Effect of Oat drinks differing in lipid composition on postprandial glucose response and appetite variables in healthy subjects

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Abstract

Introduction: Obesity and health complications surrounding it have been on rise for a long time due to various factors where lifestyle is one of the most certain causes. Individuals following poor diet, specifically the western pattern diet or anything that comprises an excess of sugars and fats are prone to cardiometabolic diseases. Thus, modifications in the diet have the potential to prevent these conditions. In this respect oat has gained attention due to its richness in potential health promoting bioactive compounds, such as dietary fiber, phenolic compounds and lipids. This study aims to investigate the effect of oat base products with different compositions of dietary lipids on glucose tolerance and subjective appetite variables.

Method: Healthy young adults (n=13) were included in a randomized crossover meal study. Four oat base test products differing in lipid amounts and composition were consumed as breakfast meals. In addition a glucose solution was included as a reference product. Glucose tolerance and subjective appetite variables (hunger, satiety and desire to eat) were investigated repeatedly in the postprandial periods after breakfast and after a standardized lunch.

Results: The main findings were that the oat base test products including added lipids (32 g) significantly lowered the acute postprandial glucose response after breakfast ($P < 0.05$). In addition, the results showed that the different lipids added to the oat base differed in the potential to lower the acute postprandial glucose response. After the lunch meal the glucose response tended to be higher after the breakfast test products with added lipids compared to the reference product. However, the impaired glucose tolerance at lunch was not similar pronounced for all products with added lipids. With respect to subjective appetite variables, regardless of the fat composition all oat base products resulted in decreased perceived sensations of hunger and desire to eat and increased satiety during the entire experimental period (0 – 330 min), compared to the glucose reference ($P < 0.05$).

Conclusions: The results from this study suggest that specific lipids could have beneficial effects on blood glucose regulation. However, the effects may differ significantly, especially at a second-meal, depending on the lipid composition. On the contrary the results in the study do not support beneficial effects of lipids on acute or second-meal postprandial subjective appetite variables. Rather, we observed an improved effect on appetite variables compared to the references which depended solely on the oat base *per se*.

Popular Science Summary

With the recent trends in consuming fast foods and foods containing excess sugars and fats, there is an alarming increase in the number of people being obese and as a result being prone to cardio metabolic diseases. However, cardiometabolic diseases are preventable with appropriate lifestyle changes. In this regard, this thesis is focused on how the nutritional potential of oats can be used to develop food products that could have a preventative effect on cardio metabolic diseases as oats has been recognized as a functional food with potential bioactive components that have proven health benefits.

This study was aimed at investigating the effect of oat base products with different compositions of dietary lipids on glucose tolerance and subjective appetite variables in healthy adults (both males and females) over a 5.5 hour duration that consisted of both breakfast and a standardized lunch meal, where 4 test products and a reference were served as the breakfast along with a standardized lunch meal.

It was found that the oat based test products with added lipids significantly lowered the acute postprandial glucose response after breakfast. After the lunch meal the glucose response tended to be higher after the breakfast test products with added lipids compared to the reference product. However with respect to the subjective appetite variables, regardless of the added lipids in the test products all the oat based products resulted in decreased perception of hunger and desire to eat and an increased satiety sensation compared to the reference glucose solution.

It can be concluded that specific lipids could have beneficial effects on blood glucose regulation while it is unclear if specific lipids could positively influence the appetite variables. By performing more studies on similar lines, it could be possible to develop food products with potential health benefits to prevent cardio metabolic diseases. The result from this study may form a base for further studies aiming at designing foods with preventive effect on cardio metabolic diseases.

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Abbreviations

CVD	Cardiovascular Diseases
T2D	Type two diabetes
FDA	Food and Drug Administration
DF	Dietary Fiber
DGDG	Galactolipid Digalactosyldiacylglycerol
LOO	Fractionated Oat Oil
BMI	Body Mass Index
IBS	Irritable Bowel syndrome
VAS	Visual Analoge Scale
iAUC	Incremental area under the curve
EVOO	Extra Virgin Olive oil
FFA	Free Fatty Acids

1. Introduction

1.1 Background Information

The prevalence of obesity and diseases linked to metabolism and cardiometabolic disorders has seen a significant increase in the recent past. Cardiometabolic diseases pose a serious health concern given the lifestyle followed in the recent years. Conditions such as insulin resistance, pre-diabetes, cardiovascular diseases (CVD) and type 2 diabetes (T2D) are grouped under the umbrella of cardiometabolic diseases (1). Some of the risk factors contributing to such diseases are being overweight, being obese, dyslipidemia, and high blood pressure (1). Alarmingly, 30% (2.1 billion) of the global population is either overweight or obese and CVD is the leading cause of death worldwide, which makes it a public health imperative to reduce the cardiometabolic risk (1). Physical activity, improving diet quality, reducing tobacco and alcohol intake have been focused on traditionally to reduce the risk of developing cardiometabolic diseases (2).

Poor diet practices is a leading risk factor for illness disability and death worldwide (3). With the increasing consumption of empty calories, the dietary recommendations are rather not met (4). The recommended dietary patterns are rich in plant-based foods such as fruit, vegetables, legumes, whole grains, nuts, seeds, soy products, and vegetable oils (5). Since the cardiometabolic diseases are potentially preventable by making positive lifestyle changes, where diet plays one of the major roles, it is important to increase the knowledge in the area of preventive food concepts. In this respect oat has gained attention due to its richness in potential health promoting bioactive compounds, such as dietary fiber, phenolic compounds and lipids.

1.2 Oats and its Nutritional benefits

Sativa Avena, also commonly known as *oats* is typically cultivated in temperate regions as they require more water, however they require lesser nutrients for growth (N-Sodium, P-Phosphorus and K-Potassium) than that required for wheat or maize (6). European and American countries are predominant regions of oats cultivation. The reason for oats to have received considerable attention in the recent past is its nutritional and non-nutrient bioactive components and related health benefits (6). Oats or oat derived components has been linked to the properties that might alleviate or reduce diseases such as diabetes and heart diseases, which largely is attributed to the high abundance of different dietary fiber (DF), such as β-Glucan, arabinoxylans and cellulose (7).

