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An investigation into the nutritional composition and cost of gluten free versus non-gluten free food products in the UK

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Authorship: LF formulated the original research idea, designed the study, undertook data collection and analysis, wrote the first draft, and co-wrote the manuscript. RF contributed to the study design, supervised all aspects, undertook additional analysis and co-wrote the manuscript. AMM contributed to the study design and co-wrote the manuscript. All authors approved the final version of the manuscript.

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Conflict of interest

The authors declare that they have no conflict of interests.

1 **Abstract**

2 **Background:** The gluten free (GF) food market has expanded considerably but there is
3 limited comparative evidence for the nutritional quality and cost of GF food products. This
4 study aims to compare the nutrient composition and cost of GF and gluten-containing
5 (regular) foods across ten food categories in the UK.

6 **Methodology:** Nutritional information and cost of GF foods available in the UK ($n = 679$)
7 and comparable regular foods ($n = 1045$) were systematically collected from manufacturer
8 and supermarket websites. Foods were classified using UK front-of-pack labelling for
9 content of fat, saturated fat, sugar and salt and nutrient content and cost per 100g were
10 identified and compared between GF and regular foods.

11 **Results:** Overall, more GF foods were classified as containing high and medium fat,
12 saturated fat, sugar and salt than regular foods but this was not universally consistent.
13 Whilst more GF bread and flour products contained high fat and sugar, fewer GF crackers
14 contained high fat and sugar compared to regular foods. High salt content was found more
15 frequently in GF than regular products. On average, GF products were 159% more
16 expensive than regular (£0.44/100g versus £1.14/100g). GF items were also more likely
17 to be lower in fibre and protein content than regular foods.

18 **Conclusions:** Differences exist in the nutritional composition of GF and regular food. GF
19 food is unlikely to offer healthier alternatives to regular foods, except for those who require
20 a GF diet for medically diagnosed conditions, and is associated with higher costs.

21 Introduction

22 Coeliac disease is an enteropathy caused by an abnormal immune reaction to
23 ingestion of gluten, a protein derived from wheat, rye, and barley ⁽¹⁾. Life-long adherence to
24 a gluten-free (GF) diet, comprising foods naturally GF or containing less than 20ppm
25 gluten, is the only treatment for individuals with coeliac disease, which has an estimated
26 world-wide prevalence of 1% ⁽²⁻⁴⁾. Those with a confirmed diagnosis of coeliac disease in
27 the UK are currently eligible for procurement of GF foods via monthly prescription available
28 from their General Practitioner, Pharmacist, or Dietitian ('prescribed GF' foods), however
29 GF products are also available for purchase from high street and online retailers
30 ('commercial GF' foods) ⁽⁵⁾. A GF diet is also recommended for individuals with other
31 gluten-related disorders, including gluten ataxia, dermatitis herpetiformis and non-coeliac
32 gluten sensitivity ⁽⁶⁾. However, many choose to follow a GF diet for other perceived health
33 benefits ⁽⁷⁾. Regardless of the rationale for avoiding gluten, nutritional adequacy of GF
34 substitute foods is important to both short- and long-term health.

35 Gluten is an important constituent of foods made from cereal grains or their
36 derivatives, providing a matrix of viscoelasticity, which, if removed, can negatively affect
37 the structural integrity and crumb structure of staple foods such as bread and pasta ⁽⁵⁾. No
38 substitute raw materials or additives have been found to replicate the qualities of gluten
39 and therefore products manufactured in place of traditional gluten-containing foods require
40 the utilisation of a combination of GF flours (e.g. rice, amaranth, potato), hydrocolloids
41 (e.g. xanthan gum, guar gum), emulsifiers, stabilisers and enzymes ^(8; 9). The use of these
42 different ingredients can affect structure, palatability, shelf-life, mouth-feel and the
43 nutritional composition of the end product ⁽⁸⁾.

44 Gaining a better understanding of the nutrient composition of GF food compared to
45 regular items is likely to be important for individuals avoiding gluten ⁽¹⁰⁾. Furthermore,
46 people with coeliac disease have shown concern about the nutritional quality of the GF

47 diet, and in particular the fat, sugar and salt content of some manufactured GF foods⁽¹¹⁾.
48 Healthcare professionals responding to such concerns or assessing diet histories would
49 also likely benefit from furthered understanding of nutritional composition of GF foods
50 available. Additionally, some consumers choose a GF diet for non-medical reasons or to
51 alleviate a range of symptoms not medically diagnosed, and may also benefit from more
52 information comparing GF and regular foods⁽⁷⁾. Evidence suggests consumers consider
53 that a GF diet contributes to a healthy lifestyle, reflecting a popular perception of health
54 benefits and weight loss-aiding properties of GF food that has led to increasing sales in the
55 UK and worldwide⁽¹²⁻¹⁵⁾.

56 Despite this increased interest in the GF diet, data comparing the nutritional
57 composition of GF foods to regular equivalents is limited. Studies from Europe ⁽¹⁶⁾ and
58 Australia suggest nutritional differences exist between GF and regular foods, with higher
59 carbohydrate and salt content ⁽¹⁷⁾, and lower protein content reported ^(15; 18). An Australian
60 study that evaluated over 600 GF products concluded that GF foods conferred no
61 additional health benefits to those individuals not medically advised to adhere to the diet
62 ⁽¹⁵⁾. However, differences in manufacturers, ingredients, products, and domestic public
63 health guidelines between geographical regions limit the transferability of these findings to
64 the UK.

65 Additionally, GF products tend to be more expensive than regular equivalents ^(19; 20)
66 and recent changes to UK government policy have lead to the quantities that can be
67 prescribed, i.e. obtained either without charge or by paying a prescription fee (as per local
68 policy), being reduced or removed in some areas ⁽²¹⁾.

69 The present study aims to fill gaps in evidence on the cost, nutritional quality and
70 composition of GF foods in the UK (prescribed and commercial), by comparing GF and
71 regular foods across ten food categories.

72 **Methods**

73 This study involved comparisons between regular foods versus GF foods, and the GF
74 subgroups of prescribed GF and commercial GF foods. Analyses investigated the
75 differences in proportions of foods from those groups with high and medium contents of
76 fat, saturated fat, sugar and salt (Table 1), and differences in median nutrient content and
77 cost of food from those groups.

