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

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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

1 **Abstract**

2 Objective: To apply a dietary modelling approach to investigate the impact of substituting beef
3 intakes with three types of alternate fatty acid composition of beef on population dietary fat intakes.

4 Design: Cross-sectional, national food consumption survey-the National Adult Nutrition Survey
5 (NANS). The fat content of the beef-containing food codes ($n=52$) and recipes ($n=99$) were updated
6 with FA composition data from beef from animals receiving one of three ruminant dietary
7 interventions: grass-fed (GRASS), grass finished on grass silage and concentrates (GSC), or
8 concentrate-fed (CONC). Mean daily fat intakes, adherence to dietary guidelines and the impact of
9 altering beef FA composition on dietary fat sources were characterised.

10 Setting: Ireland.

11 Subjects: Beef consumers ($n=1,044$) aged 18-90 years.

12 Results: Grass-based feeding practices improved dietary intakes of a number of individual fatty
13 acids, wherein myristic acid (C14:0) and stearic acid (C16:0) were decreased, with an increase in
14 conjugated linoleic acid (C18:2c9,t11) and *trans*-vaccenic acid (C18:1t11) ($P<0.05$). Improved
15 adherence with dietary recommendations for total fat (98.5%), SFA (57.4%) and PUFA (98.8%)
16 was observed in the grass-fed beef scenario ($P<0.001$). *Trans*-fat intakes were significantly
17 increased in the grass-fed beef scenario ($P<0.001$).

18 Conclusions: To the best of our knowledge, this is the first study to characterise the impact of grass-
19 fed beef consumption at population level. This study suggests that habitual consumption of grass-
20 fed beef may have potential as a public health strategy to improve dietary fat quality.

21 **Introduction**

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

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

45
46 There are a number of on-going public health strategies to improve population dietary fat intakes,
47 including the increased availability of low-fat products and product reformulation⁽¹⁶⁾. Alternatively,
48 grass-based ruminant feeding practices naturally modifies the FA composition of animal products
49 by reducing the SFA and increasing the PUFA concentrations, including alpha-linolenic acid (ALA)
50 and docosapentaenoic acid (DPA), in comparison to concentrate-based feeding⁽¹⁷⁾. A recent
51 predictive modelling analysis by Benbrook *et al.* characterised the FA profile of milk following
52 grass-based feeding and applied nutrition modelling to investigate the potential impact on dietary
53 fat intakes. In comparison to concentrate-fed and organic milk, there was a significant improvement
54 in the FA composition of grass-fed milk, wherein omega-3 (n-3) PUFA levels were increased⁽¹⁸⁾.

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

63
64 Furthermore, red meat is commonly consumed, providing an important source of protein, iron and
65 vitamins, particularly vitamin B12⁽²¹⁾, and meat and meat dishes are important contributors to
66 dietary total fat (22%), SFA (22%), MUFA (26%) and PUFA (19.3%) intakes⁽⁸⁾. A randomized
67 controlled trial by McAfee *et al.* investigated the impact on long chain (LC) *n*-3 PUFA status
68 following consumption of 3 portions of grass-fed or concentrate-fed lamb and beef for 4 weeks.
69 Dietary intakes and plasma and platelet concentrations of LC *n*-3 PUFA increased significantly in
70 the grass-fed red meat consumers⁽²²⁾. However, the impact of grass-fed beef consumption at
71 population level is currently unknown. Therefore, the aim of this analysis was to apply a predictive
72 modelling technique to assess the potential impact of replacing habitual beef intakes with grass-fed
73 beef on dietary fat intakes in a nationally representative Irish adult cohort.

74

75 **Methods**

76 Ruminant dietary intervention

77 The FA data used in this analysis were derived following a dietary intervention trial using three
78 different animal feeding practices. Fifteen spring-born suckler Aberdeen Angus heifers were
79 assigned to one of three diets: grass only (GRASS), grass finished on grass silage and concentrates
80 (GSC) or concentrates only (CONC), until they reached a target carcass weight of 260kg. The
81 composition of the GRASS intervention was: grass silage *ad libitum* plus a routine mineral
82 supplement during the winter (123 days) followed by rotational grazing of a perennial rye-grass-
83 dominant pasture until slaughter. The CONC intervention was comprised of *ad libitum* concentrates
84 (870g/kg rolled barley, 60g/kg soya bean meal, 50g/kg molasses, 20g/kg minerals/vitamins) and
85 grass silage (1kg dry matter/animal daily), indoors⁽²³⁾. The third intervention group included grazed
86 grass followed by grass silage *ad libitum* and 4kg/d concentrates (GSC) for approximately 4
87 months. Four muscles (striploin, eye of the round, fillet, chuck tender) were collected at 48h post
88 slaughter, aged for 14 days at 2°C, prior to storage at -20°C. Prior to FA analysis, the samples were
89 cooked to an internal temperature of 72°C. The lipids were subsequently extracted and analysed