Oat has a balanced nutritional composition and is well accepted in human nutrition. Accordingly, it is a good source of carbohydrates and proteins with high essential amino acids content (Histideine, isoleucine, and leucine, lysine, methionine, threonine, and valine) compared to wheat (7). Compared to other common Nordic cereals oat contain a relative high percentage of lipids, especially unsaturated fatty acids. In addition oat is rich in minerals, and compounds with antioxidant- and anti-inflammatory effects, such as vitamins (e.g. Vit-E) and phenolic components (8). With respect to phenolics, oat produce avenanthramides, which is a group phenolic alkaloids found mainly in oats and exert well-known antioxidant- and anti-inflammatory effects (9).

1.3 Beta glucans in Oats

As stated above oat is rich in β-Glucans, which is a viscous easily fermentable dietary fiber. The β-Glucan content in oat ranges from 2.3 g to 8.5-g/100 g (10). The Food and Drug Administration (FDA) has accepted a health claim stating that a daily intake of 3 grams of soluble oat β-Glucan can lower the risk of coronary heart diseases by reducing the plasma cholesterol levels (11). β-glucan reduces the total serum and low-density lipoprotein cholesterol by creating a viscous mass in the small intestine therefore restricting intestinal absorption of dietary cholesterol as well as the re-absorption of bile acids (12). Oat β-Glucans may also be beneficial regarding postprandial glucose tolerance (13). Thus, it has been documented that foods rich in β-Glucans are responsible for flattening of the postprandial blood glucose and insulin rises. (13). β-Glucans are reported to delay gastric emptying and intestinal absorption of nutrients such as digestible carbohydrates, hence reducing post-prandial glycemia (13). The FDA allowed a health claim stating that diets low in saturated fats and cholesterol consisting of soluble fibers from whole oats 'may' reduce the risk of heart diseases and recognized β-glucans as the primary bioactive component responsible of this (11).

In a review that examined the effect of β-glucans on satiety (14) it was found that the viscous nature of β-glucans interferes with the peristaltic mixing process in the small intestine to impede digestion and absorption of nutrients, which precipitates satiety signals. Measurements of the physicochemical and rheological properties of β-glucan suggest that viscosity plays a key role in modulating satiety (14). Although results of the effects of oats on

satiety are inconsistent, majority of the evidence suggests that oat β-glucan has a positive effect on perceptions of satiety (14). Some research suggests that the mechanism by which oat soluble fiber lowers blood lipids is probably said to be related to either reduce the reabsorption of cholesterol and bile acids or delay lipid digestion while others suggest that the phenolic compounds in oats could be responsible for the same mechanism (9).

1.4 Lipids in Oats

Oat is rich in lipids, with a fat content ranges between 5% - 9% (15). Extracted oat oil has a high concentration of polar lipids, about 15 wt.% (16). The main component of polar lipids in oats is galactolipid digalactosyldiacylglycerol (DGDG). In oats, 50% of the DGDG contain a hydroxyl fatty acid, 15(R)-hydroxy linoleic acid, mainly in sn-2 position on the glycerol (17). The hydroxyl group is completely esterified with another fatty acid. This acyldigalactosyl diacylglycerol is a natural estolide, which is unique for oats (17). In a study conducted to investigate a hypothesis that galactolipid-rich small particles affect the release of gastrointestinal satiety hormones and postprandial lipidemia, small stable and uniform liposomes were produced from fractionated oat oil (LOO) that were given to healthy volunteers in a breakfast meal (17). Results showed that the intake of LOO significantly increased plasma concentrations of cholecystokinin, glucagon like peptide 1 (GLP-1), and glucagonlike peptide 2 (GLP-2) and peptide YY (PYY) postprandially (17). It was also observed from the results that intake of 14g lipids from LOO at breakfast substantially reduced energy intake during the rest of the day (17).

1.5 Objective

The overall goal with the presently described work was to broaden the knowledge that can be used for the development of food products with preventive properties, with the purpose to facilitate healthier food choices for people. More specifically the primary purpose of this project was to evaluate the effects of oat base products with different lipid composition and amounts on the acute postprandial and second meal glucose responses, along with investigations of appetite variables. Knowledge obtained from this study may be useful in developing oat varieties with potentially unique health properties, and for the development of food products with enhanced health values.

1.6 Hypothesis

As described above, oats contain several components with potential beneficial effects on cardiometabolic risk markers. Enrichment of foods with these specific components could possibly have positive health effects. The hypothesis in this study is that specific lipid compositions may positively influence on postprandial and second meal metabolic variables such as blood glucose response and appetite parameters.

2. Materials and Methods

2.1 Experimental Design

A randomized single blinded crossover design was applied with a total of 20 subjects. The subjects consumed the intervention products at breakfast and metabolic effects were investigated repeatedly up to 5.5 hours post breakfast. A standard lunch consisted of meatballs and white bread was served 3.5 hours after the start of breakfast. The test days for each subject were separated by a minimum of one-week washout period. On the evening prior to the test day the subjects were instructed to standardize their dinner by consuming white bread and a topping of their choice. They were also informed to refrain from consumption of alcohol and high fiber foods such as lentils, whole grain bread and rigorous physical exercises. Participants arrived at the research unit (department of Food Technology, Lund University) at 7.30am after an overnight fasting, and the fasting values of test variables were determined prior to the test breakfast served at 8.00. The breakfast was consumed at an even pace in a standard duration of 10-12 minutes.

2.2 Recruitment of volunteers

The study involved a total of 20 subjects, however, the data presented in this thesis work covers only 13 subjects (3 males and 10 females) due to time constraints related to the time frame for the thesis work. The subjects were recruited by advertising on various notice boards at Lund University and Studentkaninen.se.

2.3 Inclusion Criteria

The volunteers recruited in the study are healthy men and women aged between 20-40 years with a normal body mass index (BMI: 18.5-25 kg/m^2). Participants were non-smokers or snuff users and they were non-vegetarians.

2.4 Exclusion Criteria

Participants with a fasting blood glucose concentration higher than 6.1 mmol/L were not eligible to participate in the study. Also, participants who had any known case of metabolic disorders, gastrointestinal ailments such as irritable bowel syndrome (IBS), food allergies or other diseases, or were under any particular medication were excluded. Participants recruited were advised not to consume any antibiotics and/or probiotics at least 4 weeks before the study commenced and during the study.