78

79 *Design and data collection*

80 Items were considered to be GF if the product packaging or description included a
81 declaration of GF status. Items without this explicit declaration were classified as regular.
82 An exhaustive list of commercial GF foods was collected from the websites of four leading
83 UK supermarkets: Tesco, Sainsbury's, Morrisons, ASDA, and the online retailer Ocado⁽²²⁾.
84 The regular foods were then randomly sampled from the same five supermarkets (see
85 sampling). The full population of prescribed GF items was collected from the Coeliac UK
86 *Prescribable Products List* (June 2016), and nutritional data was obtained from
87 manufacturer's websites⁽²³⁾.

88 Nutritional information (per 100 grams) that must be declared on packaging under EU
89 legislation 1169/2011⁽²⁴⁾ (fat, saturated fat, sugar, salt and protein) was systematically
90 collected between September 2015 and June 2016. Fibre content per 100 g, which is not
91 mandated in packaging legislation, was recorded where available. Where data were not
92 provided or were inconsistent on the manufacturer or supermarket websites, or on the
93 packaged product, the company was contacted to obtain further information.

94 Products without nutrition labels, such as unpackaged bakery products, and those
95 sold in variety packages and assortments were excluded. Duplicate items from different
96 supermarkets (e.g. branded items), and the same product in different weights were only
97 counted once. Where products were excluded from the regular sample group, a new

98 random number was generated and a substitute collected. Xantham gum and egg
99 replacer, present on the *Prescribable Products List*, represented component ingredients
100 used in cooking and are unique to GF foods and so were excluded. Where nutritional
101 values were given for the cooked product, or 'as served', the dry weight nutrient content
102 was calculated using conversion factors for percentage weight change from *McCance and*
103 *Widdowson's The Composition of Foods* (e.g., +138% for cooked wholewheat spaghetti)
104 ⁽²⁵⁾.

105 Product prices for regular and commercial GF foods were collected from supermarket
106 websites. Prescribed GF products, which are either not directly funded by the consumer,
107 or obtained after payment of a fixed prescription fee, were excluded from the cost
108 comparison. Where duplicate products were found across supermarkets or where the
109 same product was offered in different sized packaging (with no difference in nutritional
110 content), an average price was calculated and the product only counted once.

111

112 *Food Categories*

113 Products were categorised according to ten food groups: brown bread; white bread;
114 breakfast cereals; wholegrain flour (including mixes); white flour (including mixes); pizza
115 bases; wholegrain pasta; regular pasta; crackers; biscuits. These categories reflect groups
116 of manufactured foods traditionally containing gluten, and are similar to those previously
117 studied by Gibert et al. ⁽²⁶⁾ and Miranda et al ⁽¹⁶⁾.

118

119 *Sampling*

120 Power calculations were used to determine the size of sample required for each of the ten
121 food categories of regular products. Sample sizes generated for regular white flour,
122 wholegrain flour, pizza bases, and wholegrain pasta were larger than those available on
123 supermarket websites and so the full population was collected. In all other cases the

124 number of regular products collected was determined by the sample size generated. Food
125 category search terms were entered into supermarket websites and results sorted
126 alphabetically (ordered A to Z) by product name. 'Wholemeal' was entered as an
127 alternative search term for 'brown' or 'wholegrain' in relevant categories, and the search
128 returning the most results was used. Random numbers were produced using a random
129 number generator and were used to select products based on their order.

130

131 *Outcomes*

132 The primary outcome used to compare the nutritional composition of GF and regular foods
133 was the proportion of foods classified as containing high and medium content of fat,
134 saturated fat, sugar, and salt using the Department of Health (DH) traffic light system ⁽²⁷⁾
135 (Table 1). The DH traffic light classifications are a voluntary front-of-pack nutritional
136 profiling system for interpreting the nutritional quality of manufactured foods ⁽²⁸⁾.

137 The secondary outcome was a comparison of medians and interquartile ranges
138 (IQR), to provide additional insight into the differences between per 100g values for all
139 nutrients examined, in particular for fibre and protein content. Product prices (pence per
140 100g) were compared for GF and regular products only. All analyses were conducted
141 across the ten food categories.

142

143 *Statistical analysis*

144 The proportion of GF foods (prescribed and commercial) in each food category with high
145 and medium content of fat, saturated fat, sugar, and salt were used to determine the
146 sample size required for each regular food category. The sample size equation used one
147 proportion to determine one sample with two-sided equality, as follows $[n = p(1-p)((z_{1-\alpha/2}) + (z_{1-\beta})) / (p-p_0)^2]$ where p is the true proportion, p_0 is the comparison proportion (a
148 value of 10% difference to p), α is the Type I error, β is the Type II error, and z is a
149

150 quantile function for the standard normal distribution at power level = 0.80, and type I error
151 = 0.05 ^(29; 30). The largest sample size required for each of the four nutrients was selected.
152 Chi-squared tests were used to compare the proportions of foods in high and medium and
153 high classifications for each food category. Mann-Whitney tests were used to compare the
154 median nutritional content and cost where data distribution was non-parametric. Unpaired
155 t-tests were used for categories with parametric distributions. P values were considered
156 statistically significant if <0.05 . Data were analysed using SPSS version 23 ⁽³¹⁾.

157 **Results**

158 A total of 1724 food items from ten food categories were collected and analysed:
159 prescribed GF (n=197) were compared with commercial GF foods available from
160 supermarkets (n=482) giving a combined total of 679 products for all GF. The combined
161 group of these was then compared to regular products of the same food categories
162 (n=1045). The number of items in each food category ranged between 3-99 for GF
163 products (total populations for each category) and 11-196 for regular (total available or
164 randomised sample of category). Fibre data were not available for 83 of the 1724 items
165 (4.8% of total), due to the voluntary nature of declaring fibre content on packaging. Of the
166 83 missing values for fibre, 40 were from GF products (48%), and 43 from regular products
167 (52%). Duplicate product prices were averaged for 17 items (1% of total products) and
168 only counted once.