90 using gas chromatography⁽²⁴⁾. In brief, the FA were extracted using a 2-step microwave-assisted
91 (CEM Corporation) saponification and esterification process. Methanolic potassium hydroxide (10
92 ml, 2.5%) was added for saponification, microwaved and heated to 130°C, and held for four
93 minutes. Methanolic acetyl chloride (15ml, 5%) was added for esterification, microwaved, heated to
94 120°C in four minutes and held for two minutes. Pentane (10ml) was added to extract the fatty acid
95 methyl esters (FAME) and saturated sodium chloride (20ml) was added to induce phase separation.
96 FAME were then measured using a GC-FID for fatty acid quantification, as described
97 previously⁽²⁴⁾. An average of four muscles(striploin, eye of the round, fillet, chuck tender), chosen
98 based on lipid concentration, muscle fibre distribution and consumer relevance⁽²⁵⁾ and a pooled fat
99 samples ($n=3$) from each diet group was applied in the current analysis.

100

101 Food consumption data

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

105

106 Written consent was obtained from each participant, in accordance with the Declaration of Helsinki.
107 A detailed description of the NANS recruitment, sampling and methodologies has been outlined
108 elsewhere^(26,27). In brief, participants recorded their dietary intakes using a semi-weighed food diary,
109 over 4 consecutive days, including one weekend day. Product packaging, brand information, recipes
110 and cooking methods were also recorded. A food consumption database was created containing
111 2552 food codes, which were updated for nutrient composition⁽²⁶⁾. The methodology applied to
112 calculate the dietary fat composition (total fat, SFA, MUFA, PUFA, ALA, eicosapentaenoic acid
113 (EPA), docosahexaenoic acid (DHA) and *trans* fat) for each of the NANS food codes has been
114 previously detailed⁽⁸⁾. All food codes were classified into 33 food groups which were representative
115 of the overall diet, including unprocessed and processed red meat⁽²⁸⁾. These were further aggregated
116 by beef product for the purpose of this analysis and in total included 52 beef food codes and 99
117 beef-containing recipes. Sixty-nine percent ($n=1044$) of NANS participants were beef consumers,
118 with a mean daily intake of 86g/d (SD:62).

119 Predictive modelling scenarios

120 The potential impact of replacing habitual beef intakes in three modelling scenarios was determined
121 by substituting the fatty acid data of beef-containing foods with data from beef from the GRASS,
122 GSC or CONC interventions. For the modelling scenarios the beef compositions will be referred to
123 as G-FB (grass-fed beef) as derived from the GRASS intervention, GC-FB (grass-fed beef finished

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

143

144 Statistical analysis

145 Data analysis was carried out using SPSS[®] for Windows[™] statistical software package version 20.0
146 (SPSS Inc. Chicago, IL, USA). A one-way ANOVA was used to calculate differences between beef
147 dietary modelling scenarios. Bonferroni correction was applied by multiplying each P value by the
148 number of rows, each representing a trait, in each table. $P \leq 0.05$ was considered significant and
149 those that exceeded 1.0 were marked down to 1.000⁽³⁰⁾. The cohort was split by tertile of beef
150 consumption, to create equivalent consumption groups to determine whether the quantity of beef
151 consumed affected the dietary fat intake modelling scenarios. A 100% modelling scenario was
152 subsequently applied using the beef compositional data from the three beef interventions. Mean
153 daily intakes of total fat and the fat subtypes were calculated and are presented as mean values with
154 standard deviations. Mean daily intakes for 14 compositional fatty acids were subsequently
155 calculated and a one-way ANOVA with Bonferroni correction applied. A chi-squared test examined
156 differences in population adherence to dietary fat recommendations between beef scenarios. In
157 brief, compliance with the UK Department of Health recommendations for total fat ($\leq 33\%$), SFA
158 ($\leq 10\%$), MUFA ($\geq 12\%$) and PUFA ($\geq 6\%$)⁽³¹⁾, the ESFA recommendation for ALA ($\geq 0.5\%$)⁽⁹⁾ and

159 the SACN recommendation for *trans*-fat ($\geq 2\%$)⁽¹¹⁾ was determined by estimating the maximal
160 subgroup of the population that complied with the population target, by ranking individuals based
161 on their mean daily intakes, as outlined in Wearne *et al.*⁽³²⁾. The impact of altering the FA
162 composition on overall dietary total fat, SFA, MUFA, PUFA and ALA contributions from beef-
163 containing food groups was assessed using a one-way ANOVA.

