Fermented foods: availability, cost, ingredients, nutritional content and on-pack claims

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Conflict of Interest
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Abstract

Introduction

Fermented foods have been consumed for millennia and commercially-produced variants are now available in the food supply. The aim was to investigate the availability, cost, ingredients, nutritional content and on-pack claims of commercially-available fermented foods in the United Kingdom (UK).

Methods

All products from seven categories of commercially-available fermented foods were systematically identified at eight national supermarket chains in the UK. Data were extracted from manufacturer and retailer websites and were compared between categories using Kruskal-Wallis test and Fisher's exact test.

Results

A total of 143 fermented foods were identified, with kombucha (41, 28.7%), kefir drinks (32, 22.4%), sauerkraut (22, 15.4%) and kefir yoghurts (21, 14.7%) being most common. The number of products sold at each retailer differed between categories (P=0.016), and was greatest for kefir drink (median 7.0, IQR 9.0), kombucha (5.5, 11.5) and kefir yoghurts (5.0, 8.5). Kombucha (£1.99/serving) and kefir drinks (£1.26/serving) were the most expensive fermented foods and sauerkraut (£0.66/serving) and miso (£0.20/serving) the least expensive. Energy, fat, saturated fat, sugar, protein and salt content varied between fermented foods (P<0.001). Nutrition claims were made on 72 (50.3%) products, the total number of cultures was labelled on 29 (20.3%), specific strains were named on 53 (37.1%) and bacteria-related benefits were promoted on 39 (27.3%) products.

Conclusions

Commercially-produced fermented foods are widely available in the UK, but are diverse in their cost, nutritional content, ingredients and use of on-pack claims. Consumers should be aware of these variations given limited evidence of functional benefits from controlled human trials.

Keywords: Fermented foods, probiotics, food supply, availability, labelling

Introduction

Fermented foods are defined as 'foods made through desired microbial growth and enzymatic conversions of food components' [1]. The microorganisms responsible for fermentation are either endogenous to the food (e.g. sauerkraut or kimchi where bacteria on the vegetable leaves are used in the ferment) or exogenous and are added to the food (e.g. kefir or kombucha where starter cultures are added). The consumption of fermented foods dates back many millennia due to their favourable organoleptic properties and reduced perishability [1].

Many different types of fermented foods are in existence as a result of variations in raw material availability, climatic conditions and cultural preferences [2]. However, the major fermented foods that are made in the home and also commercially are kefir, kimchi, sauerkraut, miso, tempeh, and kombucha. Kefir is the product of milk fermentation by a symbiotic culture of lactic acid bacteria, acetic acid bacteria and yeasts, and originated from the Caucasus Mountains [3]. Kimchi is a preparation of spicy fermented vegetables (e.g. Chinese cabbage, radish, garlic, ginger) that originated in Korea but is now widely consumed across East Asia [4]. Sauerkraut is a fermented salted cabbage, typically associated with German and Eastern European cuisines but which originated in China [5]. Miso is a savoury paste of soybeans fermented by *Aspergillus oryzae* and is usually consumed as a broth and is a staple in traditional Japanese diets [6]. Tempeh is typically produced from yellow-seeded soybeans fermented by *Rhizopus* spp., to form a dense 'cake' and is of Indonesian origin [7]. Finally, kombucha is a beverage resulting from the fermentation of black tea and sugar with a symbiotic culture of acetic acid bacteria and yeasts first used in China but now consumed worldwide [8].

The consumption of fermented foods has been associated with health and disease prevention, in particular in the context of gastrointestinal health and thought to be due to the presence of the microorganisms or their metabolites [9, 10]. Evidence from *in vitro* and animal studies demonstrate some favourable effects of fermented foods, however there are limited human clinical trials of the impact of fermented foods on health [11]. For example, in diabetic rats, feeding of kombucha tea *versus* unfermented black tea for 30 days resulted in improved glycaemic control [12]. However, a recent review failed to identify any controlled human studies investigating kombucha in health and disease [13].

Advances in food production, including the development of efficient supply chains the use of cold storage (refrigeration, freezing) to permit access to fresh foods and the development of food additive preservatives for use in processed foods, might reasonably have been expected to threaten the popularity of fermented foods that have long been used for their reduced perishability. However, the fermented food market has proved increasingly popular, for example, sales of kefir at a major

UK retailer increased by 400% between 2018 and 2020 [14]. Large companies have taken opportunities to add fermented foods to their portfolios through the acquisition of smaller niche companies [15], which has the potential to increase the number of fermented foods in the food supply. However, no studies have yet examined the availability and cost of fermented foods in the food supply.