169

170 *Gluten free versus non-gluten free food products*

171 Differences in the proportion of foods classified as high and medium content were
172 observed in all relevant nutrients (fat, saturated fat, sugar, and salt), and across all food
173 categories (Table 2). Many of these (65%) indicated significantly higher proportions of
174 foods categorised as containing high and medium content of nutrients in GF compared to
175 regular products.

176 High and medium total fat classification significantly differed in five food categories.
177 With the exception of crackers, GF groups had a higher percentage of high and medium
178 fat products. Differences ranged from white flour (31.9% in GF, 0.0% in regular, $P<0.001$),
179 and white bread (78.1% in GF, 25.8% in regular, $P<0.001$). Median total fat content (g) for
180 GF brown bread and white bread were more than double those for regular products (Table
181 3).

182 For saturated fat, significantly more foods were classified as containing high and
183 medium in GF white bread ($P=0.030$) and white flour ($P=0.006$) than in regular items.
184 Conversely, for crackers, significantly more regular products contained high and medium
185 saturated fat compared with GF varieties (76.5% versus 48.4%, $P<0.001$). Median content
186 of saturated fats were significantly different between groups in 50% of food categories,
187 indicating higher levels in GF products for brown bread (0.3g difference, $P=0.001$), white
188 bread (0.2g difference, $P=<0.001$), and white flour (0.2g difference, $P=0.033$), and higher
189 levels in regular for white pasta (0.1g difference, $P=0.002$) and crackers (3.3g difference,
190 $P=<0.001$).

191 High and medium sugar classification significantly differed in eight of ten food
192 categories (Table 2), 62.5% of these differences resulting from higher proportions in GF
193 foods compared to regular in the same food category. These differences were evident in
194 white bread (26.0% in GF, 4.3% in regular, $P<0.001$), white flour (18.8% in GF, 1.4% in
195 regular, $P=0.001$), wholegrain flour (42.9% in GF, 5.6% in regular, $P<0.001$), pizza bases
196 (45.5% in GF, 0.0% in regular, $P=0.011$), and white pasta (6.3% in GF, 0.0% in regular,
197 $P=0.011$). In contrast, however, the median sugar content of GF products were observed
198 to be significantly lower than regular across six food categories (ranging from 0.7g lower in
199 GF brown bread ($P=0.001$), to 8.0g lower in GF breakfast cereals ($P<0.001$)) (Table 3).

200 The proportions of foods containing high and medium salt were significantly different
201 in four food categories, with two of these being higher in the GF groups wholegrain flour
202 (42.9% in GF, 13.2% in regular, $P=0.013$) and white pasta (6.3% in GF, 0.0% in regular,
203 $P=0.012$), and two higher in the regular groups breakfast cereals (34.3% in GF, 47.5% in
204 regular, $P=0.027$) and crackers (76.4% in GF, 96.4% in regular, $P=<0.001$) (Table 2).

205 Protein content was found to be consistently lower in GF products when compared
206 with their regular equivalents. Significant differences were found in eight of the ten food

207 categories, with differences ranging between 1.1g lower in GF biscuits ($P<0.001$) to 6.2g
208 lower in GF pizza bases ($P<0.001$) (Table 3).

209 Fibre content was found to be significantly different in 50% of food categories, the
210 median values for which in GF items were higher in bread products for both white (2.4g
211 difference, $P<0.001$) and brown (0.4g difference, $P=0.027$) classifications. In contrast, fibre
212 content was significantly lower for GF products in the breakfast cereal (1.2g difference,
213 $P=0.002$) and white (1.1g difference, $P<0.001$) and wholegrain (4.8g difference, $P<0.001$)
214 pasta categories (Table 3).

215 On average, GF products were 159% more expensive than regular (£0.44/100g
216 versus £1.14/100g) (Table 4) with costs of GF products significantly higher across all food
217 categories ($P<0.001$). The median cost (pounds per 100g) of GF brown and white bread,
218 and white and wholegrain flour was over four times the price of regular equivalents. For
219 example, GF white flour cost £0.93/100g whereas regular white flour cost £0.11/100g. The
220 range (IQR) of costs was also greater for GF products.

221 *Prescribed gluten free versus commercial GF food products*

222 The numbers of prescribed and commercial GF products included in this analysis
223 were limited by the small number of products available, i.e. less than 25 in some food
224 categories. In eight of the ten food categories, a greater proportion of commercial GF
225 foods were categorised as high and medium fat products than their prescribed GF
226 counterparts in white bread (89.6% versus 66.7%, respectively, $P=0.007$), breakfast
227 cereals (71.7% versus 33.3%, $P=0.018$), white flour (45.5% versus 8.0%, $P=0.001$), and
228 wholegrain pasta (55.6% versus 0%, $P=0.038$) (Table 5).

229 Significantly more prescribed GF products were classified as having high and
230 medium salt content than commercial equivalents. This trend was seen in breakfast
231 cereals (66.7% versus 31.3%, respectively, $P=0.032$), crackers (100% versus 72.4%,
232 $P=0.030$), and biscuits (100% versus 73.0%, $P=0.048$) (Table 5), with differences in

233 medians ranging from 0.1 - 0.3g/100g higher in prescribed GF products (Table 6). White
234 pasta was the only food category where the proportion of high and medium salt content of
235 products was higher in commercial GF (7.0% versus 5.0% in prescribed GF, $P=0.037$).

236 Discussion

237 Based on this cross-sectional analysis of GF and regular foods in the UK, statistically
238 significant differences in the proportions of products with high and medium content of fat,
239 saturated fat, sugar, and salt, and in the content of fibre and protein per 100g were found
240 across the ten food categories examined. However a key finding of the present study was
241 the lack of a pattern in the comparison of overall nutritional quality of GF and regular
242 dietary foods. This finding is consistent with previous studies ^(15; 16), and supports recent
243 evidence suggesting that there is no general nutritional advantage to a GF diet over a
244 regular one ⁽³²⁾. Furthermore, GF products cost significantly more than comparable regular
245 items.