2.5 *Ethical Considerations*

The study was approved by the Regional Ethical Review Board in Lund, Sweden (Dnr 2018/658), and was registered at ClinicalTrials.gov (id: NCT03830736). The trial participants are healthy volunteers and were thoroughly informed that they can terminate their participation at any time without giving any reasons. All individual analysis results are coded and strictly confidential, and available with code key solely for responsible researchers, as well as relevant research staff. All data from the study will be stored in accordance with the guidelines issued by the Data Inspection. Information was given to the participants regarding the data protection act and each subject signed in duplicate that he or she has received all the trial information.

2.6 *Test Products and Meal Composition*

Three oat base beverages differing in their lipid profile thanks to the addition of vegetable oils (**Table 1**) and served as breakfast meals. Also included were a similar oat base beverage without added lipids, and a glucose solution (reference product). The oat beverages and glucose solution included the same amounts of available carbohydrates (42 g), and the portion size of all test products was 500 ml. The oat base test products were specifically designed and manufactured for this study, and kindly provided Oatly AB and Swedish Oat Fiber AB.

A standardized lunch consisted of 100 g meatballs (Scan, Sweden**)**, 122 g white bread (Pågen, Jättefranska, Sweden**)** and 250 ml water was served 3.5 hours after breakfast (**Table 2**).

Table 1. Breakfast test products: compositions and nutritional content [1]

Test product	Reference	P40	P4	R	OB
Composition	Glucose solution	Oat base + lipid composition 1	Oat base + lipid composition 2	Oat base + lipid composition 3	Oat base
Carbohydrate per 100g	*8,4*	*8,4*	*8,4*	*8,4*	*8,4*
Sugar (g/100g)	*42*	*5.1*	*5,1*	*5,1*	*5,1*
Fiber (g/100g)	*0*	*1.0*	*1,0*	*1,0*	*1,0*

Protein per 100 g	0	1,25	1,39	1,31	1,26
Fat per 100g	0	6,4	6,3	6,5	0,4
β-glucan 100g	0	0.5	0.5	0,5	0,5
Calorie per serving (500ml)	168	470,2	470,2	470,2	201

[1.] The data regarding the nutrient composition and dietary fiber in the test products was provided by the supplier.

Table 2. Lunch meal composition

Meal Components			Total CHO (g)	Total Energy (Kcal)
Meatballs (g)	White Bread (g)	Water (ml)		
100	122	250	50	388

2.7 Blood Sampling

Glucose concentrations were determined in capillary blood taken by finger prick testing (HemoCue, B-glucose, Angelhölm, Sweden). The blood glucose was measured starting from fasting at time 0 min, and then at 15 min, 30 min, 45 min, 60 min, 90 min,120 min, 150 min, 210 min, 225 min, 240 min, 255 min, 270 min, 300 min and finally at 330 min; i.e. over a period of 5.5 h (see Appendix for study design).

2.8 Appetite variables

Visual analogue scales (VAS), 0-100 mm, were used to assess the magnitude of the appetite variables hunger, desire to eat and satiety. On separate scales the subjects were supposed to put a vertical mark to answer on the following questions:

- How hungry do you feel? (Not at all hungry–Extremely hungry)
- How full do you feel? (Not at all full–Totally full)
- How strong is your desire to eat? (Not at all strong–Extremely strong)

Not at all" is anchored on the left side of a scale while "Extremely" or "Totally" is anchored on the right side of the scale. Between these extremes, a mark on a scale indicates a weaker feeling to the left, and the stronger the feelings; the more to the right the mark should be placed. The length of the scale was measured from the left side (0 mm) to the point that was marked. Participants were asked to rate their hunger, desire to eat and fullness using the VAS scales immediately before the breakfast, and then after breakfast at 15, 30, 45, 60, 90, 120, 150 180 min, immediately prior to lunch and at 225, 240, 255, 270, 300 and 330 min after breakfast, i.e. over a period of 5.5 h (Appendix). The VAS ratings for each time points were on separate sheets and participants were told not to refer back to ratings of earlier time points.

2.9 Statistical analysis

For glucose, the incremental area under the curve (iAUC) was calculated according to the trapezoidal method and used in the statistical evaluations. All the areas below baseline (fasting value) were excluded from the calculations. Mean values based on determinations obtained every 30 min were used for the statistical calculation for satiety, hunger and desire to eat. GraphPad Prism (Version 8.1.1, GraphPad software Inc, San Diego) was used for graph plotting and calculation of areas. Significant differences in test variables after different test products were assessed with ANOVA (general linear model) followed by Tukey's pairwise multiple comparison procedure in Mnitab (Version 18, Minitab Inc, State collage, PA). Differences resulting in $p <0.05$ were considered significant. The results were expressed as Means ± SEM. Generally, n= 13 for all the calculations.

3. Results

3.1 Blood Glucose Response

3.1.1 Acute postprandial blood glucose response after breakfast

No significant differences were seen in fasting values before consumption of the different intervention products ($P > 0.05$). **Table 3, Figure 1** and **Figure 2** display the results of postprandial glucose responses (iAUC) at breakfast after the test products and the reference. The test products P40, P4 and R resulted in significantly lower glucose responses (iAUC) at the time intervals 0-45 min and 0-60 min post breakfast compared to both the reference product and OB ($p < 0.05$). Further, the 0-90 min glucose iAUCs were significantly reduced after the test products P4 and P40 compared to the reference product ($p < 0.05$), and in addition the test product P40 resulted in significantly reduced glucose responses also compared to OB in this time frame ($p < 0.05$). In the time period 0-120 min post breakfast the P40 product resulted in significantly reduced glucose iAUC compared to both the reference, R and OB ($p < 0.05$).   No significant differences in iAUC were observed between the test products and the reference when investigating the iAUC over the whole test period, i.e. 0-330 min.

Table 3. Postprandial glucose iAUC at different time intervals after the test- and reference products consumed at breakfast[1].