Some fermented foods are marketed as functional foods, claiming health benefits above and beyond their basic nutritional composition. However, some commercially-produced fermented foods may contain added ingredients such as salt, sugar and food additives, although, to date, no studies have evaluated the nutritional quality and ingredients of fermented foods, or the claims made on packaging.

The aim of this study was to investigate the availability, cost, ingredients, nutritional content and on-pack claims of selected commercially-available fermented foods in the United Kingdom (UK).

Methods

This study was a systematic survey of selected fermented food products commercially available in supermarkets in the UK.

Fermented food eligibility criteria

Fermented foods were eligible for inclusion if they could reasonably be expected to contain live microorganisms and to retain the associated proposed benefits. Exclusion criteria were the use of high heat treatment as an integral part of the manufacturing process (e.g. sourdough bread), or removal of live bacteria prior to sale (e.g. wine, beer) [9]. Products made from fermented foods (e.g. miso soup) were not eligible, only the original fermented foods themselves. Live yogurts were also excluded because an extensive study has recently reported their nutritional profiles in the UK [16].

Kefir, kimchi, kombucha, miso, sauerkraut and tempeh were therefore eligible for inclusion. Kefir drinks and kefir yogurts were treated as separate categories.

Fermented food identification

Fermented foods were identified from eight major food retailers with an online presence in the UK: Sainsbury's, Tesco, Asda, Morrisons, Waitrose, Ocado, Holland and Barrett and Amazon Fresh. These retailers were selected for their large grocery market share. With the exception of Holland and Barrett and Amazon Fresh, for which specific data were unavailable, these retailers account for 72.6% of the total grocery market in Great Britain [17]. In addition, these retailers provided detailed product information online.

Fermented foods were identified from retailer websites between 12 May and 4 June 2020. The website search function was used to identify products, with a single word entered for each of the fermented foods detailed above (e.g. 'kefir') and the search was repeated across all eight websites. Data were extracted into a spreadsheet for each brand of a specific fermented food. Where a specific brand was sold by more than one retailer, the item was entered only once so that a list of unique items was produced, though the availability and retail price was captured separately for each retailer. Flavour variants were considered as unique items, and each was entered individually. Where identical products and flavours were available in multiple pack sizes (e.g. 250 ml and 500 ml), only the most frequently available variant was entered, to prevent double counting of unique items.

Data extraction

Once all fermented foods were identified from all eight websites, data on availability and cost were extracted from the retailer website but all other data were extracted from the manufacturer's website (where available). For each unique item, the following data were extracted: brand, product name, organic credentials, pack weight or volume, serving size, energy and nutrient content per 100 g or 100 mL, energy and nutrient content per serve, ingredients, bacteria strains, nutrition and health claims, as well as any claims pertaining to the ingredients or manufacturing process.

In the absence of a specified serving size, one serving was assumed to be consistent with other products of the same brand, e.g. if a 250 mL bottle of kefir was marketed as one serving, then a 500 mL bottle of the same kefir was assumed to contain two servings. Where no equivalent product was available, the mean serving size for other similar products was used.

Where nutritional declarations were made only per 100 g / mL, or per serving, the missing information was calculated. Declarations of sodium content were converted to salt content for comparability. To enable statistical analysis, where nutrient content was not provided as a discrete value, the following imputation was used for consistency: 'trace' was entered as 0, '<0.1' was entered as 0.05; and '<0.5' was entered as 0.25.

Once all data were extracted from the manufacturer's website, data were then cross-checked against the retailer website for completeness and correctness; where data disagreed, the manufacturer's website was taken as the correct version. In four instances, manufacturers were contacted by email to confirm data for a specific product.

Data analysis

IBM SPSS Statistics version 26 was used for statistical analyses. Data were compared across categories (i.e. kefir drink, kefir yoghurt, kimchi, kombucha, miso, sauerkraut, tempeh) all using the Kruskal-Wallis test for non-parametric data, with Bonferroni *post hoc* correction for paired comparisons (e.g. kefir drink vs kefir yoghurt). Fisher's exact test was used to compare categorical variables. A P value <0.05 was used to indicate statistical significance.

Data for nutrition claims were evaluated by comparing the content of energy, fat, saturated fat, protein, fibre and micronutrients against the relevant nutrition claims regulated under EU law [18].

Results

A total of 143 unique fermented foods were identified, six of which were retailer own-label, the remaining 137 were manufacturer brands.

Availability and cost

The greatest range of fermented foods and beverages was available from Ocado (n=85), almost double the number sold by the next retailer, Sainsbury's (n=45), followed by Waitrose (n=42), Amazon Fresh (n=23), Morrisons (n=20), Tesco (n=18), Asda (n=16) and Holland and Barrett (n=14).