246 A similar conclusion was reached by Wu et al. in their survey of supermarket foods in
247 Australia ⁽¹⁵⁾. Their results differed, however, in that they only found differences in sodium,
248 saturated fat, and sugar content in discretionary categories that included biscuits, cake
249 mixes, and cereal bars, and not in core food groups. The present study, however,
250 observed such differences across all categories, in both the proportions of high and
251 medium content (Table 2) and median g/100g (Table 3). Neither of these findings supports
252 the popular perception that GF foods offer a healthy alternative to regular products, or can
253 aid weight loss ^(16; 32).

254 The content of fat, saturated fat, sugar and salt in foods is of particular interest given
255 that these are nutrients that the UK population are likely to consume in excess of
256 recommended intake levels ^(28; 33). In some population groups, habitual intake of more than
257 twice the healthy consumption levels has been observed ⁽²⁸⁾. The traffic light classifications
258 are voluntary front of pack nutrition labels implemented in response to an agenda set out
259 in the Department of Health white paper *Choosing Health* ⁽³⁴⁾, with an aim to improve
260 comprehensibility of nutrition labels ⁽²⁷⁾. Consumers generally spend around four to ten

261 seconds selecting products, and so the traffic light system has been implemented to
262 attempt to convey nutrition information in this short space of time ⁽²⁸⁾.

263 Dietary fats are considered under traffic light guidance due to their effect on blood
264 cholesterol levels, and potential for contributing to weight gain if consumed in excess ⁽²⁸⁾.
265 Though the UK population is meeting recommended guidelines for total fat (35% of total
266 energy intake), and intakes have reduced since surveyed nationally in 1986-1987,
267 saturated fats are still consumed in excess of recommended amounts (11% of total
268 energy) ^(35; 36).

269 Higher fat content of GF foods, in particular GF bread, has been observed previously
270 in chemical analyses by Segura and Rosell ⁽⁹⁾, and in nutritional comparisons conducted in
271 Australia and Canada ^(15; 37), and may be inevitable due to the differing nutritional
272 composition of alternative grain ingredients used, or additional fats added in their
273 development to optimise consistency of the final product ^(37; 38). It may therefore be
274 possible that the criteria for selection of prescribed GF products are weighted more heavily
275 towards lower fat content compared with supermarket-bought GF foods. Although
276 prescribed GF products may have fewer proportions of products with high and medium fat
277 across numerous food categories the proportion of high and medium saturated fat, sugar
278 and salt were still higher than commercial GF foods, meaning they might not necessarily
279 be healthier products overall (Table 5).

280 Intake of saturated fats in the diet is associated with increased serum cholesterol
281 concentration, and reduced consumption of these fats has been associated with a small
282 but significant reduction in cardiovascular risk ⁽³⁹⁾. The present study found more GF food
283 categories above both high and medium saturated fat thresholds, and median content was
284 higher for white flour and bread products, compared to regular equivalents (Table 2),
285 although these are not major contributors to the saturated fat intake in the UK diet ⁽⁴⁰⁾. The
286 commercial GF white flour category was notably affected by high saturated fat outliers,

287 likely to be a result of inclusion of non-wheat alternatives such as almond flour (8g
288 saturated fat/100g) and organic coconut flour (14g/100g).

289 Coconut-based products in particular have recently been promoted in various media
290 as containing 'healthy' fats, contrary to evidence of relatively high saturated fat content ⁽³⁸⁾.
291 The choice to use coconut flour as a regular cooking ingredient could therefore result in a
292 higher consumption of saturated fats than if alternative GF flours were used (for example
293 quinoa, sorghum, maize) ^(38; 41). The presence of these flours as GF ingredients is a
294 reflection of the wide variety of alternative flours available in supermarkets, and requires
295 consumers to be discerning about their choice of GF flours if wanting low saturated fat
296 options.

297 Statistically significant differences in the median sugar contents were found in 6 food
298 categories. In all 6 categories, the GF products had lower median sugar contents.
299 However this should be interpreted with caution as a variable pattern was observed for
300 proportions of products in the high and medium sugar classifications in both GF and
301 regular products. White bread, white and wholegrain flour, and pizza bases had higher
302 proportions of medium and high sugar content in GF products. Yet GF breakfast cereals,
303 crackers and biscuits had lower proportions than regular equivalents, and also had lower
304 median sugar content. Uniquely, in the white pasta category, GF products were found to
305 have a greater proportion above high sugar thresholds but with a lower median, likely to
306 indicate to an existence of outliers with high sugar content diverging significantly from that
307 of most GF white pasta products.

308 The Scientific Advisory Committee on Nutrition guidelines advise that average intake
309 of 'free sugars' should not exceed 5% of total dietary energy, to reduce risk of dental
310 caries and excess energy consumption ⁽⁴²⁾. However the lack of discernable pattern of
311 median sugar content or proportion of high sugar items per category challenges the idea
312 that choosing either GF or regular items would increase the consumer's likelihood of

313 exceeding this guideline daily threshold. Discerning consumers may instead benefit from
314 understanding the food categories more likely to contain high sugar products, and
315 choosing products within that category based on a comparison of individual labels.

316 Although the sodium derived from salt is an essential nutrient, there is a strong
317 association between salt and increased risk of high blood pressure and cardiovascular
318 disease⁽⁴³⁾. Most people in the UK consume around 8g of salt each day, which is in
319 excess of the recommended intake level of 6g per day^(43; 44). The present study found that
320 GF items had higher proportions of high salt products for white flour, wholemeal flour and
321 biscuits than regular (Supplementary Table 1) and that significant differences found for salt
322 content was more often a result of prescribable GF foods having more high and medium
323 salt content foods and higher medians than non-prescribable items (Tables 5 & 6). This
324 could mean those on GF diets may be consuming more salt if more of the staple products
325 sit within the higher salt classifications. However, estimates from the INTERMAP study
326 suggest that over 50% of salt consumed in the UK is sourced from food items not explored
327 in the present study (e.g. red meats, vegetable products, dairy and soups)⁽⁴⁵⁾. Comparison
328 of weighed food records from individuals following GF and non-GF diets would provide
329 further insight.