Test Product	iAUC 0-45 (mmol*min\L)	iAUC 0-60 (mmol*min\L)	iAUC 0-90 (mmol*min\L)	iAUC 0-120 (mmol*min\L)	iAUC 0-330 (mmol*min\L)
Reference	102 ± 7 [a]	134 ± 10 [a]	154 ± 15 [a]	155 ± 15 [a]	308 ± 48 [a]
P40	$49 \pm 7.$ [b]	54 ± 10 [b]	69 ± 14 [b]	78 ± 17 [b]	276 ± 56 [a]
P4	$56 \pm 7.$ [b]	72 ± 8 [b]	91 ± 11 [bc]	112 ± 12 [ab]	361 ± 49 [a]
R	60 ± 10 [b]	80 ± 13 [b]	109 ± 18 [abc]	135 ± 20 [a]	395 ± 46 [a]
OB	$93. \pm 11$ [a]	119 ± 15 [a]	135 ± 18 [ac]	142 ± 18 [a]	326 ± 43 [a]

[1] Values are expressed as Mean ±SEM; n=13. Results within a column with different superscript letters are significantly different (*p*-value < 0.05: one-way ANOVA followed by Tukey's test). P40, P4 and R: oat base beverages added with different compositions of lipids; OB: oat base beverage with no added lipids; Reference; glucose solution. The portion sizes of all products were 500 ml, and all products included 42 g available carbohydrates.
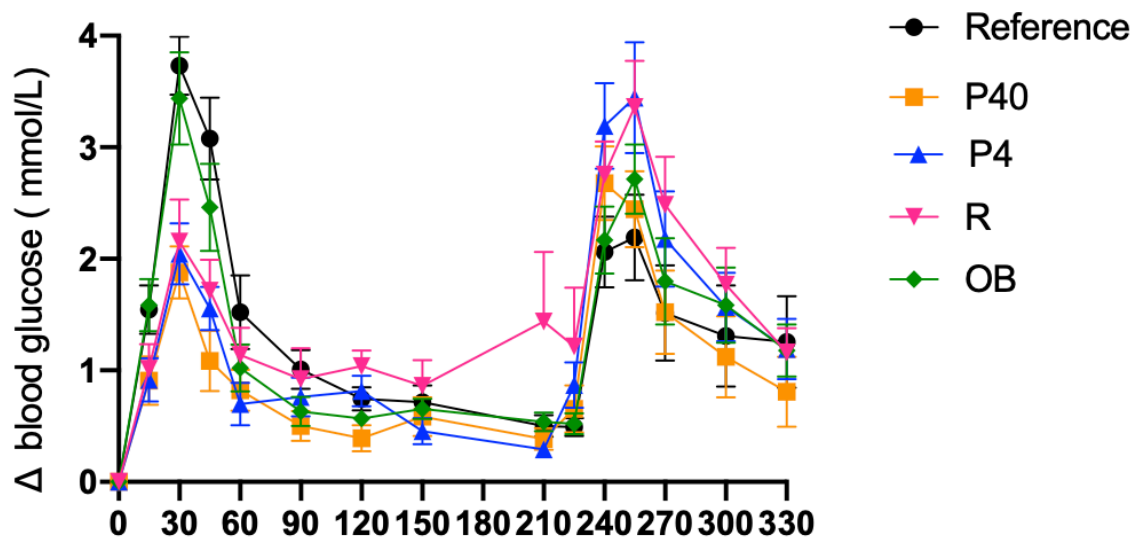
Figure 1. Mean incremental changes (Δ) in blood glucose response post the breakfast intervention products. A standardized lunch was served at 210 min. Values are expressed as Means ± SEM. P40, P4 and R: oat base beverages added with different compositions of lipids; OB: oat base beverage with no added lipids; Reference; glucose solution. The portion sizes of all products were 500 ml, and all products included 42 g available carbohydrates.
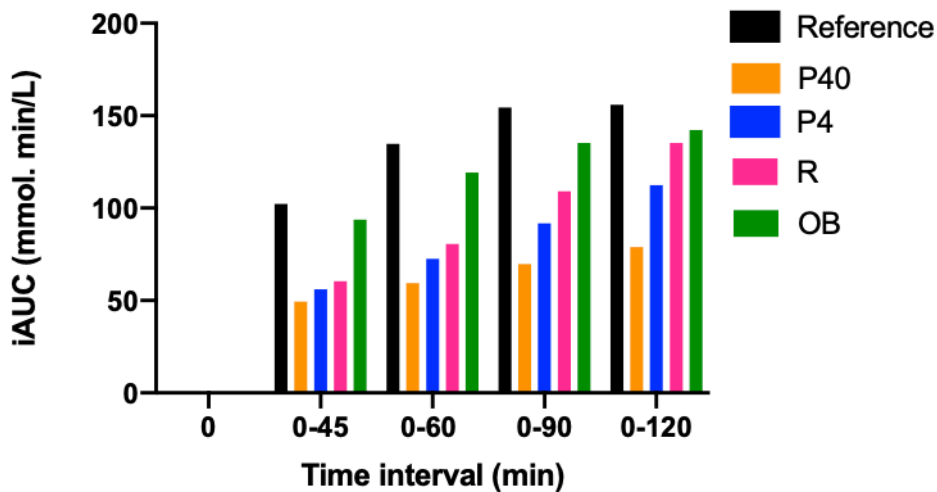

Figure 2. Postprandial glucose iAUC at different time intervals post breakfast with test- and reference products. P40, P4 and R: oat base beverages added with different compositions of lipids; OB: oat base beverage with no added lipids; Reference; glucose solution. The portion sizes of all products were 500 ml, and all products included 42 g available carbohydrates. n =13 healthy subjects. Values are expressed as Means.

3.1.2 Second-meal postprandial blood glucose response after the standardized lunch

Results regarding postprandial glucose responses (iAUC) after the standardized lunch, following consumption of the test and reference products at breakfast are shown in **Table 4** and **Figure 3**. The glucose responses (iAUC) at 210-240 min and at 210-255 min after the standardized lunch were significantly higher following consumption of the test product P4 at breakfast compared to the reference breakfast product ($p < 0.05$). In addition the P4 breakfast resulted in a higher 210-255 min glucose iAUC after lunch also compared to the OB breakfast ($p < 0.05$). At the time interval between 210-270 min, the glucose iAUC after the standardized lunch were significantly higher after consuming the P4 and R breakfasts, respectively, compared to the reference breakfast ($p < 0.05$).