The number of products in each fermented food category varied widely in the UK food supply, with kombucha (41, 28.7%), kefir drinks (32, 22.4%), sauerkraut (22, 15.4%) and kefir yoghurts (21, 14.7%) being the most common (**Table 1**).

When analysed at the category level for each of the eight retailers, the availability of fermented foods was significantly different between categories (P=0.016) (**Table 1, Figure 1**). The number of products per retailer was greatest for kefir drink (median 7.0 products per retailer, IQR 9.0), followed by kombucha (median 5.5, IQR 11.5) and kefir yoghurts (median 5.0, IQR 8.5). Pairwise comparisons demonstrated significant differences only between kefir drink (median 7.0, IQR 9.0) and tempeh (median 1.0, IQR 2.5) (P=0.024) (**Table 1, Figure 1**). Overall, each fermented food category was available at the majority of retailers, ranging from kombucha and tempeh, where at least one product was available in six of the eight retailers, to kimchi and sauerkraut, where at least one product was available in all eight retailers (**Table 1**).

At the individual product level, no products were available from all eight retailers, and the majority of each product (86, 60.1%) was stocked by only one retailer. The most widely available products were in the kefir yogurt category; for which each product was available on average at two of the eight retailers (median 2 retailers, IQR 2), followed by kefir drink (median 1.5 retailers, IQR 3), and all

other products available in a median of only one retailer. However, there was no significant difference in the number of retailers stocking each category of fermented foods (P=0.078).

There was significant variation in retail price between categories of fermented foods (both per 100 g / 100 mL and per serving) (**Table 1**). Kefir drink was the cheapest per 100 mL (£0.55 / 100 ml), followed by kombucha (£0.73 / 100 ml). However, data were different when price per serving was calculated, where kombucha (£1.99 / serving) and kefir drink (£1.26 /serving) were actually the most expensive products. Per serving, kombucha (£1.99 /serving) was significantly more expensive than kefir drink (£1.26 /serving, P=0.006), kefir yogurt (£0.77 /serving, P<0.001), sauerkraut (£0.66 /serving, P<0.001) and miso (£0.20 /serving, P<0.001).

Ingredients

Sixty-eight (47.6%) fermented foods were marketed as organic. The proportion of fermented foods that were organic differed significantly between categories (P<0.001), with the highest proportion for kombucha, (29, 70.7%), followed by tempeh (3, 60.0%), sauerkraut (13, 59.1%), miso (8, 57.1%), kefir drink (9, 28.1%), kimchi (2, 25.0%) and kefir yogurt (4, 19.0%).

Food additives were identified in 47 (32.9%) products. The most common additives were pectin (n=19), stevia (n=16) and erythritol (n=9), all present exclusively in kefir drink, kefir yogurt and kombucha. However, there was no significant difference in number of food additives between categories of fermented foods (P=0.083).

Nutritional content

There were significant differences in composition of all legally declarable nutrients between fermented foods, both per 100 g/100 ml and per serving (**Table 2**).

Kefir drinks contained the highest energy per serve (140.3 kcal/serving), at close to nine times that of sauerkraut (16.0 kcal/serve), but was comparable to kefir yogurt (119.0 kcal/serve, P=1.000) and tempeh (139.0 kcal/serve, P=1.000). Sauerkraut contained the lowest energy per serving (16.0 kcal/serve), significantly lower than kefir drinks (140.3 kcal/serving, P<0.001), kefir yogurts (119.0 kcal/serving, P<0.001), kombucha (38.5 kcal/serving, P=0.048) and tempeh (139.0 kcal/serving, P<0.001).

Tempeh contained the highest amounts of fat (6.9 g/serving) followed by kefir drink (5.4 g/serving), with no significant difference between the two (P=1.000). Tempeh was significantly higher in fat than kombucha (0.0 g/serving, P<0.001) and sauerkraut (0.2 g/serving, P=0.001). Similarly, kefir drinks (5.4 g/serving) and kefir yogurts (2.9 g/serving) were both significantly higher in fat than

kombucha (0.0 g/serving, $P<0.001$) and sauerkraut (0.2 g/serving, $P<0.001$). The median fat contents of kimchi, kombucha and sauerkraut, all less than 1 g/serving did not differ significantly ($P=1.000$).