330 Fibre content varied depending on the categories examined, with significantly higher
331 fibre found in regular white and wholegrain pasta compared to GF equivalents. GF breads
332 were significantly higher in fibre than regular products for white and brown breads, but
333 lower for breakfast cereals, reflecting the same findings as Wu et al.⁽¹⁵⁾ in Australia. Other
334 studies found that no significant difference existed between fibre content of GF and regular
335 items across all food categories^(18; 46), and that GF breads contained a 'good' amount of
336 fibre (at least 3g per 100g)⁽⁹⁾. This could be a result of manufacturers responding to
337 previously published data on deficiencies of fibre in the GF diet⁽⁴⁷⁾, and improved texture of

338 cereal products with the addition of ingredients such as hydrocolloids and inulin, and
339 pseudo-cereals such as amaranth, and quinoa^(48; 49).

340 GF products were found to have significantly lower protein content than regular
341 equivalents across nine of ten food categories (the biscuit category the only exception,
342 with no significant difference). These findings are consistent with prior research from other
343 countries showing lower protein content in GF foods^(9; 15; 16; 18), indicating that the removal
344 of the gluten protein can impact the overall protein intake from cereal and grain-based
345 products. Approximately 23% of dietary protein is obtained from cereals in the UK⁽⁵⁰⁾ with
346 11% coming from bread indicating that there is potential for a reduction in protein intake
347 when wheat-based products are replaced by GF foods. Although this may have little
348 clinical importance for those on a GF diet who consume protein from meat, fish, eggs and
349 dairy products, those on strict vegan diets (containing no animal proteins) may potentially
350 be at more risk of an inadequate protein intake.

351 The present study found that GF products were significantly more expensive than
352 regular equivalents, as reported previously^(19; 20; 37; 51-53). In the UK, Singh and Whelan
353 found that GF versions of wheat-based foods (n=10) cost 76-518% more than regular
354 versions (P<0.001)⁽²⁰⁾; and Burden et al. found that commonly purchased GF foods were
355 4.1 times more expensive than regular equivalents (P<0.0001)⁽¹⁹⁾. In Brazil, a significant
356 difference in cost between GF and regular products was reported for bread (P<0.01) but
357 not for pasta⁽⁵¹⁾. The difference in cost seems to be particularly disparate in flour and
358 bread products due to the high cost of alternative grains to replace wheat (e.g. rice, millet
359 and tapioca). Furthermore, expertise is needed to develop GF foods and maintain the
360 organoleptic properties associated with the gluten protein, resulting in higher product
361 costs. In light of the significantly higher cost of GF foods (159% more expensive than
362 regular) and recent reduction or withdrawal of GF prescriptions in some UK NHS Trusts,
363 there is risk that individuals with coeliac disease who are not be able to pay higher prices

364 of GF foods may reduce adherence to their gluten free diet thus compromising their short
365 and long-term health. Further studies are required to evaluate this.

366 This study has a number of limitations. Firstly, direct chemical analysis of food was
367 not undertaken resulting in a reliance on data obtained via manufacturers' and
368 supermarket websites or product packaging. Although indirect analyses have been used
369 previously in studies and shown to be a valid method of estimating nutritional composition
370 ⁽¹⁵⁻¹⁸⁾, reliance on anything other than the 'gold standard' direct chemical analysis can
371 potentially introduce inaccuracies. Nutrient data on packaging is commonly based on
372 manufacturer estimation rather than chemical analysis, and the values provided could not
373 be measured for errors in reporting ⁽⁵⁴⁾. Secondly, the traffic light system used to classify
374 foods does not provide a direct estimate of daily intake for the average consumer of GF or
375 regular foods, however these provide some indication of the relative difference between
376 the two groups. Thirdly, the findings of this study focus on statistically significant
377 differences of nutrient composition not on actual nutrient intake. As a result, it is not
378 possible to comment on the clinical importance at an individual level. However, whilst this
379 may be small for most individuals, the findings are likely to have greater relevance at
380 population level. Strengths of the present analysis include a larger sample size than
381 reported previously in the UK, comparison of both nutrients and cost between GF and
382 regular foods and, the additional comparison between prescribed and commercially
383 available GF items.

384 Future research could investigate micronutrient content of GF foods as analysis of
385 the intake of 139 adults with coeliac disease and following a GF diet showed that they
386 consumed low intakes of magnesium, iron, zinc, manganese, selenium and folate ⁽⁵⁵⁾. Iron,
387 calcium, and vitamin D are also particularly relevant to coeliac disease due to the
388 increased risk of anaemia and osteoporosis associated with the condition ^(10; 56).

389 Evaluating micronutrient content would require laboratory analysis as legislation does not
390 mandate that these are listed in food labels.

391 In conclusion, the differences in foods categorised as containing high and medium
392 amounts of fat, saturated fat, sugar and salt, and content of fibre and protein found in the
393 present study confirm that nutritional composition of GF and regular foods are not the
394 same across all food categories. Those people adhering to a strict GF diet might therefore
395 be consuming manufactured foods that are at times of lower nutritional quality than the
396 regular alternatives, but the lack of a consistent pattern complicates the process of
397 drawing conclusions. It is clear however, that the differences observed indicate a need for
398 consumers to be discerning in their purchasing behaviour and choose items according to
399 the nutritional quality and composition they desire from that product. Policy makers and
400 manufacturers who determine the nutritional composition of GF products have an
401 important role to play in ensuring that these foods are of comparable nutritional quality to
402 the regular products they replace.

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406

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410

411 **Conflict of interest**

412 None

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Table 1. Classification thresholds for total fat, saturated fat, sugar and salt content in foods⁽²⁴⁾

Nutrients	High classification (g/100 g)	Medium classification (g/100 g)
Total fat	>17.5	>3.0
Saturated fat	>5.0	>1.5
Sugar	>22.5	>5.0
Salt	>1.5	>0.3

Table 2. Proportion of gluten free (GF) versus regular products classified with a high and medium nutrient content across ten food categories in the UK^a