Table 4. Postprandial glucose iAUC at different time intervals after a standardized lunch, following consumption of test and reference products consumed at breakfast [1].

Test Product	iAUC 210-240 (mmol*min\L)	iAUC 210-255 (mmol*min\L)	iAUC 210-270 (mmol*min\L)	iAUC 210-300 (mmol*min\L)
Reference	16 ± 3^a	$48 \pm 8\ ^a$	$76 \pm 13\ ^a$	116 ± 25^a
P40	$30 \pm 5\ ^{ab}$	$68 \pm 9\ ^{ab}$	$98 \pm 14\ ^{ab}$	$138 \pm 23\ ^a$
P4	$35 \pm 6\ ^b$	$85 \pm 12\ ^b$	$127 \pm 18\ ^b$	$182 \pm 28\ ^a$
R	$26 \pm 4\ ^{ab}$	$72 \pm 9\ ^{ab}$	$116 \pm 14\ ^b$	$180 \pm 25\ ^a$
OB	$20 \pm 4\ ^{ab}$	$56 \pm 8\ ^a$	$90 \pm 12\ ^{ab}$	$140 \pm 22\ ^a$

[1] Values are expressed as Mean ±SEM; n=13. Results within a column with different superscript letters are significantly different (p-value < 0.05: one-way ANOVA followed by Tukey's test). The standardized lunch was served at 210 min. P40, P4 and R: oat base beverages added with different compositions of lipids; OB: oat base beverage with no added lipids; Reference; glucose solution. The portion sizes of all products were 500 ml, and all products included 42 g available carbohydrates.
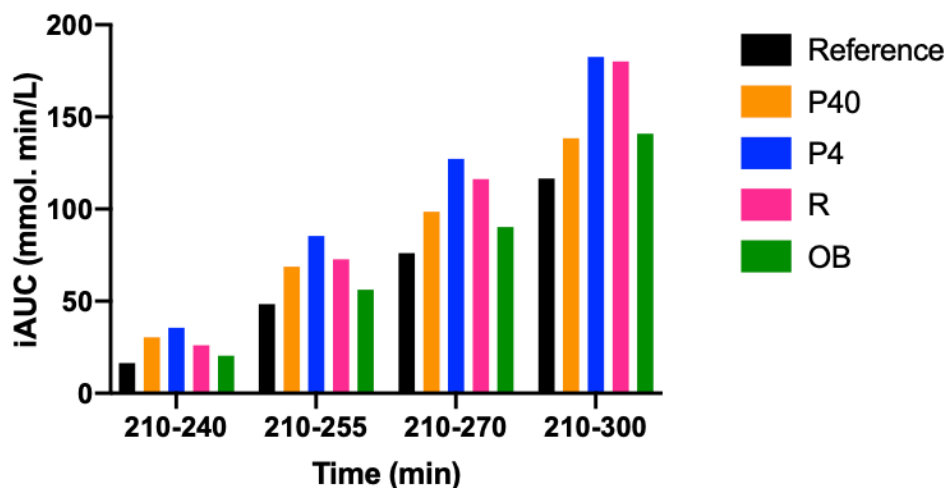
Figure 3. Postprandial glucose iAUC at different time intervals after the standardized lunch (meat balls and white bread), following consumption of intervention products in the morning. The standardized lunch was served at 210 min. P40, P4 and R: oat base beverages added with different compositions of lipids; OB: oat base beverage with no added lipids; Reference; glucose solution. The portion sizes of all intervention products at breakfast were 500 ml, and all products included 42 g available carbohydrates. n =13 healthy subjects. Values are expressed as Means.

3.2 Appetite variables

3.2.1 Hunger

Table 5 and **Figure 4** displays the Mean ±SEM values of hunger scores acutely post intake of the test- and reference products at breakfast, and after the second-meal standardized lunch. Postprandial breakfast (30-210 min) the test products P40, P4, R and OB resulted in significantly lower hunger scores compared to the reference product ($p < 0.05$). However, at 210 min i.e. directly prior to the lunch meal, only the test product P4 resulted in significantly lower hunger scores compared to the reference product ($p < 0.05$). At the time interval 210-330 min, i.e. after the standardized lunch, the test products P40, P4 and OB resulted in significantly lower hunger scores compared to the reference product ($p < 0.05$). Results based on the entire experimental period (30-330 min) show significant reduced hunger scores after all test products (P40, P4, R and OB) compared to the reference ($p < 0.05$).

Table 5. Postprandial subjective hunger sensations at different time intervals after the intervention products consumed at breakfast and after a standardized lunch consumed at time = 210 min[1].

Test Product	Mean 30-210 min	Mean 30-330 min	Mean 210-330 min	210 min
Reference	63 ± 4 [a]	58 ± 5 [a]	54 ± 6 [a]	83 ± 5 [a]
P40	50 ± 4 [b]	44 ± 4 [b]	41 ± 4 [b]	71 ± 4 [ab]
P4	46 ± 5 [b]	42 ± 4 [b]	42 ± 5 [b]	66 ± 7 [b]
R	50 ± 5 [b]	46 ± 5 [b]	45 ± 5 [ab]	72 ± 5 [ab]
OB	51 ± 4 [b]	45 ± 4 [b]	41 ± 4 [b]	70 ± 7 [ab]

