A modelling approach to investigate the impact of consumption of three different beef compositions on human dietary fat intakes

Title: A modelling approach to investigate the impact of consumption of three different beef compositions on human dietary fat intakes.

Shortened title: Grass-feeding to improve fat composition

Keywords: beef feeding practices, dietary fatty acid intakes, SFA, PUFA

Abbreviations: %TE, percentage of total energy, ALA, α-linolenic acid; CLA, conjugated linoleic acid; DPA, docosapentaenoic acid, GSC, grass and concentrate-fed, NANS, national adult nutrition survey; SACN, Scientific Advisory Committee on Nutrition, FAME, fatty acid methyl esters

Abstract

Objective: To apply a dietary modelling approach to investigate the impact of substituting beef intakes with three types of alternate fatty acid composition of beef on population dietary fat intakes.
Design: Cross-sectional, national food consumption survey-the National Adult Nutrition Survey (NANS). The fat content of the beef-containing food codes (*n*=52) and recipes (*n*=99) were updated with FA composition data from beef from animals receiving one of three ruminant dietary interventions: grass-fed (GRASS), grass finished on grass silage and concentrates (GSC), or concentrate-fed (CONC). Mean daily fat intakes, adherence to dietary guidelines and the impact of altering beef FA composition on dietary fat sources were characterised.
Setting: Ireland.
Subjects: Beef consumers (*n*=1,044) aged 18-90 years.
Results: Grass-based feeding practices improved dietary intakes of a number of individual fatty acids, wherein myristic acid (C14:0) and stearic acid (C16:0) were decreased, with an increase in conjugated linoleic acid (C18:2c9,t11) and *trans*-vaccenic acid (C18:1t11) ($P<0.05$). Improved adherence with dietary recommendations for total fat (98.5%), SFA (57.4%) and PUFA (98.8%) was observed in the grass-fed beef scenario ($P<0.001$). *Trans*-fat intakes were significantly increased in the grass-fed beef scenario ($P<0.001$).
Conclusions: To the best of our knowledge, this is the first study to characterise the impact of grass-fed beef consumption at population level. This study suggests that habitual consumption of grass-fed beef may have potential as a public health strategy to improve dietary fat quality.

Introduction

Global prevalence of obesity and associated comorbidities has increased significantly in recent years. This increasing incidence is set to continue with 1.35 billion and 573 million of the global population predicted to be overweight or obese by 2030, respectively[1]. Cardiovascular disease (CVD) is currently estimated to be responsible for 17.3 million global deaths annually, with a predicted increase to 23.6 million by 2030[2], and diabetes incidence is set to increase from 415 million to 642 million by 2040[3]. Effective public health strategies are required to combat this global obesity epidemic and reduce the risk of CVD and diabetes.

Dietary fat is a key nutrient for growth and metabolism, however, not all fats exert the same effects, with dietary fatty acid composition playing an important role in health determinants[4]. Saturated fatty acid (SFA) and *trans*-fats have typically been associated with adverse CVD risk, whilst the polyunsaturated fatty acids (PUFA) have been shown to be cardioprotective[5,6]. SFA intakes are typically recommended to be less than 10% of total energy (%TE)[5,6], however, this is generally exceeded globally[7]. Irish SFA intakes are approximately 13%TE[8], which is similar to other European countries[9], and slightly higher than the US at 11%TE[10]. *Trans*-fat intakes are recommended to be ≤2%TE[11], as they have been associated with adverse effects on the blood cholesterol profile however typical reported intakes are below this level in Europe[9,12,13]. The recommended daily intake for monounsaturated fatty acids (MUFA) is ≥12%TE, which is also typically achieved in European countries (11-18%TE)[9], the US (12.5%TE)[10] and other countries[14]. PUFA intakes are recommended to exceed 6%TE[15], yet a review of global intakes across 40 countries by Harika *et al.* reported that only 50% of countries met the PUFA recommendation[14]. A recent review of the evidence by both the UK Scientific Advisory Committee on Nutrition (SACN) and the World Health Organisation (WHO) suggests that replacement of SFA with PUFA is a potential public health strategy to reduce disease risk[5,6].

There are a number of on-going public health strategies to improve population dietary fat intakes, including the increased availability of low-fat products and product reformulation[16]. Alternatively, grass-based ruminant feeding practices naturally modifies the FA composition of animal products by reducing the SFA and increasing the PUFA concentrations, including alpha-linolenic acid (ALA) and docosapentaenoic acid (DPA), in comparison to concentrate-based feeding[17]. A recent predictive modelling analysis by Benbrook *et al.* characterised the FA profile of milk following grass-based feeding and applied nutrition modelling to investigate the potential impact on dietary fat intakes. In comparison to concentrate-fed and organic milk, there was a significant improvement in the FA composition of grass-fed milk, wherein omega-3 (n-3) PUFA levels were increased[18].

Therefore replacement of habitual beef and dairy intakes with grass-fed products may provide a potential strategy to improve dietary fat quality. This provides a cost-effective feeding practice for farmers and meat processors due to the availability of grazing grass for approximately 10 months per year, particularly in Ireland and the UK. However, it does have feasibility constraints, due to the increased feeding time, and associated environmental risks. In particular, beef production has been associated with increased greenhouse gas emissions, both from grass and concentrate feeding and concentrates, with recent reviews suggesting that red meat intakes should be decreased to reduce environmental risk(19,20).