Food Category	n	Nutrient classification (high and medium)			
		Total fat	Saturated Fat	Sugar	Salt
		%	%	%	%
Brown bread					
GF	67	92.5	6.0	7.5	98.5
Regular	67	41.8	4.5	3.0	100.0
<i>P</i>		<0.001	0.698	0.244	0.315
White bread					
GF	96	78.1	8.3	26.0	99.0
Regular	163	25.8	2.5	4.3	99.4
<i>P</i>		<0.001	0.030	<0.001	0.704
Breakfast Cereals					
GF	108	68.5	30.6	75.9	34.3
Regular	181	70.7	34.8	86.2	47.5
<i>P</i>		0.693	0.458	0.027	0.027
White Flour					
GF	69	31.9	10.3	18.8	26.1
Regular	72	0.0	0.0	1.4	26.4
<i>P</i>		<0.001	0.006	0.001	0.968
Wholegrain Flour					
GF	14	14.3	0.0	42.9	42.9
Regular	54	9.3	0.0	5.6	13.2
<i>P</i>		0.581	-	<0.001	0.013
Pizza Bases					
GF	11	90.9	36.4	45.5	100.0
Regular	11	63.6	9.1	0.0	100.0
<i>P</i>		0.127	0.127	0.011	-
Wholegrain Pasta					
GF	14	35.7	0.0	0.0	0.0
Regular	57	3.5	0.0	0.0	1.8
<i>P</i>		<0.001	-	-	0.618
White Pasta					
GF	111	10.8	0.9	6.3	6.3
Regular	96	10.4	4.2	0.0	0.0
<i>P</i>		0.927	0.127	0.012	0.012
Crackers					
GF	89	60.7	49.4	19.1	76.4
Regular	196	90.8	76.5	35.2	96.4
<i>P</i>		<0.001	<0.001	0.006	<0.001
Biscuits					
GF	100	100.0	99.0	95.0	76.0
Regular	148	99.3	94.6	99.3	81.8
<i>P</i>		0.410	0.069	0.030	0.271

^aData are percentage of foods classified with either medium or high nutrient (total fat, saturated fat, sugar and salt) content according to the UK DH front-of-pack traffic light labeling⁽²⁴⁾. Differences in nutrient content between GF and regular products assessed using Chi Square Test.

Table 3. Nutritional content of gluten free (GF) compared with regular products across ten food categories^a

Food Category	N (%)	Nutrient content (per 100g)											
		Total Fat (g)		Saturated Fat (g)		Sugar (g)		Salt (g)		Fibre (g)		Protein (g)	
		Median	IQR	Median	IQR	Median	IQR	Median	IQR	Median	IQR	Median	IQR
Brown bread	134												
GF	67 (50.0)	6.80	5.00 - 10.10	0.80	0.50 - 1.10	2.60	2.10 - 3.70	0.85	0.74 - 1.00	6.8	3.8	4.4	2.7
Regular	67 (50.0)	2.80	1.80 - 3.90	0.50	0.40 - 0.80	3.30	2.80 - 4.20	0.95	0.83 - 1.00	6.4	1.8	10.2	1.2
<i>P</i>		<0.001		0.001		0.001		0.412		0.027		<0.001	
White bread	259												
GF	96 (37.1)	5.70	3.20 - 8.05	0.60	0.40 - 1.20	3.35	2.03 - 5.30	0.90	0.80 - 1.10	5.2	2.4	3.7	1.5
Regular	163 (62.9)	2.00	1.20 - 3.20	0.40	0.30 - 0.70	3.00	2.30 - 3.90	1.00	0.88 - 1.00	2.8	0.8	9.0	1.4
<i>P</i>		<0.001		<0.001		0.134		0.987		<0.001		<0.001	
Breakfast Cereal	289												
GF	108 (37.4)	5.40	2.03 - 13.48	1.00	0.43 - 1.78	13.10	6.25 - 23.00	0.12	0.03 - 0.50	6.1	5.1	8.7	4.7
Regular	181 (62.6)	5.00	2.45 - 10.05	1.00	0.50 - 2.50	21.0	13.70 - 26.00	0.29	0.05 - 0.70	7.3	4.1	9.1	3.3
<i>P</i>		0.631		0.245		<0.001		0.023		0.002		0.122	
White Flour	141												
GF	69 (48.9)	1.40	0.50 - 5.15	0.40	0.10 - 0.88	1.20	0.10 - 4.25	0.03	0.02 - 0.55	3.1	6.5	5.0	9.9
Regular	72 (51.1)	1.40	1.30 - 1.60	0.20	0.20 - 0.30	1.50	1.30 - 1.88	0.01	0.00 - 0.62	3.1	0.5	10.5	3.0
<i>P</i>		0.587		0.033		0.750		0.039		0.484		<0.001	
Wholegrain Flour	68												
GF	14 (20.6)	1.55	0.58 - 2.63	0.50	0.20 - 0.85	3.15	0.90 - 6.78	0.30	0.03 - 1.18	7.8	5.9	5.6	3.4
Regular	54 (79.4)	2.20	1.90 - 2.50	0.40	0.30 - 0.50	2.10	1.40 - 2.73	0.01	0.00 - 0.08	9.1	4.2	12.2	2.8
<i>P</i> ^b		0.076		0.376		0.252		0.002		0.188		<0.001	
Pizza Bases	22												
GF	11 (50.0)	5.50	4.30 - 10.80	0.60	0.30 - 1.90	3.90	0.63 - 7.80	1.10	0.98 - 1.35	3.1	1.9	3.0	1.5
Regular	11 (50.0)	4.90	2.20 - 5.60	0.90	0.20 - 1.00	1.50	0.80 - 2.60	1.40	0.70 - 1.59	2.7	2.8	9.7	2.2
<i>P</i> ^b		0.171		0.562		0.151		0.562		0.539		<0.001	
Wholegrain Pasta	71												
GF	14 (19.7)	2.40	1.80 - 3.70	0.45	0.40 - 0.70	0.70	0.60 - 1.98	0.03	0.00 - 0.04	3.2	3.3	7.9	0.9