[1] Values are expressed as Mean ±SEM; n=13. Results within a column with different superscript letters are significantly different (p-value < 0.05: one-way ANOVA followed by Tukey's test). P40, P4 and R: oat base beverages added with different compositions of lipids; OB: oat base beverage with no added lipids; Reference; glucose solution. The portion sizes of all products were 500 ml, and all products included 42 g available carbohydrates.
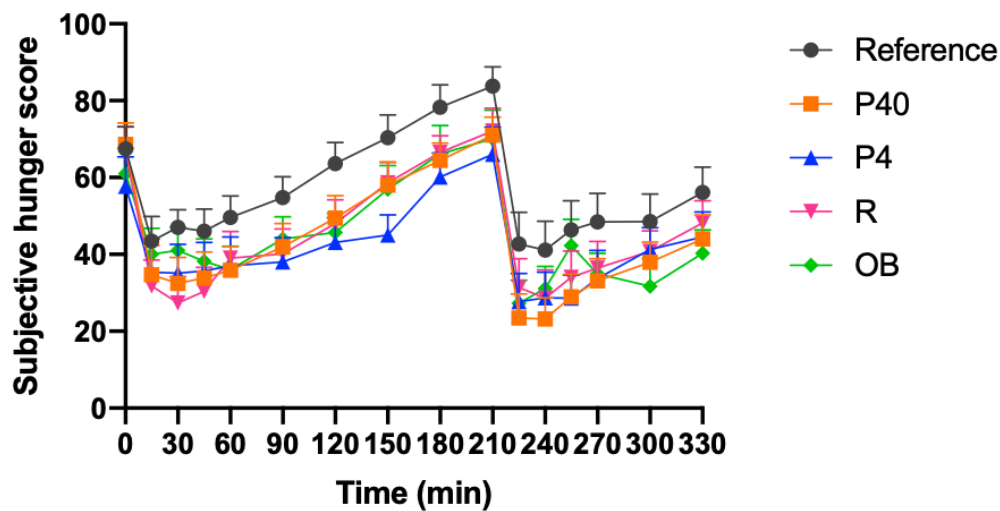

Figure 4. Hunger scores post breakfast with test and reference products, and after a standardized lunch (meat balls and white bread) at 210 min. P40, P4 and R: oat base beverages added with different compositions of lipids; OB: oat base beverage with no added lipids; Reference; glucose solution. The portion sizes of all products were 500 ml, and all products included 42 g available carbohydrates. n =13 healthy subjects. Values are expressed as Means ± SEM.

3.2.2 Desire to eat

The results regarding desire to eat scores post intake of the different test products and the reference product at breakfast, and after the standardized lunch, are shown as Mean ±SEM in **Table 6** and **Figure 5**. The results show that the test products P40, P4, R and OB resulted in significantly lower desire to eat scores compared to the reference product, both in the breakfast postprandial period 30-210 min and after the standardized lunch at the time interval 210-330 min ($p < 0.05$). Consequently, with respect to desire to eat all test products resulted in improved appetite regulation during the entire experimental period $0 - 30$ min ($p < 0.05$). However, at 210 min i.e. directly prior to the lunch meal, there were no differences in the mean desire to eat scores between the test products and the reference product ($p > 0.05$).

Table 6. Postprandial subjective sensations of desire to eat at different time intervals after the intervention products consumed at breakfast and after a standardized lunch consumed at time = 210 min[1]

Test Product	Mean 30-210 min	Mean 30-330 min	Mean 210-330 min	210 min
Reference	68 ± 4 [a]	62 ± 3 [a]	59 ± 5 [a]	89 ± 3 [a]
P40	48 ± 4 [b]	43 ± 3 [b]	41 ± 5 [b]	70 ± 5 [a]
P4	47 ± 4 [b]	43 ± 2 [b]	43 ± 4 [b]	68 ± 8 [a]
R	53 ± 4 [b]	48 ± 3 [b]	46 ± 5 [b]	72 ± 6 [a]
OB	56 ± 4 [b]	47 ± 3 [b]	42 ± 5 [b]	75 ± 8 [a]

[1] Values are expressed as Mean ±SEM; n=13. Results within a column with different superscript letters are significantly different (*p*-value < 0.05: one-way ANOVA followed by Tukey's test). P40, P4 and R: oat base beverages added with different compositions of lipids; OB: oat base beverage with no added lipids; Reference; glucose solution. The portion sizes of all products were 500 ml, and all products included 42 g available carbohydrates.
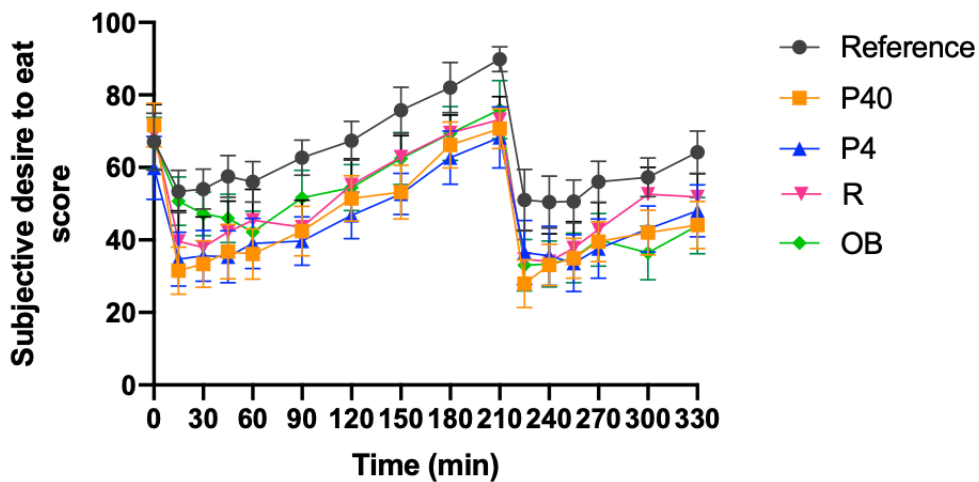
Figure 5. Desire to eat scores post breakfast with test and reference products, and after a standardized lunch (meat balls and white bread) at 210 min. P40, P4 and R: oat base beverages added with different compositions of lipids; OB: oat base beverage with no added lipids; Reference; glucose solution. The portion sizes of all products were 500 ml, and all products included 42 g available carbohydrates. n =13 healthy subjects. Values are expressed as Means ± SEM.

3.2.3 Satiety

Table 7 and **Figure 6** displays the results (Mean ±SEM) regarding subjective satiety scores after the different test products and the reference product post breakfast and the standardized lunch. Post breakfast (30-210 min) and during the entire experimental period 30-330 min, the test products P40, P4, R and OB resulted in significantly higher mean satiety scores compared to the reference product ($p < 0.05$). Similarly, at the time interval 210-330 min i.e. after lunch, the test products P40, P4, R and OB resulted in significantly higher satiety scores compared to the reference product ($p < 0.05$). However, at t = 210 min i.e. directly prior to the lunch meal, there were no differences in the satiety scores between the test products and the reference product.

