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

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Conflict of interest

The authors declare that they have no conflict of interests.

Abstract

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

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

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

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

Introduction

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

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

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

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

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

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

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

Methods

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

Design and data collection

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

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

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

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

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

Food Categories

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

Sampling

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

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

Outcomes

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

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

Statistical analysis

The proportion of GF foods (prescribed and commercial) in each food category with high and medium content of fat, saturated fat, sugar, and salt were used to determine the sample size required for each regular food category. The sample size equation used one proportion to determine one sample with two-sided equality, as follows [$n = p(1-p)((z1-\alpha/2)+(z1-\beta))/(p-p0)^2$] where p is the true proportion, $p0$ is the comparison proportion (a value of 10% difference to p), α is the Type I error, β is the Type II error, and z is a

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

Results

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

Gluten free versus non-gluten free food products

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

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

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

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

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

Protein content was found to be consistently lower in GF products when compared 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

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

Discussion

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

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

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

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

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

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

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

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

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

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

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

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

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

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

cereal products with the addition of ingredients such an hydrocolloids and inulin, and pseudo-cereals such as amaranth, and quinoa[48; 49].

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

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

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

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

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

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

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

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Conflict of interest

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]

		Nutrient classification (high and medium)			
		Total fat	**Saturated Fat**	**Sugar**	**Salt**
Food Category	*n*	%	%	%	%
Brown bread					
GF	67	92.5	6.0	7.5	98.5
Regular	67	41.8	4.5	3.0	100.0
P		**<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
P		**<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
P		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
P		**<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
P		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
P		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
P		**<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
P		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
P		**<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
P		0.410	0.069	**0.030**	0.271

[a] Data 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]

		Nutrient content (per 100g)											
		Total Fat (g)		**Saturated Fat (g)**		**Sugar (g)**		**Salt (g)**		**Fibre (g)**		**Protein (g)**	
Food Category	*N (%)*	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
P			**<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
P			**<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
P			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
P			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
P [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
P [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
P			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
P			**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
P			**<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
P			**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]

	Cost (pounds per 100g)						
	GF			non-GF			
Food Category	*n*	Median	IQR	*n*	Median	IQR	*P*
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]

		Nutrient classification (High/Medium)			
		Total fat	**Saturated Fat**	**Sugar**	**Salt**
Food Category	*n*	%	%	%	%
Brown bread					
Prescribed GF	29	86.2	10.3	10.3	96.6
Commercial GF	38	97.4	2.6	5.3	100.0
P		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
P		**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
P		**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
P		**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
P		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
P		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
P		**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
P		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
P		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
P		**-**	**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]

			Nutrient content (per 100g)							
			Total Fat (g)		Saturated Fat (g)		Sugar (g)		Salt (g)	
Food Category	*n*	% products	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
P			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
P			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
P			**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
P			**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
P			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

P			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
P			**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
P			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
P			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
P			0.134		0.101		**0.001**		**0.048**	

[a]Differences 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]

		Nutrient classification (high)			
		Total fat	**Saturated Fat**	**Sugar**	**Salt**
Food Category	*n*	%	%	%	%
Brown bread					
GF	67	0.0	0.0	0.0	3.0
Regular	67	0.0	0.0	0.0	0.0
P		**-**	-	-	0.154
White bread					
GF	96	0.0	1.0	0.0	0.0
Regular	163	0.0	1.2	0.0	0.6
P		**-**	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
P		**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
P		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
P		-	-	**-**	**0.001**
Pizza Bases					
GF	11	0.0	0.0	0.0	9.1
Regular	11	0.0	0.0	0.0	27.3
P		-	-	**-**	0.269
Wholegrain Pasta					
GF	14	0.0	0.0	0.0	0.0
Regular	57	0.0	0.0	0.0	0.0
P		**-**	-	-	-
White Pasta					
GF	111	0.0	0.0	0.0	0.0
Regular	96	0.0	0.0	0.0	0.0
P		-	-	**-**	**-**
Crackers					
GF	89	20.2	33.7	7.9	38.2
Regular	196	53.1	49.0	0.0	50.0
P		**<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
P		**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