Regular	57 (80.3)	2.00	1.90 - 2.47	0.40	0.35 - 0.48	3.00	1.43 - 3.60	0.04	0.01 - 0.10	8.0	1.7	12.5	1.3
<i>P</i>			0.087		0.088		0.002		0.143		<0.001		<0.001
White pasta	207												
GF	111 (53.6)	1.30	0.90 - 1.62	0.20	0.10 - 0.41	0.80	0.40 - 1.50	0.02	0.00 - 0.07	1.9	2.2	6.8	1.4
Regular	96 (46.4)	1.50	1.22 - 1.60	0.30	0.20 - 0.40	2.00	1.02 - 3.00	0.01	0.00 - 0.02	3.0	3.0	12.4	2.2
<i>P</i>			0.048		0.002		<0.001		0.027		<0.001		<0.001
Crackers	285												
GF	89 (31.2)	8.30	2.20 - 16.90	1.50	0.50 - 6.45	1.70	0.80 - 4.00	1.25	0.42 - 1.81	3.5	5.4	7.6	3.3
Regular	196 (68.6)	18.00	11.50 - 22.63	4.80	1.60 - 10.23	3.40	1.93 - 6.40	1.51	1.20 - 1.90	3.8	2.3	10.0	3.0
<i>P</i>			<0.001		<0.001		<0.001		0.009		0.391		<0.001
Biscuits	248												
GF	100 (40.3)	22.00	18.63 - 28.00	10.40	8.35 - 15.38	28.4	22.10 - 36.28	0.61	0.39 - 1.00	2.9	3.2	4.6	3.0
Regular	148 (59.7)	21.60	15.80 - 25.00	11.55	7.23 - 14.00	32.85	27.10 - 38.18	0.58	0.40 - 0.80	2.5	1.3	5.7	1.5
<i>P</i>			0.033		0.332		0.005		0.157		0.097		<0.001

^a Differences in nutrient content between GF and regular products assessed using Independent Samples Mann Whitney U Test

^b Assessed using Independent Samples T Test

Table 4. Cost of GF versus regular products in the UK^a

Food Category	Cost (pounds per 100g)						P
	GF			non-GF			
	n	Median	IQR	n	Median	IQR	
Brown bread	66	0.83	0.36-1.84	64	0.19	0.06-0.80	<0.001
White bread	95	0.90	0.23-2.18	158	0.20	0.02-0.75	<0.001
Breakfast Cereals	104	0.90	0.40-2.00	181	0.53	0.05-2.58	<0.001
White flour	69	0.93	0.12-2.72	72	0.11	0.03-0.36	<0.001
Wholegrain flour	14	1.00	0.17-1.47	15	0.14	0.04-1.00	<0.001
Pizza	11	1.49	1.00-3.33	11	0.37	0.16-1.15	<0.001
Whole grain pasta	12	0.79	0.38-1.32	57	0.25	0.10-0.50	<0.001
White pasta	110	0.80	0.24-1.65	96	0.26	0.04-1.60	<0.001
Crackers	85	1.56	0.65-4.98	196	0.80	0.13-4.76	<0.001
Biscuits	100	1.59	0.54-4.50	148	0.84	0.08-2.55	<0.001

^a Differences in cost between GF and regular products assessed using Independent Samples Mann Whitney U Test

Table 5. Proportion of prescribed GF compared with commercial GF products classified with a high and medium nutrient content across ten food categories in the UK^a

Food Category	<i>n</i>	Nutrient classification (High/Medium)			
		Total fat %	Saturated Fat %	Sugar %	Salt %
Brown bread					
Prescribed GF	29	86.2	10.3	10.3	96.6
Commercial GF	38	97.4	2.6	5.3	100.0
<i>P</i>		0.850	0.187	0.433	0.249
White bread					
Prescribed GF	48	66.7	10.4	27.1	97.9
Commercial GF	48	89.6	6.3	25.0	100.0
<i>P</i>		0.007	0.460	0.816	0.315
Breakfast Cereals					
Prescribed GF	9	33.3	0.0	55.6	66.7
Commercial GF	99	71.7	33.3	77.8	31.3
<i>P</i>		0.018	0.038	0.135	0.032
White Flour					
Prescribed GF	25	8.0	4.0	28.0	24.0
Commercial GF	44	45.5	14.0	13.6	27.3
<i>P</i>		0.001	0.193	0.142	0.766
Wholegrain Flour					
Prescribed GF	11	9.1	0.0	54.5	45.5
Commercial GF	3	33.3	0.0	0.0	33.3
<i>P</i>		0.287	-	0.910	0.707
Pizza Bases					
Prescribed GF	6	83.3	66.7	50.0	100.0
Commercial GF	5	100.0	0.0	40.0	100.0
<i>P</i>		0.338	0.022	0.740	-
Wholegrain Pasta					
Prescribed GF	5	0.0	0.0	0.0	0.0
Commercial GF	9	55.6	0.0	0.0	0.0
<i>P</i>		0.038	-	-	-
White Pasta					
Prescribed GF	40	7.5	2.5	0.0	5.0
Commercial GF	71	12.7	0.0	9.9	7.0
<i>P</i>		0.399	0.181	0.040	0.037
Crackers					
Prescribed GF	13	69.2	69.2	30.8	100.0
Commercial GF	76	59.2	46.1	17.1	72.4
<i>P</i>		0.494	0.122	0.247	0.030
Biscuits					
Prescribed GF	11	100.0	90.9	100.0	100.0
Commercial GF	89	100.0	100.0	94.4	73.0
<i>P</i>		-	0.004	0.420	0.048

^a Data are percentage of foods classified with a high and medium nutrient (total fat, saturated fat, sugar and salt) content according to the UK DH front-of-pack traffic light labeling⁽²⁴⁾. Differences in nutrient content between prescribed and commercial GF products assessed using Chi Square Test.

