM, Miroshnichenko LA, Kulakova SN, et al. Amaranth oil application for coronary heart disease and hypertension. Lipids Health Dis. 2007, 6:1.

Tables

Table 1. Fatty acid composition of the ASO and RSO.

Component	Amaranth seed oil	Rapeseed oil
16:0 (palmitic acid) SFA	18.5-23.4%	2.9%
18:0 (stearic acid) SFA	3.4-4.5%	4.5%
18:1 n-9 (oleic acid) MUFA	22.6-26.0%	59%
18:2 n-6 (linoleic acid) PUFA omega 6	38.2-49.9%	21%
18:3 n-3 (α-linolenic) PUFA omega 3	0.92-1.2%	11.2%
Squalene	58.8-77.7 mg/g	< 0.05 mg/g

Table 2. Baseline anthropometric characteristics of RO, AO, and C groups.

Variable	RO group (n = 26)	AO group (n = 26)	C (n = 29)	*P*-value[a]
Weight, kg	120.5 (102.9-135)	118.5 (108.0-132.4)	115.0 (101.4-133.3)	0.82
BMI, kg/m^2	39.8 (36.9-44.0)	40.6 (36.7-44.3)	38.4 (36.1-41.7)	0.49
WC, cm	126.3±13.3	124.3±17.2	122.3±20.6	0.60
HC, cm	128.0±13.3	130.6±12.9	119.9±20.6	0.11
WHR	0.99±0.09	0.95±0.1	1.02±0.06	0.11
FM, %	41.0±5.4	42.1±6.1	40.9±6.7	0.64
FM, kg	46.9 (41.9-56.2)	49.7 (41.0-59.6)	46.7 (40.4-54.1)	0.59
LBM, kg	66.9 (58.6-75.6)	68.7 (56.5-77.2)	70.1 (58.5-80.4)	0.81
VFM, n	15.0 (12.0-21.0)	14.0 (13.0-21.0)	16.0 (12.0-20.0)	0.97
TBW, %	41.6 (40.3-44.5)	41.4 (38.7-44.7)	41.8 (39.0-44.9)	0.79
TBW, kg	49.1 (43.7-58.9)	50.6 (42.6-58.1)	48.6 (41.6-57.0)	0.78
ECW, kg	22.7 ±2.9	23.1 ±4.2	22.1 ±3.5	0.70
ICW, kg	25.6 (23.0-32.9)	27.9 (22.5-33.5)	26.0 (21.4-31.8)	0.80

Data with normal distribution are presented as mean ± SD and skewed data are presented as median (interquartile range). P value < 0.05 is considered significant.

[a]ANOVA Kruskal-Wallis test

Abbreviations: BMI, body mass index; ECW, extracellular water; FM, fat mass; HC, hip circumference, ICW, intracellular water, LBM, lean body mass; TBW, total body water; VFM, visceral fat mass; WC, waist circumference; WHR, waist-to-hip ratio

Table 3. Baseline clinical characteristic of RO, AO, and C groups

Variable	RO group (n=26)	AO group (n=26)	C (n=29)	*P*-value[a]
Age	50.7±13.5	46.6±10.4	49.9±13.4	0.27
Fasting plasma glucose, mg/dl	105.0 (98.0-119.0)	110.5 (95.0-131.0)	104.0 (98.0-114.0)	0.85
Fasting insulin, µU/l	18.5 (11.3-29.3)	22.6 (13.2-27.5)	15.5 (13.0-22.2)	0.59
HOMA-IR	4.8 (2.9-7.5)	6.1 (3.2-8.9)	4.0 (3.3-5.3)	0.41
TC, mg/dl	196.6±39.5	193.8±37.0	192.5±47.8	0.94
HDL, mg/dl	48.0 (41.0-66.0)	42.5 (37.0-48.0)	49.0 (42.0-57.0)	0.06
HDL, %	29.2 (19.0-33.)	21.1 (18.0-29.6)	26.0 (22.0-32.0)	0.19
Non-HDL, mg/dl	143.5±39.8	149.6±39.7	149.1±43.9	0.77
TG/HDL ratio	2.3 (1.4-4.0)	3.7 (2.4-5.4)	2.9 (2.0-5.6)	0.09
LDL, mg/dl	121.5±33.9	117.6±35.1	108.0±36.6	0.48
TG, mg/dl	97.0 (79.0-177.0)	143.0 (103.0-204.0)	142.0 (104.0-196.0)	0.08