Furthermore, red meat is commonly consumed, providing an important source of protein, iron and vitamins, particularly vitamin B12(21), and meat and meat dishes are important contributors to dietary total fat (22%), SFA (22%), MUFA (26%) and PUFA (19.3%) intakes(8). A randomized controlled trial by McAfee *et al.* investigated the impact on long chain (LC) *n*-3 PUFA status following consumption of 3 portions of grass-fed or concentrate-fed lamb and beef for 4 weeks. Dietary intakes and plasma and platelet concentrations of LC *n*-3 PUFA increased significantly in the grass-fed red meat consumers(22). However, the impact of grass-fed beef consumption at population level is currently unknown. Therefore, the aim of this analysis was to apply a predictive modelling technique to assess the potential impact of replacing habitual beef intakes with grass-fed beef on dietary fat intakes in a nationally representative Irish adult cohort.

Methods

<u>Ruminant dietary intervention</u>

The FA data used in this analysis were derived following a dietary intervention trial using three different animal feeding practices. Fifteen spring-born suckler Aberdeen Angus heifers were assigned to one of three diets: grass only (GRASS), grass finished on grass silage and concentrates (GSC) or concentrates only (CONC), until they reached a target carcass weight of 260kg. The composition of the GRASS intervention was: grass silage *ad libitum* plus a routine mineral supplement during the winter (123 days) followed by rotational grazing of a perennial rye-grass-dominant pasture until slaughter. The CONC intervention was comprised of *ad libitum* concentrates (870g/kg rolled barley, 60g/kg soya bean meal, 50g/kg molasses, 20g/kg minerals/vitamins) and grass silage (1kg dry matter/animal daily), indoors(23). The third intervention group included grazed grass followed by grass silage *ad libitum* and 4kg/d concentrates (GSC) for approximately 4 months. Four muscles (striploin, eye of the round, fillet, chuck tender) were collected at 48h post slaughter, aged for 14 days at 2˚C, prior to storage at -20°C. Prior to FA analysis, the samples were cooked to an internal temperature of 72˚C. The lipids were subsequently extracted and analysed using gas chromatography[24]. In brief, the FA were extracted using a 2-step microwave-assisted (CEM Corporation) saponification and esterification process. Methanolic potassium hydroxide (10 ml, 2.5%) was added for saponification, microwaved and heated to 130˚C, and held for four minutes. Methanolic acetyl chloride (15ml, 5%) was added for esterification, microwaved, heated to 120˚C in four minutes and held for two minutes. Pentane (10ml) was added to extract the fatty acid methyl esters (FAME) and saturated sodium chloride (20ml) was added to induce phase separation. FAME were then measured using a GC-FID for fatty acid quantification, as described previously[24]. An average of four muscles(striploin, eye of the round, fillet, chuck tender), chosen based on lipid concentration, muscle fibre distribution and consumer relevance[25] and a pooled fat samples (*n*=3) from each diet group was applied in the current analysis.

<u>Food consumption data</u>

This study used population food intake data from the 2008-2010 cross-sectional Irish National Adult Nutrition Survey (NANS), which collected data from 1500 nationally representative adults (m=740; f=760) aged 18-90 years.

Written consent was obtained from each participant, in accordance with the Declaration of Helsinki. A detailed description of the NANS recruitment, sampling and methodologies has been outlined elsewhere[26,27]. In brief, participants recorded their dietary intakes using a semi-weighed food diary, over 4 consecutive days, including one weekend day. Product packaging, brand information, recipes and cooking methods were also recorded. A food consumption database was created containing 2552 food codes, which were updated for nutrient composition[26]. The methodology applied to calculate the dietary fat composition (total fat, SFA, MUFA, PUFA, ALA, eicosapentaenoic acid (EPA), docosahexaenoic acid (DHA) and *trans* fat) for each of the NANS food codes has been previously detailed[8]. All food codes were classified into 33 food groups which were representative of the overall diet, including unprocessed and processed red meat[28]. These were further aggregated by beef product for the purpose of this analysis and in total included 52 beef food codes and 99 beef-containing recipes. Sixty-nine percent (*n*=1044) of NANS participants were beef consumers, with a mean daily intake of 86g/d (SD:62).

<u>Predictive modelling scenarios</u>

The potential impact of replacing habitual beef intakes in three modelling scenarios was determined by substituting the fatty acid data of beef-containing foods with data from beef from the GRASS, GSC or CONC interventions. For the modelling scenarios the beef compositions will be referred to as G-FB (grass-fed beef) as derived from the GRASS intervention, GC-FB (grass-fed beef finished on grass silage and concentrates) from the GSC intervention and C-FB (concentrate fed-beef) from the CONC intervention. Fatty acid concentrations (*n*=31) were provided for cooked muscle and fat components of beef from each intervention. The proportion of muscle and fat (g/100g of food) was calculated using the online *McCance and Widdowson's Composition of Foods* integrated dataset and manufacturer information[29]. The beef food codes were then updated for fatty acid concentration (*n*=31) for each of the three beef compositions (G-FB, GC-FB, C-FB) for both muscle and fat. Similarly, the codes for the beef-containing recipes, which accounted for weight loss factors, were disaggregated into their ingredient components and their percentage contribution to each recipe was calculated and subsequently re-aggregated. Three versions of the original dataset were created, containing the updated fatty acid compositional data for the three different beef types and the aggregated recipes. Each fatty acid was then converted from grams per 100g (muscle/fat) to grams per weight of food consumed. These data were subsequently used to characterise the impact of the compositional changes in beef as affected by the animal feeding practices. This included investigating the differences in fatty acid composition of cooked beef by animal feeding practice, calculating total fat and fat sub-type intakes using a 100% replacement modelling scenario, wherein, dietary beef products in the NANS were replaced with equivalent products derived from altered animal feeding practices. The impact on intakes of 14 individual fatty acids, adherence to dietary fat guidelines and the impact of altering fat composition of the beef-containing food groups on contributions to overall dietary fat intakes in beef consumers was also determined.