Results

164

165 *FA composition of cooked beef post feeding intervention*

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

175

176 *Impact of altering animal feeding practices on dietary fat intakes*

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

182

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

184 Differences were observed in dietary intakes (%TE) of individual fatty acids between the three beef
185 scenarios (**Table 3**). In terms of intakes of individual fatty acids related to SFA a significant
186 stepwise decrease of myristic acid (C14:0) and stearic acid (C16:0) was observed across tertiles,
187 wherein they were significantly lower in all G-FB scenario ($P < 0.001$). While intakes of vaccenic
188 acid (C18:1t11) was observed to be significantly greater in the G-FB scenario ($P < 0.001$); these
189 differences were consistent across all three consumption groups. In terms of PUFA intakes, a
190 significant increase in arachidonic acid (AA) (C20:4) was noted from G-FB to C-FB ($P < 0.001$).
191 Intakes of DPA (C22:5) and CLA (C18:2c9,t11) were significantly greater in the G-FB scenario,

192 with a stepwise decrease across tertiles observed between GC-FB and C-FB ($P<0.001$). Similar
193 trends were observed when the intakes were expressed as g/day (data not shown). In addition, a
194 reduction in the PUFA ratio (LA:ALA) was observed in the G-FB scenario in the high beef
195 consumers ($P<0.001$).

196
197 *Adherence to population-based dietary guidelines*

198
199 The predicted adherence to dietary fat recommendations of the UK Department of Health and
200 SACN for total fat, SFA, MUFA and PUFA^(5,31), the EFSA recommendation for ALA (9) and the
201 SACN recommendation for *trans*-fat⁽¹¹⁾ are presented in **Figure 1**. All three beef groups adhered to
202 the MUFA, ALA and *trans*-fat recommendations. Greater compliance was observed in the G-FB
203 scenario, compared to the GC-FB and C-FB scenarios for total fat (98.5%, 98.3%, 95.5%), SFA
204 (57.4%, 52.9%, 51.1%) and PUFA (98.8%, 94.0%, 93.7%) recommendations ($P<0.05$).

205
206 *Impact of altering the beef composition on contributions of food groups to dietary fat intakes*

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

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232 **Discussion**

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

241

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

259

260 In line with previous studies, the fatty acid composition of the cooked muscle and fat differed
261 significantly in the current analysis, with reduced SFA and increased PUFA concentrations
262 observed following the GRASS intervention⁽¹⁷⁾. However, with the exception of *trans*-fat this failed
263 to translate into significant differences in dietary total fat and subtype intakes. The current
264 modelling scenario suggested that intakes of *trans*-fat were significantly greater across all G-FB
265 groups, regardless of the quantity consumed ($P < 0.001$). Analysis of the intakes of individual fatty

266 acids identified a significant increase in C18:1t11 (*trans*-vaccenic acid; TVA), which is a ruminant
267 derived *trans*-fatty acid. Adherence to the trans-fat recommendation of $\leq 2\%TE^{(11)}$ was achieved in
268 all three beef scenarios. Moreover, while there was no observed impact on overall dietary SFA
269 intakes, individual SFA intakes. In particular myristic acid (C14:0) and palmitic acid (C16:0), were
270 significantly lower in the G-FB scenarios ($P < 0.001$). This is an important observation as both of
271 these fatty acids have been associated with increased CVD risk due to their adverse effect on LDL
272 cholesterol levels. Furthermore, levels of CLA (C18:2c9,t11) in cooked muscle and fat were
273 increased significantly by the grass-based feeding practice, which translated into significantly
274 greater intakes of C18:2c9,t11 (CLA) in the G-FB scenario ($P < 0.001$). The G-FB modelling
275 scenario significantly reduced intakes of the n-6 PUFA, AA (C20:4), which were previously
276 associated with increased inflammation, however a recent review by Innes *et al.* has challenged this,
277 due to a lack of association in healthy adults, concluding that the omega n-6 fatty acid and
278 inflammation paradigm is complex and requires further investigation⁽³⁹⁾. Moreover, a significant
279 increase in DPA (C22:5) was observed in muscle concentrations following the GRASS
280 intervention, this translated into a predicted increase in DPA intakes in the G-FB modelling
281 scenario. In comparison to the other LC n-3 PUFA, DPA is a major circulating fatty acid in beef,
282 and is an intermediary in the conversion of EPA to DHA⁽⁴⁰⁾. The evidence relating to the biological
283 role of DPA is limited; however, studies have demonstrated an association between intakes of DPA
284 and an improvement in markers of metabolic health, including inflammation and reduced risk of
285 myocardial infarction⁽⁴¹⁾. Consumption of grass-fed beef, within the recommended dietary
286 guidelines, may provide a strategy to increase intakes of the LC n-3 PUFA.