Data with normal distribution are presented as mean ± SD and skewed data are presented as median (interquartile range). *P*-value < 0.05 is considered significant.

[a]ANOVA Kruskal-Wallis test

Abbreviations: HDL, high-density lipoprotein cholesterol; HOMA-IR, homeostatic model assessment of insulin resistance; LDL, low-density lipoprotein cholesterol; TC, total cholesterol; TG, triglycerides.

SI conversion factors: to convert TC, HDL, and LDL to mmol/l, multiply by 0.02586; TG to mmol/l, by 0.0114; glucose to mmol/l, by 0.05551.

Table 4. End-of-study (EOS) anthropometric characteristics of RO, AO, and C groups.

Variable	RO group (n = 26)	RO group Δ	AO group (n = 26)	AO group Δ	C group (n = 29)	C group Δ	*P*-value[a] EOS OR vs OA vs C	RO EOS vs baseline	AO EOS vs baseline	C EOS vs baseline
weight, kg	114.9 (97.7-128.2)	-5.6	111.9 (106.5-126.0)	-6.6	108.0 (96.4-127.0)	-7.0	0.95	0.0001[b]	0.00008[b]	0.0009[b]
BMI, kg/m^2	39.1 (34.9-41.9)	-0.7	38.9 (35.6-43.3)	-1.7	37.7 (34.6-40.1)	-0.7	0.60	0.001[b]	0.00007[b]	0.00009[b]
WC, cm	123.2 ±13.3	-0.4	120.5±16.8	-3.8	121.1±20.1	-1.2	0.66	0.00006[c]	0.0000001[c]	0.001[c]
HC, cm	125.9±13.3	-2.1	125.5±11.6	-5.1	118.3±19.5	-1.6	0.22	0.00002 [c]	0.000001[c]	0.0004[c]
WHR	0.99±0.11	0.0	0.96±0.11	+0.01	1.03±0.05	-0.01	0.10	0.85[b]	0.20[b]	0.07[b]
FM, %	40.1±5.7	-0.9	41.3±7.1	-0.8	39.1±6.9	-1.8	0.43	0.03[c]	0.14[c]	0.0002[c]
FM, kg	44.9 (36.8-52.6)	-2.0	46.2 (37.1-56.9)	-3.5	41.0 (37.2-51.4)	-5.7	0.63	0.002[b]	0.001[b]	0.00005[b]
LBM, kg	63.6 (55.2-74.8)	-3.3	64.3 (56.9-76.5)	-4.4	64.5 (55.1-76.9)	-5.6	0.99	0.006[b]	0.002[b]	0.000004[b]
VFM, n	14.0 (11.0-20.0)	-1.0	13.5 (12.0-21.0)	-0.5	14.0 (11.0-18.0)	-2.0	0.90	0.0008[b]	0.03[b]	0.00006[b]
TBW, %	43.2 (40.5-45.1)	+1.6	42.8 (39.5-47.6)	+1.4	42.0 (40.2-46.3)	+0.2	0.85	0.01[b]	0.01[b]	0.00003[b]
TBW, kg	47.9 (41.3-56.9)	-1.2	48.5 (40.6-59.0)	-2.1	49.1 (41.2-58.7)	+0.5	0.99	0.01[b]	0.01[b]	0.94[b]
ECW, kg	22.4 ±3.2	-0.3	22.5 ±4.1	-0.6	21.9 ±3.5	-0.2	0.82	0.14[b]	0.01[b]	0.15[b]
ICW, kg	25.1 (22.2-31.8)	-0.5	25.8 (21.9-31.6)	-2.1	26.6 (21.6-32.0)	+0.6	0.99	0.1[b]	0.009[b]	0.24[b]

Data with normal distribution are presented as mean ± SD and skewed data are presented as median (interquartile range). *P*-value < 0.05 is considered significant.