<u>Statistical analysis</u>

Data analysis was carried out using SPSS® for Windows™ statistical software package version 20.0 (SPSS Inc. Chicago, IL, USA). A one-way ANOVA was used to calculate differences between beef dietary modelling scenarios. Bonferroni correction was applied by multiplying each P value by the number of rows, each representing a trait, in each table. $P \leq 0.05$ was considered significant and those that exceeded 1.0 were marked down to 1.000[30]. The cohort was split by tertile of beef consumption, to create equivalent consumption groups to determine whether the quantity of beef consumed affected the dietary fat intake modelling scenarios. A 100% modelling scenario was subsequently applied using the beef compositional data from the three beef interventions. Mean daily intakes of total fat and the fat subtypes were calculated and are presented as mean values with standard deviations. Mean daily intakes for 14 compositional fatty acids were subsequently calculated and a one-way ANOVA with Bonferroni correction applied. A chi-squared test examined differences in population adherence to dietary fat recommendations between beef scenarios. In brief, compliance with the UK Department of Health recommendations for total fat (≤33%), SFA (≤10%), MUFA (≥12%) and PUFA (≥6%)[31], the ESFA recommendation for ALA (≥0.5%)[9] and the SACN recommendation for *trans*-fat (≥2%)[11] was determined by estimating the maximal subgroup of the population that complied with the population target, by ranking individuals based on their mean daily intakes, as outlined in Wearne *et al.*[32]. The impact of altering the FA composition on overall dietary total fat, SFA, MUFA, PUFA and ALA contributions from beef-containing food groups was assessed using a one-way ANOVA.

Results

FA composition of cooked beef post feeding intervention

The FA composition of the cooked beef muscle and fat following intervention with either GRASS, GSC or CONC are presented in **Table 1,** with the entire complement of ruminant fatty acids quantified presented in **Supplemental Table 1.** Significant differences were observed in the beef muscle and fat composition, particularly across individual SFA, MUFA and PUFA concentrations. The muscle concentration of myristic acid (C14:0), stearic acid (C16:0), myristoleic acid (C14:1) and oleic acid (C18:1) (g/100g) were significantly lower following the GRASS intervention, in comparison to both the GSC and CONC interventions, as were the n-6 PUFA, including linoleic acid (C18:2) ($P<0.05$). The GRASS intervention increased concentrations of the n-3 PUFA; ALA (C18:3), CLA (C18:2c9t11) and DPA (C22:5) ($P<0.001$).

Impact of altering animal feeding practices on dietary fat intakes

Mean daily fat intakes following predictive modelling assuming 100% consumption are presented in **Table 2**, by tertile of beef consumption. No difference was observed in total fat, SFA, MUFA and PUFA intakes, however intakes of *trans*-fat were greater in the grass-fed beef groups ($P<0.001$). Altering the composition of beef also increased *trans*-fat and intakes in the overall NANS cohort (*n*=1500) **(Supplemental Table 2).**

Impact of altering animal feeding practices on intakes of individual fatty acids

Differences were observed in dietary intakes (%TE) of individual fatty acids between the three beef scenarios (**Table 3)**. In terms of intakes of individual fatty acids related to SFA a significant stepwise decrease of myristic acid(C14:0) and stearic acid (C16:0) was observed across tertiles, wherein they were significantly lower in all G-FB scenario ($P<0.001$). While intakes of vaccenic acid (C18:1t11) was observed to be significantly greater in the G-FB scenario ($P<0.001$); these differences were consistent across all three consumption groups. In terms of PUFA intakes, a significant increase in arachidonic acid (AA) (C20:4) was noted from G-FB to C-FB ($P<0.001$). Intakes of DPA (C22:5) and CLA (C18:2c9,t11) were significantly greater in the G-FB scenario, with a stepwise decrease across tertiles observed between GC-FB and C-FB (P<0.001). Similar trends were observed when the intakes were expressed as g/day (data not shown). In addition, a reduction in the PUFA ratio (LA:ALA) was observed in the G-FB scenario in the high beef consumers (P<0.001).

Adherence to population-based dietary guidelines

The predicted adherence to dietary fat recommendations of the UK Department of Health and SACN for total fat, SFA, MUFA and PUFA[5,31], the EFSA recommendation for ALA (9) and the SACN recommendation for *trans*-fat[11] are presented in **Figure 1.** All three beef groups adhered to the MUFA, ALA and trans-fat recommendations. Greater compliance was observed in the G-FB scenario, compared to the GC-FB and C-FB scenarios for total fat (98.5%, 98.3%, 95.5%), SFA (57.4%, 52.9%, 51.1%) and PUFA (98.8%, 94.0%, 93.7%) recommendations (P<0.05).

Impact of altering the beef composition on contributions of food groups to dietary fat intakes

Unprocessed and processed red meat are among the top contributors to dietary fat intakes in the Irish population (**Supplemental Table 3)**. Modification of the fatty composition of red meat therefore has the potential to improve dietary fat quality. The impact of modifying the red meat food groups on their contribution to overall dietary fat intakes in the current analysis is presented in **Table 4.** Grass-based animal feeding beneficially altered fat composition of unprocessed red meat (beef and veal) to reduce percentage contributions to overall SFA and MUFA intakes, and to increase PUFA and ALA contributions (P<0.05). However, modification of the fatty acid profile of processed beef products did not affect dietary fat quality.