Table 7. Postprandial subjective sensations of satiety at different time intervals after the intervention products consumed at breakfast and after a standardized lunch consumed at time = 210 min[1]

Test Product	Mean 30-210 min	Mean 30-330 min	Mean 210-330 min	210 min
Reference	26 ± 4 [a]	36 ± 3 [a]	43 ± 5 [a]	16 ± 2 [a]
P40	48 ± 13 [b]	56 ± 3 [b]	60 ± 6 [b]	23 ± 4 [a]
P4	49 ± 4 [b]	56 ± 3 [b]	59 ± 7 [b]	23 ± 0 [a]
R	49 ± 4 [b]	54 ± 3 [b]	57 ± 4 [b]	26 ± 3 [a]
OB	46 ± 5 [b]	53 ± 3 [b]	57 ± 5 [b]	24 ± 1 [a]

[1] Values are expressed as Mean ±SEM; n=13. Results within a column with different superscript letters are significantly different (p-value < 0.05: one-way ANOVA followed by Tukey's test). P40, P4 and R: oat base beverages added with different compositions of lipids; OB: oat base beverage with no added lipids; Reference; glucose solution. The portion sizes of all products were 500 ml, and all products included 42 g available carbohydrates.
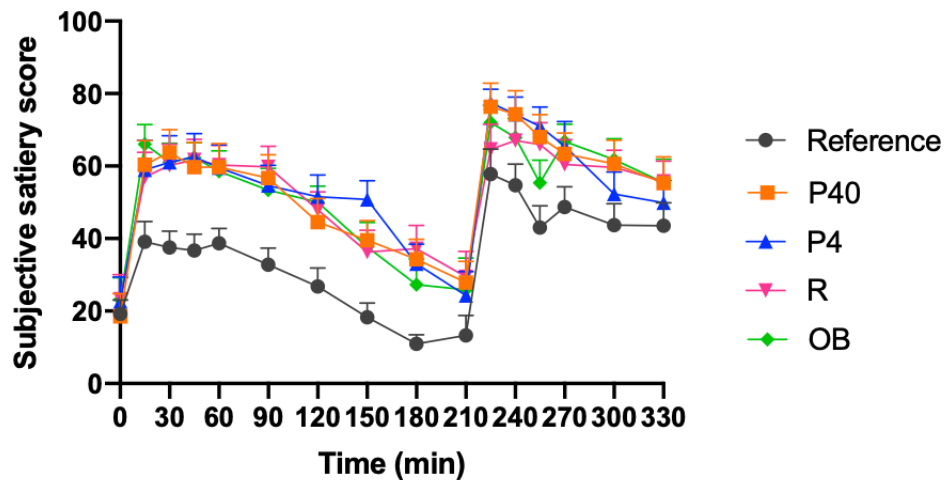

Figure 6.

Satiety scores post breakfast with test and reference products, and after a standardized lunch (meat balls and white bread) at 210 min. P40, P4 and R: oat base beverages added with different compositions of lipids; OB: oat base beverage with no added lipids; Reference; glucose solution. The portion sizes of all products were 500 ml, and all products included 42 g available carbohydrates. n =13 healthy subjects. Values are expressed as Means ± SEM.

4. Discussion

The current study aimed to evaluate the effects of oat base beverages with different compositions and amounts of lipids on glucose tolerance and subjective perceived appetite variables in healthy humans. The test beverages were provided as breakfast meals and the test variables were determined repeatedly in the postprandial period after breakfast and after a standardized lunch meal. The main findings were that the test beverages with added lipids (32 g) significantly lowered the acute postprandial glucose responses at breakfast. In addition, the results showed that the different lipids added to the oat base differed in the potential to lower the acute postprandial glucose responses post breakfast, and also differed in the effects on the glucose response after a second meal, i.e. at the following lunch. Accordingly, after the standardized lunch meal the glucose responses tended in general to be increased after the breakfast beverages with added lipids compared to the reference product. However, there was a trend towards a less increase in blood glucose concentrations after the lunch for the test product P40 compared to the test products R and P4. Consequently, at lunch the glucose responses after P40 breakfast were more similar to the glucose responses after OB breakfast, i.e. the oat base without added lipids. . The OB breakfast resulted in similar glucose responses as the glucose reference product; both acutely after intake and at the second-meal standardized lunch.

With respect to subjective appetite variables, all oat base products resulted in decreased perceived hunger and desire to eat sensations and an increased satiety sensation during the entire experimental period compared to the glucose reference, regardless of the fat composition and amounts.

The presence of added dietary fats in the oat base test products played a significant role in lowering the iAUC post breakfast. Collier (18) conducted several second meal studies on the influence of fat consumption on blood glucose and insulin levels. The author reported that a combination of fat and carbohydrate feeding lowered blood glucose and increased insulin levels compared with carbohydrate feeding alone (18). Gatti et al. (19) have studied the effect of consuming several types of fats on plasma glucose and insulin responses in ten healthy subjects (19), and concluded that olive and corn oils reduced the postprandial area under the glucose curve, whereas butter postponed the plasma glucose rise without changing

the magnitude of the area under the curve (19). These findings are in line with our results showing that different fat compositions have different effects on the glucose iAUC.

A study by Carnevale et al. (20) showed that in healthy subjects extra virgin olive oil (EVOO) decreased post-prandial glycaemia with a mechanism relating to up-regulation of incretin hormone activity and increased blood insulin concentrations (20). The meal containing EVOO was associated with an approximately 20% postprandial decrease of blood glucose concentrations and a 40% increase of insulin concentrations compared with a meal not containing EVOO (20). Beneficial effects of EVOO on postprandial glucose tolerance were seen also in patients with impaired fasting glucose concentrations where the underlying mechanisms were ascribed to up regulating of incretins (21). Consistently EVOO supplementation was associated with GLP-1 increase coinciding with a decrease of dipeptidyl peptidase IV (DPP-4) activity, which proposes DPP-4 inhibition as a potential mechanism accounting for GLP-1 and insulin up-regulation after the EVOO (21). Investigations of effects of the test products on insulin or incretins were not within the scope of our thesis work, but in the light of previous findings it is feasible to speculate that the different lipid compositions in the oat base products might possess different effects on glucose responses through mechanisms involving incretins, However, it has been shown that fat in general reduces gastric emptying rate. Accordingly, it might be possible to lower the early postprandial glucose response just by adding fat to the diet (22). This might explain the reason behind the significantly lower glucose responses at breakfast after the oat base test products with high content of lipids compared to the beverage with low or zero amounts of lipids, i.e. the OB and the reference. Nevertheless, despite similar lipid quantities, the lipid compositions in our study seems to differ in the potential to affect glucose responses, both acutely and at a second meal, pointing at additional mechanisms related to the lipid quality and not solely to the lipid quantity *per se*.