[a]ANOVA Kruskal-Wallis test, [b]Wilcoxon, [c]t- Student's test

Abbreviations: BMI, body mass index; ECW, extracellular water; FM, fat mass; HC, hip circumference, ICW, intracellular water, LBM, lean body mass; TBW, total body water; VFM, visceral fat mass; WC, waist circumference; WHR, waist-to-hip ratio

Table 5. End-of-study (EOS) clinical characteristics of RO, AO, and C groups

Variable	RO group (n = 26)	AO group (n = 25)	C group (n = 29)	RO group Δ	AO group Δ	C group Δ	*P*-value[a] EOS RO vs AO vs C	RO EOS vs baseline	AO EOS vs baseline	C EOS vs baseline
Fasting glucose, mg/dl	103.5 (97.0-111.0)	102.0 (94.0-110.0)	104.5 (96.0-111.0)	-1.5	-8.5	+0.5	0.82	0.09[b]	**0.03**[b]	0.41[b]
Fasting insulin, µU/l	12.6 (9.7-28.3)	16.9 (9.9-22.6)	16.8 (12.4-26.1)	-5.9	-5.7	+1.3	0.29	**0.001**[b]	**0.005**[b]	0.48[b]
HOMA-IR	3.7 (2.4-6.9)	5.6 (2.6-6.6)	4.4 (3.1-6.6)	-1.1	-0.5	+0.4	**0.05**	**0.002**[b]	**0.03**[b]	0.13[b]
TC, mg/dl	192.5±32.4	179.2±32.7	179.9±38.1	-4.1	-14.6	-12.6	0.46	0.49[c]	**0.03**[c]	0.26[c]
HDL, mg/dl	51.0 (43.0-61.0)	44.5 (38.0-51.0)	48.0 (44.0-54.0)	+3.0	+2.0	-1.0	**0.04**	0.37[b]	0.15[b]	0.14[b]
HDL, %	30.6 (21.0-33.2)	24.7 (20.8-31.4)	28.0 (24.0-36.0)	+1.4	+3.6	+2.0	0.29	**0.05**[b]	**0.005**[b]	0.44[b]
non-HDL, mg/dl	137.8±33.6	133.7±34.1	128.6±36.9	-5.7	-15.9	-20.5	0.80	0.26[c]	**0.01**[c]	0.06[c]
TG/HDL ratio	2.2 (1.5-3.2)	3.1 (1.9-4.7)	2.5 (1.6-3.1)	-0.1	-0.6	-0.4	0.14	0.55[b]	**0.03**[b]	0.17[b]
LDL, mg/dl	110.4±35.1	105.3±30.2	100.9±33.5	-11.1	-12.3	-7.1	0.70	0.13[c]	**0.04**[c]	0.44[c]
TG, mg/dl	120.0 (93.0-155.0)	136.5 (94.0-170.0)	133.0 (95.0-148.0)	-23.0	-6.5	-9.0	0.59	0.66[b]	**0.000008**[b]	0.09[b]

Data with normal distribution are presented as mean ± SD and skewed data are presented as median (interquartile range). *P*-value < 0.05 is considered significant.

[a]ANOVA Kruskal-Wallis test, [b]Wilcoxon, [c]t-Student's test

Abbreviations: HDL, high-density lipoprotein cholesterol; HOMA-IR, homeostatic model assessment of insulin resistance; LDL, low-density lipoprotein cholesterol; TC, total cholesterol; TG, triglycerides.

SI conversion factors: to convert TC, HDL, and LDL to mmol/l, multiply by 0.02586; TG to mmol/l, by 0.0114; glucose to mmol/l, by 0.05551.