Discussion

Grass-based feeding practices can alter the fatty acid composition of beef, but whether this can translate into improvements in population dietary fat intakes is hitherto unknown. Using a predictive modelling approach, this analysis demonstrated that consumption of grass-fed beef has the potential to change the composition of dietary fatty acids and to improve population adherence to dietary recommendations for total fat, SFA and PUFA, in line with recent scientific recommendations[5,6]. Moreover, in this dietary modelling scenario, altering the fatty acid profile of unprocessed, but not processed beef, through grass-based feeding practices presented a potential strategy to improve the quality of dietary fat intakes.

Red meat is a primary source of dietary fat, with beef contributing to 7.5% of total fat and 8.2% of SFA intakes in the overall NANS cohort, which is comparable to other countries[33,34]. Red meat is also an important source of protein, iron, vitamin D and vitamin B12[21]. Nevertheless high intakes have been associated with increased risk of heart disease[35] and diabetes[36] in observational studies, however no such association was observed in the current cohort[28]. To mitigate any such risk the World Cancer Research Fund (WCRF) recommend a weekly intake of 3 portions (≤500g) red meat[37], with Irish guidelines suggesting 50-75g of cooked lean red meat per day[38]. Of note, the recent EAT-Lancet Commission recommend that red meat consumption should be reduced to one portion per week, for health and environmental reasons[20]. Therefore, future public health guidelines may promote less frequent consumption of higher quality red meat. In the current analysis, the cohort was split by beef consumption, with low and medium beef consumers presenting mean daily intakes of 29 and 73g/d respectively, thus adhering to the red meat recommendations. This modelling scenario identified significant differences in dietary fatty acid intakes across the low, medium and high beef consumers. Therefore, altering the ruminant feeding practice has the potential to improve the quality of the dietary fat consumed, and potentially health outcomes, without increasing consumption or exceeding the current red meat consumption guidelines.

In line with previous studies, the fatty acid composition of the cooked muscle and fat differed significantly in the current analysis, with reduced SFA and increased PUFA concentrations observed following the GRASS intervention[17]. However, with the exception of *trans*-fat this failed to translate into significant differences in dietary total fat and subtype intakes. The current modelling scenario suggested that intakes of *trans*-fat were significantly greater across all G-FB groups, regardless of the quantity consumed ($P<0.001$). Analysis of the intakes of individual fatty acids identified a significant increase in C18:1t11 (*trans*-vaccenic acid; TVA), which is a ruminant derived *trans*-fatty acid. Adherence to the trans-fat recommendation of ≤2%TE[11] was achieved in all three beef scenarios. Moreover, while there was no observed impact on overall dietary SFA intakes, individual SFA intakes. In particular myristic acid (C14:0) and palmitic acid (C16:0), were significantly lower in the G-FB scenarios ($P<0.001$). This is an important observation as both of these fatty acids have been associated with increased CVD risk due to their adverse effect on LDL cholesterol levels. Furthermore, levels of CLA (C18:2c9,t11) in cooked muscle and fat were increased significantly by the grass-based feeding practice, which translated into significantly greater intakes of C18:2c9,t11 (CLA) in the G-FB scenario ($P<0.001$). The G-FB modelling scenario significantly reduced intakes of the n-6 PUFA, AA (C20:4), which were previously associated with increased inflammation, however a recent review by Innes *et al.* has challenged this, due to a lack of association in healthy adults, concluding that the omega n-6 fatty acid and inflammation paradigm is complex and requires further investigation[39]. Moreover, a significant increase in DPA (C22:5) was observed in muscle concentrations following the GRASS intervention, this translated into a predicted increase in DPA intakes in the G-FB modelling scenario. In comparison to the other LC n-3 PUFA, DPA is a major circulating fatty acid in beef, and is an intermediary in the conversion of EPA to DHA[40]. The evidence relating to the biological role of DPA is limited; however, studies have demonstrated an association between intakes of DPA and an improvement in markers of metabolic health, including inflammation and reduced risk of myocardial infarction[41]. Consumption of grass-fed beef, within the recommended dietary guidelines, may provide a strategy to increase intakes of the LC n-3 PUFA.

Modification of the fatty acid composition of beef in the current cohort impacted adherence to population dietary fat recommendations. The majority of the G-FB scenario (98.5%) achieved the total fat recommendation of ≤33%TE, which was 3% greater than the CONC group ($P<0.001$). Adherence to the SFA recommendation of ≤10%TE was achieved by 57.4% of the G-Fb scenario, which was 4.5% and 6.3% greater than the GC-FB and C-FB scenarios, respectively ($P=0.013$). Similarly, 98.8% of the G-FB scenario adhered to the PUFA (≥6%TE) recommendation compared to 94.0% and 93.7% in the GC-FB and C-FB scenarios, respectively ($P<0.001$). Increased adherence to the SFA recommendation has been reported over the previous decade[8], potentially as a result of increased availability of low-fat dairy products or product reformulation[42] and reducing SFA contributions by replacement with PUFA[43]. This predictive modelling scenario suggests that consumption of grass-fed beef may further contribute to reducing population SFA intakes to the desired ≤10%TE whilst retaining population intakes of red meat within consumption guidelines.

Processed red meat has been associated with increased risk of CVD[35], diabetes[36] and colon cancer[44]. Therefore, current dietary guidelines advocate limiting processed red meat consumption[37]. The current modelling scenario investigated the impact of altering the composition of red meat products by altering animal feeding practices. Significant improvements were observed across unprocessed red meat groups, wherein G-FB scenario displayed lower SFA and MUFA intakes and increased PUFA and ALA intakes ($P<0.05$). This beneficial impact was not observed in the processed red meat groups. Thus, this analysis supports the recommendation to limit processed red meat consumption, and highlights the potential to improve dietary fat quality by consuming grass-fed unprocessed red meat, in line with current red meat recommendations.