Table 6. Nutritional content of prescribed GF compared with commercial GF products across ten food categories^a

Food Category	Nutrient content (per 100g)									
	n	% products	Total Fat (g)		Saturated Fat (g)		Sugar (g)		Salt (g)	
			Median	IQR	Median	IQR	Median	IQR	Median	IQR
Brown bread	67									
Prescribed GF	29	43.3	6.60	4.00 - 9.80	1.10	0.50 - 1.25	3.10	1.35 - 4.40	1.00	0.83 - 1.25
Commercial GF	38	56.7	7.15	5.68 - 10.33	0.75	0.50 - 1.00	2.50	2.10 - 3.35	0.78	0.70 - 1.00
<i>P</i>			0.260		0.092		0.825		0.004	
White bread	96									
Prescribed GF	48	50.0	4.79	2.93 - 6.86	0.70	0.33 - 1.20	3.35	2.20 - 5.38	1.00	0.84 - 1.25
Commercial GF	48	50.0	5.80	4.70 - 8.10	0.55	0.40 - 0.90	3.35	1.93 - 5.20	0.90	0.75 - 1.00
<i>P</i>			0.082		0.609		0.956		0.003	
Breakfast Cereal	108									
Prescribed GF	9	8.3	1.90	1.00 - 4.75	0.30	0.25 - 0.90	6.50	1.40 - 7.75	0.80	0.00 - 1.65
Commercial GF	99	91.7	5.60	2.80 - 15.40	1.00	0.50 - 1.80	15.00	6.50 - 24.40	0.10	0.03 - 0.50
<i>P</i>			0.005		0.027		0.010		0.118	
White Flour	69									
Prescribed GF	25	36.2	0.60	0.30 - 1.50	0.30	0.06 - 0.50	3.70	0.45 - 5.70	0.02	0.02 - 0.34
Commercial GF	44	63.8	2.65	0.90 - 6.95	0.50	0.13 - 1.00	0.90	0.10 - 2.73	0.03	0.00 - 0.69
<i>P</i>			0.002		0.098		0.076		0.738	
Wholegrain Flour	14									
Prescribed GF	11	78.6	1.30	0.50 - 2.20	0.50	0.20 - 0.70	5.60	1.00 - 8.50	0.30	0.04 - 1.70
Commercial GF	3	21.4	3.00	0.90 - 6.20	0.80	0.20 - 1.00	1.10	0.50 - 3.00	0.13	0.00 - 1.00
<i>P</i>			0.291		0.555		0.225		0.555	
Pizza Bases	11									
Prescribed GF	6	54.5	8.95	4.23 - 12.60	1.80	0.50 - 2.95	4.65	0.60 - 8.60	1.28	1.08 - 1.56
Commercial GF	5	45.5	4.80	4.05 - 7.40	0.60	0.30 - 1.00	2.90	1.05 - 7.90	0.98	0.70 - 1.10

<i>P</i>			0.247		0.177		0.792		0.030	
Wholegrain Pasta	14									
Prescribed GF	5	35.7	1.80	1.50 - 2.10	0.40	0.25 - 0.50	1.40	1.00 - 4.40	0.03	0.02 - 0.30
Commercial GF	9	64.3	3.60	2.40 - 3.70	0.70	0.40 - 0.71	0.60	0.60 - 0.70	0.00	0.00 - 0.03
<i>P</i>			0.004		0.112		0.060		0.147	
White pasta	111									
Prescribed GF	40	36.0	1.40	0.90 - 1.80	0.10	0.00 - 0.40	1.00	0.80 - 1.50	0.00	0.00 - 0.03
Commercial GF	71	64.0	1.30	0.95 - 1.60	0.20	0.10 - 0.50	0.50	0.20 - 1.60	0.03	0.00 - 0.10
<i>P</i>			0.438		0.052		0.002		0.050	
Crackers	89									
Prescribed GF	13	14.6	12.80	2.35 - 17.00	5.90	0.75 - 9.25	3.00	1.90 - 5.45	1.40	0.98 - 1.80
Commercial GF	76	85.4	6.50	2.05 - 16.95	1.20	0.50 - 5.85	1.55	0.65 - 3.58	1.23	0.30 - 1.88
<i>P</i>			0.423		0.121		0.072		0.282	
Biscuits	100									
Prescribed GF	11	11.0	19.00	16.00 - 26.00	9.00	5.70 - 13.00	21.00	20.00 - 22.00	0.90	0.75 - 1.00
Commercial GF	89	89.0	22.30	18.70 - 28.00	11.20	8.40 - 15.85	30.10	23.20 - 37.75	0.60	0.30 - 1.02
<i>P</i>			0.134		0.101		0.001		0.048	

^aDifferences in nutrient content between prescribed GF and commercial GF products assessed using Independent Samples Mann Whitney U Test.

Supplementary Table 1. Proportion of GF versus regular products classified with a high nutrient content across ten food categories in the UK^a

Food Category	n	Nutrient classification (high)			
		Total fat	Saturated Fat	Sugar	Salt
		%	%	%	%
Brown bread					
GF	67	0.0	0.0	0.0	3.0
Regular	67	0.0	0.0	0.0	0.0
<i>P</i>		-	-	-	0.154
White bread					
GF	96	0.0	1.0	0.0	0.0
Regular	163	0.0	1.2	0.0	0.6
<i>P</i>		-	0.893	-	0.442
Breakfast Cereals					
GF	108	14.8	8.3	27.8	1.9
Regular	181	6.6	7.7	43.6	1.1
<i>P</i>		0.023	0.856	0.007	0.599
White Flour					
GF	69	4.3	7.4	1.4	11.6
Regular	72	0.0	0.0	0.0	1.4
<i>P</i>		0.074	0.021	0.305	0.013
Wholegrain Flour					
GF	14	0.0	0.0	0.0	21.4
Regular	54	0.0	0.0	0.0	0.0
<i>P</i>		-	-	-	0.001
Pizza Bases					
GF	11	0.0	0.0	0.0	9.1
Regular	11	0.0	0.0	0.0	27.3
<i>P</i>		-	-	-	0.269
Wholegrain Pasta					
GF	14	0.0	0.0	0.0	0.0
Regular	57	0.0	0.0	0.0	0.0
<i>P</i>		-	-	-	-
White Pasta					
GF	111	0.0	0.0	0.0	0.0
Regular	96	0.0	0.0	0.0	0.0
<i>P</i>		-	-	-	-
Crackers					
GF	89	20.2	33.7	7.9	38.2
Regular	196	53.1	49.0	0.0	50.0
<i>P</i>		<0.001	0.016	<0.001	0.064
Biscuits					
GF	100	81.0	91.0	73.0	5.0
Regular	148	69.6	85.1	87.2	0.7
<i>P</i>		0.044	0.171	0.005	0.030

^a Data are percentage of foods classified with a high nutrient (total fat, saturated fat, sugar and salt) content according to the UK DH front-of-pack traffic light labeling⁽²⁴⁾. Differences in nutrient content between GF and regular products assessed using Chi Square Test