287

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

300

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

310

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

324

325 Recent reviews of the evidence, including the EAT-Lancet report have recommended that meat
326 intakes need to be reduced in order to combat the current global health and environmental
327 sustainability issues^(19,20). However, public health strategies will be required to achieve a gradual
328 reduction of intakes, and the health and environmental properties of the replacement foods must
329 also be considered. One such strategy includes enhancing the nutritional quality, yet reducing the
330 quantity of red meat consumed⁽⁴⁵⁾. A recent review by Provenza *et al.* highlights the impact of the
331 processed food consumption trend on global health, and while grass-fed diets do have some
332 environmental constraints, a diet limited in processed foods and rich in natural, wholesome plant
333 and animal-based foods is required to improve health and environmental issues⁽⁴⁶⁾. This modelling
334 scenario highlights the importance of beef quality on dietary fat intakes in an Irish population. This
335 adds to previous findings from Benbrook *et al.* which found that grass-fed milk consumption was

336 associated with improved PUFA status⁽¹⁸⁾ and McAfee *et al.* that identified improved n-3 PUFA
337 intakes and plasma and platelet LC n-3 status following replacement of replacement of habitual
338 meat consumption with grass-fed beef and lamb⁽²²⁾. Lamb was consumed by 15% of the current
339 cohort, therefore the impact of grass-based lamb feeding merits investigation. A recent review by
340 Givens *et al.* suggested that modification of the bovine diet could potentially reduce CVD risk but
341 that further research, using randomised controlled trials, are required⁽⁴⁷⁾. The collective impact of
342 dietary substitution with grass-fed beef, lamb and milk should also be investigated as this may
343 provide a potential future public health initiative to replace SFA with PUFA, in accordance with the
344 recent WHO and SACN recommendations^(5,6).

345

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

360 In conclusion, this is the first study to model the impact of grass-fed beef consumption at population
361 level. These findings suggest that altering ruminant fatty acid composition using a grass-based
362 feeding system has the potential to significantly improve dietary fat quality and adherence to
363 population dietary fat recommendations. WHO and SACN recently recommended that replacement
364 of SFA with PUFA is a potential future health strategy to reduce the risk of disease^(5,6). Thus, this
365 analysis suggests that habitual consumption of grass-fed beef, either alone or in tandem with grass-
366 based milk and lamb, is a promising initiative to further improve SFA and PUFA intakes. Further
367 research is required to determine if the fatty acid composition of grass-fed ruminants could be
368 further improved through dietary manipulation. Furthermore, to encourage adherence to grass-based
369 products consumption, governments could consider incentives for farmers who apply grass-based
370 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		P*	GRASS		GSC		CONC		P*
	Mean	SD	Mean	SD	Mean	SD		Mean	SD	Mean	SD	Mean	SD	
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
<i>trans</i> -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. Bonferoni 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			P*	G-FB		GC-FB		C-FB			P*	G-FB		GC-FB		C-FB			P*
	Mean	SD	Mean	SD	Mean	SD	Mean		SD	Mean	SD	Mean	SD	Mean	SD		Mean	SD	Mean	SD	Mean	SD	Mean	
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			
<i>trans</i> -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			
<i>trans</i> -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.

%TE	Low (29g/d)							Medium (n=73g/d)			
	G-FB		GC-FB		C-FB		P*	G-FB		GC-FB	
	Mean	SD	Mean	SD	Mean	SD		Mean	SD	Mean	SD
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. Bonferoni 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
<i>Individual food groups</i>																				
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. Bonferoni 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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