The influence of grass and concentrate animal feeding practices on beef fatty acid composition has been well-characterised[17]. However, as grass-based feeding alone is not always a feasible feeding option, this analysis sought to investigate the impact of grass grazing followed by grass silage and partial concentrate feeding on beef fatty acid composition and subsequently population dietary intakes, using composition data from the GSC dietary intervention. In terms of beef fatty acid composition, this group presented an intermediary fatty acid profile to the GRASS and CONC groups. This translated to intermediate improvements in dietary fatty intakes, wherein in comparison to the GC-FB scenario, intakes of individual SFA were reduced, adherence to the total fat recommendation was significantly greater and as above, improvements in dietary fat contributions following altering the composition of unprocessed red meat products in the GC-FB scenario. This suggests that both grass only and partial grass feeding presents a healthier fatty acid profile than solely concentrate feeding; translating into improvements in dietary fat quality and potentially long-term health outcomes.

Recent reviews of the evidence, including the EAT-Lancet report have recommended that meat intakes need to be reduced in order to combat the current global health and environmental sustainability issues[19,20]. However, public health strategies will be required to achieve a gradual reduction of intakes, and the health and environmental properties of the replacement foods must also be considered. One such strategy includes enhancing the nutritional quality, yet reducing the quantity of red meat consumed[45]. A recent review by Provenza *et al.* highlights the impact of the processed food consumption trend on global health, and while grass-fed diets do have some environmental constraints, a diet limited in processed foods and rich in natural, wholesome plant and animal-based foods is required to improve health and environmental issues[46]. This modelling scenario highlights the importance of beef quality on dietary fat intakes in an Irish population. This adds to previous findings from Benbrook *et al.* which found that grass-fed milk consumption was associated with improved PUFA status[18] and McAfee *et al.* that identified improved n-3 PUFA intakes and plasma and platelet LC n-3 status following replacement of replacement of habitual meat consumption with grass-fed beef and lamb[22]. Lamb was consumed by 15% of the current cohort, therefore the impact of grass-based lamb feeding merits investigation. A recent review by Givens *et al.* suggested that modification of the bovine diet could potentially reduce CVD risk but that further research, using randomised controlled trials, are required[47]. The collective impact of dietary substitution with grass-fed beef, lamb and milk should also be investigated as this may provide a potential future public health initiative to replace SFA with PUFA, in accordance with the recent WHO and SACN recommendations[5,6].

The use of data from the latest Irish food consumption survey was one of the strengths of this predictive modelling analysis, due to the quality of the dietary data collected using a 4-day semi-weighed food diary and product information, which underwent rigorous quality checks, including post collection and post data entry checks. As fatty acid composition changes with cooking[48], the beef was cooked prior to fatty acid analysis and weight loss factors were accounted for in the beef-containing recipes, to obtain a more realistic modelling scenario. However, this study has a number of potential limitations that must also be acknowledged. Due to the nature of the beef intervention the cattle were weight-matched at slaughter, therefore the grass-fed beef cattle were older, which may have affected the PUFA:SFA ratio[49]. Additionally, this study assumed 100% replacement with an individual beef type, which is not reflective of true population intakes. Nonetheless, the inclusion of the GSC group strengthened the analysis, as it presented novel intermediary findings in the beef muscle and fatty acid composition, which translated to differences in dietary fat intakes, highlighting that partial consumption of grass presents a more beneficial outcome on dietary fat quality than concentrate-feeding alone.

In conclusion, this is the first study to model the impact of grass-fed beef consumption at population level. These findings suggest that altering ruminant fatty acid composition using a grass-based feeding system has the potential to significantly improve dietary fat quality and adherence to population dietary fat recommendations. WHO and SACN recently recommended that replacement of SFA with PUFA is a potential future health strategy to reduce the risk of disease[5,6]. Thus, this analysis suggests that habitual consumption of grass-fed beef, either alone or in tandem with grass-based milk and lamb, is a promising initiative to further improve SFA and PUFA intakes. Further research is required to determine if the fatty acid composition of grass-fed ruminants could be further improved through dietary manipulation. Furthermore, to encourage adherence to grass-based products consumption, governments could consider incentives for farmers who apply grass-based feeding practices, coupled with effective marketing strategies.

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Table 1. Fatty acid composition of cooked muscle (average of 4 cooked cuts†) and fat following the beef intervention (g/100g). Data illustrated as means and standard deviations.