In contrast to the results observed acutely postprandial breakfast, the glucose responses at the standardized lunch tended to increase after the test breakfasts with added lipids. The reason behind this is unclear but at least one reason could be due to an acute increased insulin resistance already after a few hours after a high fat meal. Thus, it was previously observed that increased circulating free fatty acids (FFA) acutely might induce insulin resistance (23). Collier et al. (24) have studied the effects of a first meal containing 50 g CHO as white bread and 26 g fat as butter on the glucose and insulin responses to that meal and to a standardized

mixed meal given 4 h later (24). In accordance with our results, the glucose response to the first meal was reduced when fat was present, and also similar to our result, increased intake of fat impaired the glucose tolerance at a standardized lunch meal compared to an isocaloric meal with higher starch content. In this regards it is interesting to note that the impaired glucose tolerance after the beverage with added lipids tended to be minor after the P40 breakfast. Accordingly, previous findings make it feasible to suggest that the better glucose tolerance seen in the present study after P40 breakfast compared to the other beverages with added lipids might involve mechanisms related to increased insulin sensitivity due lower concentrations of circulating FFA, and/or increased concentrations of incretins at the time for the lunch meal.

With respect to second-meal effects on glucose tolerance, Wolever (25) have suggested that a low GI meal *per se* improve second meal glucose tolerance (both from dinner to breakfast, and from breakfast to lunch) compared to a high a GI meal. In the presently described study this effects are not see. Accordingly, the high fat beverage resulted in lower acute glucose responses compared with OB and reference, but induced worse second-meal glucose tolerance. The reason of this discrepancy could be that, if the first meal contains high amounts of fat, the relationship between low GI and improved second-meal glucose tolerance is not seen, as a result of decreased insulin sensitivity due to increased circulating FFA (as described above). In addition, the relationship between low GI meals and improved glucose tolerance at a second-meal consumed after approximately 4 h is only true in carbohydrate rich foods. With respect to second-meal effects on glucose tolerance in a longer time frame, e.g. from dinner to breakfast, the test product has to include specific dietary fiber (26).

Significant differences between the test products and the reference product were found for subjective appetite scores post breakfast and lunch. In fact, all test products resulted in improved appetite variables compared with the reference, regardless of the fat composition. It has previously been seen that oat products rich in dietary fiber have the potential to suppresses appetite, increases satiety, and reduces energy intake (14). The physicochemical properties of B-glucan and sufficient hydration of oats are important factors affecting satiety and subsequent energy intake after oat products. B-glucans has been shown to increase satiety-related hormones such as cholecystokinin, GLP-1, glucagonlike peptide 2 (GLP-2) and PYY (14). Possible mechanisms by which oats could have an effect on satiety is

attributed to the viscous nature of β-glucans, which interferes with the peristaltic mixing process in the small intestine to impede digestion and absorption of nutrients, which precipitates satiety signals (14). The oat base breakfast in the present study included 2.5 g *B*-glucan, and it can be speculated if the B-glucans may have contributed to the improved satiety variables observed. However, the *B*-glucan in the beverages did not result in a substantial increased viscosity, at least not in the beverages. Thus, other mechanisms than viscosity may be important with respect to satiety effects of β-glucans, or other DF included in the oat base beverage (total DF 5 g/portion). Further, in addition to the DF, the oat base test products included also other nutrients that may result in improved appetite variables, e.g. proteins.

Even if the lipid compositions investigated in the present study did not result in differences with respect to effects on subjective appetite variables, it is previously suggested that there is a number of variable lipid specific factors that may impact satiety (27). For example the melting point of the fatty acid is inversely related to its degree of unsaturation which is likely to affect the ease of emulsification of the triacylglycerol in the digestive tract. The emulsification of the triacylglycerol is predicted to markedly affect the ease of digestion and absorption of fatty acids, resulting in the modulation of the rate of interaction between fatty acids and satiety signals on the intestinal wall (27). Long chain fatty acids have been shown to suppress plasma ghrelin and stimulate secretion of CCK (28). Dietary fat is usually digested and absorbed in the upper part of the small intestine, but if occurs in the distal sections of the small intestine, it stimulates a strong feedback signal associated with slowing of gastrointestinal transit and release of various satiety hormones such as CCK, GLP-1, PYY and GLP-2 (28).

However, since the results in the present study indicate that the lipids investigated had no or just minor effects on appetite variables, the differences with respect to appetite variables between the glucose solution and oat base products must be related to other factors in the oat beverage beyond fats and probably also beyond available carbohydrates and effects on glycaemia.

Similar to all studies this study had some limitations. The most obvious limitation is the low number of participants, which probably constrain the statistical power. The lack of sufficient power might interfere with the results in such way that it increases the risk of missing significant results. Consequently, increasing the number of subjects would probably result in

an increased chance to detect differences in effects between the test products. In addition it must be stated that the amounts of fat in the test portions with added lipids (32 g) can be considered as high, which not is recommended on daily basis in a health promoting diet. The quantities in the study are exaggerated to reduce the risk of missing possible effects due to the study design with a limited number of subjects.

5. Conclusion

The results from this study are in line with the hypothesis that specific lipid compositions can have beneficial effects on blood glucose regulation. In this respect the P40 composition was superior in this study. On the contrary, we did not detect any significant effects on satiety variables of any of the lipid composition. Rather, we saw an improved effect of the oat base products on appetite variables depending solely of the oat base *per se*. The results may form a base for further studies aiming at designing foods with preventive effect on cardiometabolic diseases.

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Appendix