Figures

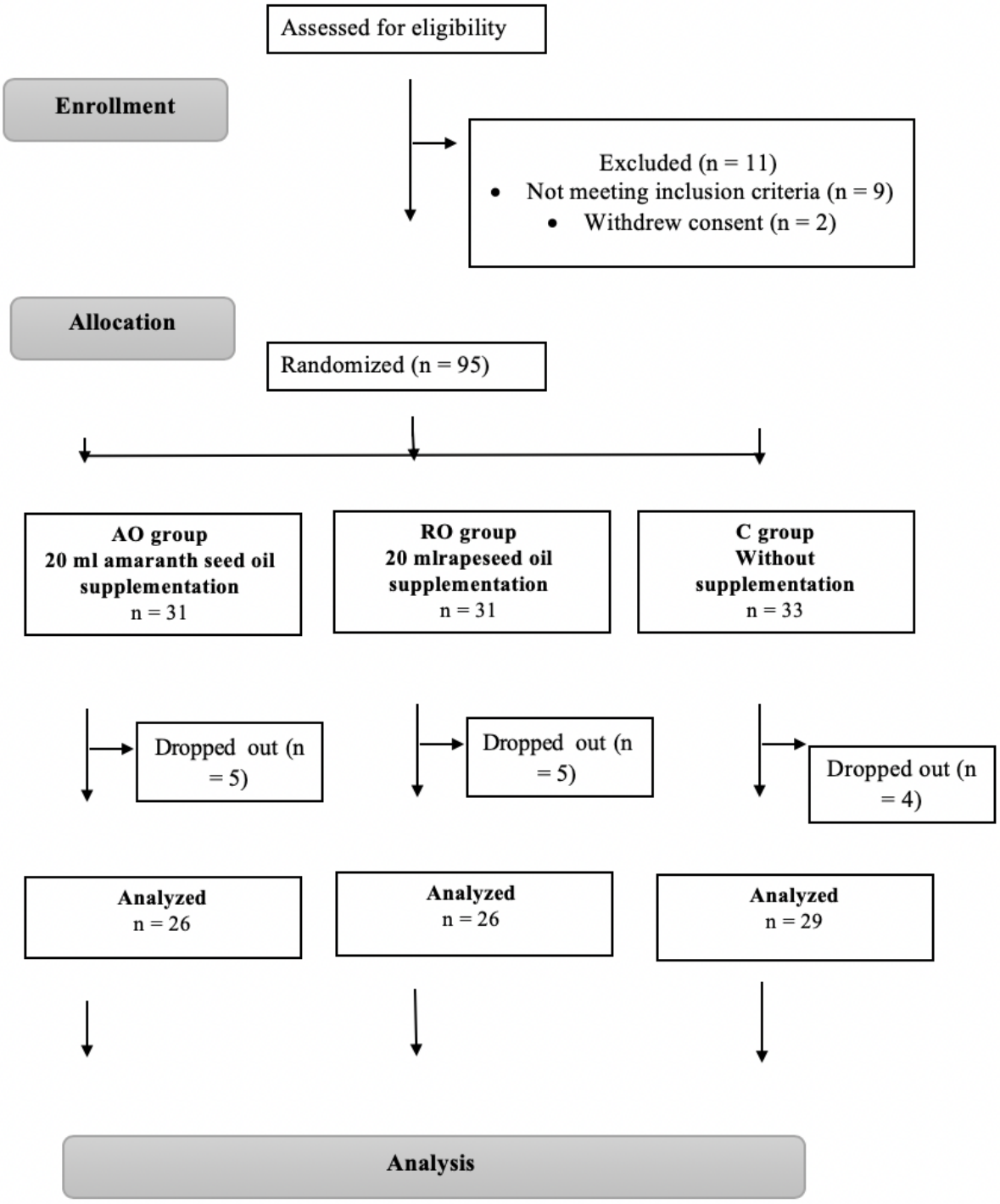

Figure 1

Study flowchart