	Muscle							Fat						
	GRASS		GSC		CONC			GRASS		GSC		CONC		
	Mean	SD	Mean	SD	Mean	SD	P*	Mean	SD	Mean	SD	Mean	SD	P*
SFA	1.78^{a}	0.36	2.12^{b}	0.45	2.55^{c}	0.49	**<0.001**	34.97	1.24	42.74	1.49	42.78	1.83	0.059
MUFA	1.83^{a}	0.37	2.05^{a}	0.49	2.89^{b}	0.56	**<0.001**	42.37^{a}	1.17	46.89^{b}	1.60	53.75^{c}	2.00	**0.035**
PUFA	0.27^{a}	0.04	0.24^{b}	0.04	0.26^{ab}	0.03	**0.039**	3.19^{a}	0.12	2.76^{b}	0.10	2.12^{c}	0.08	**<0.001**
trans-fat	0.20^{a}	0.06	0.15^{b}	0.04	0.15^{b}	0.04	**<0.001**	5.84^{a}	0.11	4.21^{b}	0.26	2.98^{c}	0.06	**<0.001**
Total n-6 PUFA	0.12^{a}	0.01	0.14^{b}	0.02	0.20^{c}	0.02	**<0.001**	0.69^{a}	0.02	0.87^{b}	0.03	1.27^{c}	0.02	**<0.001**
Total n-3 PUFA	0.10^{a}	0.01	0.06^{b}	0.01	0.03^{c}	0.01	**<0.001**	0.56^{a}	0.02	0.47^{b}	0.02	0.30^{c}	0.01	**<0.001**
LA:ALA	0.16^{a}	0.01	0.26^{b}	0.04	0.62^{c}	0.11	**<0.001**	1.23^{a}	0.00	1.87^{b}	0.03	4.29^{c}	0.05	**<0.001**
C14:0	0.10^{a}	0.02	0.14^{b}	0.03	0.18^{c}	0.04	**<0.001**	2.66^{a}	0.16	3.87^{b}	0.13	3.68^{b}	0.24	**0.019**
C15:0	0.01	0.01	0.02	0.01	0.02	0.01	0.070	0.55	0.03	0.58	0.03	0.49	0.02	0.752
C16:0	0.95^{a}	0.19	1.21^{b}	0.28	1.51^{c}	0.30	**<0.001**	20.72^{a}	0.81	26.63^{b}	0.96	27.02^{b}	1.23	**0.026**
C17:0	0.05^{a}	0.01	0.05^{a}	0.01	0.07^{b}	0.01	**<0.001**	0.89	0.03	0.99	0.04	1.10	0.04	0.078
C18:0	0.67	0.14	0.70	0.13	0.77	0.15	0.579	10.16	0.23	10.66	0.34	10.48	0.30	1.000
C14:1	0.02^{a}	0.01	0.03^{b}	0.01	0.05^{c}	0.01	**<0.001**	1.17^{a}	0.08	1.67^{b}	0.06	1.75^{b}	0.12	**0.020**
C16:1c9	0.15^{a}	0.03	0.19^{b}	0.04	0.26^{c}	0.06	**<0.001**	5.04	0.21	6.38	0.25	6.58	0.39	0.060
C18:1c9	1.59^{a}	0.31	1.75^{a}	0.42	2.43^{b}	0.47	**<0.001**	33.70^{a}	0.84	36.40^{a}	1.33	42.07^{b}	1.40	**0.040**
C18:1 t11	0.14^{a}	0.05	0.08^{b}	0.02	0.06^{c}	0.02	**<0.001**	3.54^{a}	0.10	2.04^{b}	0.11	0.88^{c}	0.02	**<0.001**
C18:2c9,12 (LA)	0.09^{a}	0.01	0.11^{b}	0.02	0.16^{c}	0.02	**<0.001**	0.69^{a}	0.02	0.87^{b}	0.00	1.27^{c}	0.00	**<0.001**
C18:2c9,t11(CLA)	0.04^{a}	0.01	0.02^{b}	0.01	0.02^{b}	0.01	**<0.001**	1.34^{a}	0.02	0.84^{b}	0.02	0.55^{c}	0.01	**<0.001**
C18:2t10,c12(CLA)	0.002^{a}	0.002	0.001^{b}	0.000	0.000^{b}	0.000	**<0.001**	0.00	0.00	0.00	0.00	0.00	0.00	1.000
C18:3 c9,12,15 (ALA)	0.06^{a}	0.01	0.04^{b}	0.01	0.03^{c}	0.01	**<0.001**	0.56^{a}	0.02	0.47^{b}	0.03	0.30^{c}	0.02	**<0.001**
C20:4 (AA)	0.03^{a}	0.00	0.03^{a}	0.00	0.04^{b}	0.00	**<0.001**	0.00	0.00	0.00	0.00	0.00	0.00	1.000
C20:5 (EPA)	0.02^{a}	0.00	0.01^{b}	0.00	0.01^{c}	0.00	**<0.001**	0.00	0.00	0.00	0.00	0.00	0.00	1.000
C22:5 (DPA)	0.002^{a}	0.00	0.01^{b}	0.00	0.00^{c}	0.00	**<0.001**	0.00	0.00	0.00	0.00	0.00	0.00	1.000
C22:6 (DHA)	0.001^{a}	0.000	0.002^{b}	0.001	0.000^{a}	0.000	**<0.001**	0.00	0.00	0.00	0.00	0.00	0.00	1.000

† striploin, eye of the round, fillet, chuck tender; GRASS, grass-fed; GSC, grass finished on grass silage and concentrates ; CONC, concentrate-fed; LA, linoleic acid; CLA; conjugated linoleic acid; ALA, α-linolenic acid; AA, arachidonic acid; EPA, eicosapentaenoic acid; DPA; docosapentaenoic acid; DHA, docosahexaenoic acid. Total n-6 PUFA:LA+AA; Total n-3 PUFA: ALA+EPA+DPA+DHA. ^{a,b,c} Indicates significant differences between ruminant dietary interventions (P<0.05) * One-way ANOVA for comparison of means between beef interventions, with a bonferoni post hoc test. Bonferroni correction was applied by multiplying the P value by the number of rows in the table. P values that exceeded 1.0 have been marked down to 1.000

Table 2. Mean daily intakes of dietary fat (g/d and %TE) by beef scenario. Cohort split by low (*n*=346), medium (*n*=354) and high (*n*=344) beef consumers. Data illustrated as means and standard deviations.

	Low (29g/d)							**Medium (*n*=73g/d)**							**High (*n*=157g/d)**						
	G-FB		GC-FB		C-FB			G-FB		GC-FB		C-FB			G-FB		GC-FB		C-FB		
	Mean	SD	Mean	SD	Mean	SD	P*	Mean	SD	Mean	SD	Mean	SD	P*	Mean	SD	Mean	SD	Mean	SD	P*
g/d																					
Total Fat	70.2	25.0	70.5	25.1	70.9	25.1	1.000	79.0	30.0	78.8	29.8	79.6	29.9	1.000	88.1	33.3	88.2	33.2	89.7	33.4	1.000
SFA	27.2	11.1	27.5	11.2	27.6	11.2	1.000	30.9	13.5	31.3	13.4	31.4	13.4	1.000	34.4	14.3	35.2	14.4	35.5	14.4	1.000
MUFA	25.9	9.7	26.0	9.8	26.3	9.8	1.000	29.3	11.6	29.2	11.5	29.9	11.7	1.000	33.3	12.9	33.4	12.9	34.7	13.2	1.000
PUFA	12.5	5.5	12.5	5.5	12.5	5.5	1.000	13.6	6.0	13.3	5.8	13.2	5.8	1.000	14.8	8.1	14.3	7.6	14.2	7.6	1.000
ALA	1.2	0.8	1.2	0.8	1.2	0.8	1.000	1.4	0.8	1.3	0.7	1.3	0.7	1.000	1.5	0.9	1.4	0.9	1.4	0.9	1.000
EPA	0.6	4.6	0.6	4.6	0.6	4.6	1.000	0.4	3.1	0.4	3.1	0.4	3.1	1.000	0.4	3.5	0.4	3.5	0.4	3.5	1.000
DHA	0.7	4.5	0.7	4.5	0.7	4.5	1.000	0.4	3.1	0.4	3.1	0.4	3.1	1.000	0.4	3.4	0.4	3.4	0.4	3.4	1.000
trans-fat	0.2^{a}	0.1	0.1^{b}	0.1	0.1^{c}	0.1	**<0.001**	0.4^{a}	0.2	0.3^{b}	0.2	0.2^{c}	0.1	**<0.001**	0.7^{a}	0.4	0.6^{b}	0.3	0.4^{c}	0.2	**<0.001**
%TE																					
Total Fat	33.5	6.0	33.7	6.0	33.9	6.0	1.000	34.3	7.0	34.3	6.7	34.6	6.7	1.000	35.0	6.8	35.1	6.7	35.7	6.8	1.000
SFA	12.9	3.4	13.1	3.4	13.1	3.4	1.000	13.4	3.6	13.5	3.5	13.6	3.5	1.000	13.7	3.5	14.0	3.5	14.1	3.5	1.000
MUFA	12.4	2.5	12.4	2.5	12.6	2.6	1.000	12.7	2.9	12.7	2.8	13.0	2.8	1.000	13.3	2.9	13.3	2.9	13.8	3.0	0.236
PUFA	6.0	2.0	6.0	1.9	6.0	1.9	1.000	6.0	2.1	5.8	1.9	5.8	1.9	1.000	5.9	2.3	5.6	2.1	5.6	2.1	1.000
ALA	0.6	0.4	0.6	0.4	0.6	0.4	1.000	0.6	0.4	0.6	0.3	0.6	0.3	1.000	0.6	0.3	0.6	0.3	0.5	0.3	1.000
EPA	0.4	3.7	0.4	3.7	0.4	3.7	1.000	0.2	1.8	0.2	1.8	0.2	1.8	1.000	0.2	1.5	0.2	1.5	0.2	1.5	1.000
DPA	0.004^{a}	0.004	0.002^{b}	0.001	0.000^{c}	0.000	**<0.001**														
DHA	0.4	3.7	0.4	3.7	0.4	3.7	1.000	0.2	1.7	0.2	1.7	0.2	1.7	1.000	0.2	1.5	0.2	1.5	0.2	1.5	1.000
trans-fat	0.1^{a}	0.1	0.1^{b}	0.1	0.0^{c}	0.0	**<0.001**	0.2^{a}	0.1	0.1^{b}	0.1	0.1^{c}	0.1	**<0.001**	0.3^{a}	0.2	0.2^{b}	0.1	0.2^{c}	0.1	**<0.001**

G-FB, grass-fed beef; GC-FB, grass-fed beef finished on grass silage and concentrates ; C-FB, concentrate-fed beef; SFA: C14:0+C15:0+C16:0+C17:0+C18:0; MUFA: C14:1+ C16:1+ C18:1c9+ C18:1t11; PUFA: C18:2c9,12+C18:2c9,t11+C18:2t10,c12+C18:3+C20:4+C20:5+C22:5+C22:6; ALA, α-linolenic acid; EPA, eicosapentaenoic acid; DHA, docosahexaenoic acid; ^{a,b,c} Indicates significant differences between beef scenarios (P<0.05) * One-way ANOVA for comparison of means between beef scenarios, with a bonferoni post hoc test. Bonferroni correction was applied by multiplying the P value by the number of rows in the table. P values that exceeded 1.0 have been marked down to 1.000.

Table 3. Mean daily intake of individual dietary fatty acids (%TE) by beef scenarios. Cohort split into low (*n*=346), medium (*n*=354) and high (*n*=344) beef consumers.
Data illustrated as means and standard deviations.

	Low (29g/d)							**Medium (*n*=73g/d)**			
	G-FB		GC-FB		C-FB			G-FB		GC-FB	
	Mean	SD	Mean	SD	Mean	SD	P*	Mean	SD	Mean	SD
%TE											
C14:0	0.05^{a}	0.05	0.06^{b}	0.05	0.07^{b}	0.05	**<0.001**	0.10^{a}	0.11	0.13^{b}	0.08
C15:0	0.01	0.01	0.01	0.01	0.01	0.01	1.000	0.02	0.01	0.02	0.01
C16:0 (PA)	0.37^{a}	0.31	0.47^{b}	0.34	0.51^{b}	0.35	**<0.001**	0.78^{a}	0.64	0.91^{b}	0.57
C18:0	0.15	0.13	0.16	0.13	0.16	0.13	1.000	0.28	0.27	0.27	0.26
C16:1	0.07^{a}	0.08	0.08^{ab}	0.09	0.09^{b}	0.09	**0.045**	0.13^{a}	0.15	0.15^{ab}	0.17
C18:1 (OA)	0.52^{a}	0.47	0.52^{a}	0.41	0.63^{b}	0.48	**0.045**	1.15^{a}	1.22	0.96^{b}	0.84
C18:1t11 (TVA)	0.06^{a}	0.05	0.04^{b}	0.03	0.02^{c}	0.01	**<0.001**	0.10^{a}	0.09	0.06^{b}	0.05
C18:2 (LA)	0.20	0.38	0.22	0.41	0.26	0.49	1.000	0.52	0.83	0.52	0.60
C18:2c9t11 (CLA)	0.02^{a}	0.02	0.01^{b}	0.01	0.01^{c}	0.01	**<0.001**	0.03^{a}	0.03	0.02^{b}	0.02
C18:3 (ALA)	0.60	0.38	0.59	0.38	0.58	0.38	1.000	0.62	0.36	0.59	0.31
C20:4 (AA)	0.004^{a}	0.003	0.004^{a}	0.003	0.005^{b}	0.003	**<0.001**	0.015^{a}	0.008	0.016^{a}	0.007
C20:5 (EPA)	0.39	3.74	0.39	3.74	0.39	3.74	1.000	0.21	1.78	0.21	1.78
C22:5 (DPA)	0.004^{a}	0.004	0.002^{b}	0.001	0.000^{c}	0.000	**<0.001**	0.008^{a}	0.006	0.004^{b}	0.002
C22:6 (DHA)	0.41	3.66	0.41	3.66	0.41	3.66	1.000	0.22	1.74	0.22	1.74
LA:ALA	0.39	0.85	0.44	0.94	0.53	1.16	1.000	0.97^{a}	1.70	1.09^{ab}	1.57

G-FB, grass-fed beef; GC-FB, grass-fed beef finished on grass silage and concentrates ; C-FB, concentrate-fed beef; PA, palmitic acid, OA, oleic acid, TVA, *trans*-vaccenic acid, ALA, α-linolenic acid; AA, arachidonic acid; EPA, eicosapentaenoic acid; DPA; do
between beef scenarios, with a bonferoni post hoc test. Bonferroni correction was applied by multiplying the P value by the number of rows in the table. P values that exceeded 1.0 have been marked down to 1.000.

Table 4. Impact of reformulating the FA composition of red meat on dietary fat quality. Data presented as percentage (%) contribution of meat food groups to dietary fat intakes by beef scenario in beef consumers (n=1044).

	Total Fat				**SFA**				**MUFA**				**PUFA**				**ALA**			
	G-FB	GC-FB	C-FB	P*	G-FB	GC-FB	C-FB	P*	G-FB	GC-FB	C-FB	P*	G-FB	GC-FB	C-FB	P*	G-FB	GC-FB	C-FB	P*
		%				%				%				%				%		
Unprocessed red meat	12.95	12.99	13.76	1.000	12.92^{a}	13.98^{ab}	14.43^{b}	**0.046**	15.86^{a}	15.86^{a}	17.50^{b}	**<0.001**	8.50^{a}	6.91^{b}	6.79^{b}	**<0.001**	12.51^{a}	9.69^{b}	8.59^{b}	**<0.001**
Processed red meat	7.76	7.87	7.98	1.000	7.85	8.00	8.05	1.000	9.51	9.65	9.86	1.000	6.26	6.29	6.26	1.000	5.18	5.12	4.92	1.000
Individual food groups																				
Beef and veal	3.89	4.26	4.72	0.142	4.18	4.86	5.14	0.078	4.95^{a}	5.37^{a}	6.32^{b}	**<0.001**	1.32	1.17	1.12	0.612	2.51^{a}	2.05^{b}	1.37^{c}	**<0.001**
Beef and veal dishes	5.04	4.64	4.97	1.000	4.76	5.07	5.26	1.000	6.24	5.76	6.50	1.000	3.72^{a}	2.19^{b}	2.13^{b}	**<0.001**	6.79^{a}	4.30^{b}	3.86^{b}	**<0.001**
Burgers	2.08	2.26	2.42	1.000	2.20	2.54	2.60	1.000	2.61	2.82	3.19	0.520	0.88	0.82	0.78	1.000	1.71	1.56	1.30	0.204
Meat pies and pastries	0.82	0.83	0.83	1.000	0.93	0.93	0.94	1.000	0.96	0.96	0.97	1.000	0.54	0.55	0.55	1.000	0.62	0.63	0.62	1.000
Meat products	2.85	2.87	2.85	1.000	1.92	1.92	1.92	1.000	3.26	3.28	3.23	1.000	4.16	4.23	4.24	1.000	4.65	4.82	4.87	1.000

G-FB, grass-fed beef; GC-FB, grass-fed beef finished on grass silage and concentrates ; C-FB, concentrate-fed beef; ALA, α-linolenic acid; [a,b,] Indicate significant differences between beef interventions ($P<0.05$); *One-way ANOVA for comparison of means between beef scenarios, with a bonferoni post hoc test. Bonferroni correction was applied by multiplying the P value by the number of rows in the table. P values that exceeded 1.0 have been marked down to 1.000

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