Similar findings were observed for saturated fat. Kefir drinks contained the highest amount of saturated fat (3.6 g/serving) and was significantly higher than kimchi (0.1 g/serving, $P=0.008$), kombucha (0.0 g/serving, $P<0.001$), miso (0.1 g/serving, $P=0.010$) and sauerkraut (0.0 g/serving, $P<0.001$). Two kefir drinks contained as much as 26.0 g/serving and 17.0 g/serving. The saturated fat content of kimchi, kombucha, miso and sauerkraut, all below 0.2 g/serving, did not differ significantly.

Kefir drinks also contained the highest amount of sugar (10.3 g/serving), comparable to that of kefir yogurts (9.9 g/serving, $P=1.000$) and kombucha (8.3 g/serving, $P=0.311$), but significantly greater than the sugar content of kimchi (0.7 g/serving, $P<0.001$), miso (1.8 g/serving, $P<0.001$), sauerkraut (1.0 g/serving, $p<0.001$) and tempeh (0.4 g/serving, $P=0.004$). The lowest sugar content was observed in tempeh (0.4 g/serving), kimchi (0.7 g/serving), sauerkraut (1.0 g/serving) and miso (1.8 g/serving), with no significant differences between any of these comparisons (all $P<0.001$).

Tempeh was the greatest source of protein (13.0 g/serving) and was significantly higher in protein than kimchi (0.9 g/serving, $P=0.038$), kombucha (0.0 g/serving, $P<0.001$) and sauerkraut (0.8 g/serving, $P=0.005$). The lowest source of protein was kombucha (0.0 g/serving).

Miso (1.6 g/serving) and sauerkraut (1.4 g/serving) contained the highest amount of salt, both significantly higher than kefir drinks (0.1 g/serving, $P<0.001$), kefir yogurts (0.2 g/serving, $P=0.001$) and kombucha (0.0 g/serving, $P<0.001$). Both kombucha and tempeh had the lowest salt content, both of which on average contained zero salt.

Only 58/143 (40.6%) fermented foods declared their fibre content and, where reported, there was a significant difference in fibre content across the categories of fermented food ($P<0.001$). Tempeh contained the highest amount of fibre (4.1 g/serving), which was significantly higher than the kombucha, which contained the lowest amount of fibre (0.1 g/serving, $P<0.001$).

Similar patterns were observed for nutrient content per 100 g or 100 mL, although differences were notable where the serving size deviated greatly from 100 g or 100 mL. For example, miso, which is used in only small quantities in cooking contained the highest energy (187.0 kcal/100 g) and sugar (11.8 g/100 g) when presented per 100 g.

Product claims

Seventy-two (50.3%) fermented foods products carried regulated nutrition claims [18], with a significant difference in the proportion between different categories of fermented foods ($P<0.001$). For kefir yogurts and tempeh all products carried at least one nutrition claim, whereas there were nutrition claims on only 5/22 (22.7%) sauerkraut products, and none on any kimchi product. The frequency of nutrient claims varied across different fermented foods, although for individual nutrients were not compared statistically due to low frequencies of claims (**Table 3**).

Based upon the available data, it was possible to verify 65/72 of the nutrition claims the fermented foods. One sauerkraut carried a fibre claim, despite the fibre content being unavailable online. Three of 72 products carried inaccurate nutrition claims; one kefir drink carried a low sugar claim yet contained 3 g/100 mL (above the 2.5 g/100 mL threshold for such claims) and two further kefir drinks carried high calcium claims but contained only 14% and 14.2% of the nutrient reference value per 100 mL (less than the 15% required for such claims).

Claims relating to some aspect of bacteria (total numbers, named species/strains, bacteria-related health outcomes) in the fermented foods were present on 74 of the 143 (51.7%) fermented foods (**Figure 2**). The total number of bacterial cultures was detailed on only 29 (20.3%) products with a significant difference between the categories of fermented foods ($P=0.001$). The only fermented foods containing information on total number of bacterial cultures were kombucha (15/41, 36.6%), kefir drinks (10/32, 31.3%) and kefir yogurts (4/21, 19.0%). This information was not available for any kimchi, miso, sauerkraut or tempeh.

Specific bacterial species or strains were named on 53/143 (37.1%) products (**Figure 2**), with a significant difference between the categories of fermented foods ($P<0.001$). Specific bacterial species of strains were named on all kefir yogurts (21/21, 100%), the majority of kefir drinks (23/32, 71.9%) and some kombucha products (9/41, 22.0%), but not on any kimchi, miso, sauerkraut or tempeh.

Product labels alluded to bacteria-related benefits (e.g. 'gut-friendly cultures', 'packed full of friendly bacteria') on 39/143 (27.3%) fermented foods (**Figure 2**), with a significant difference between the categories of fermented foods ($P<0.001$). Bacteria-related health outcomes were alluded to on kefir yogurts (11/21, 52.4%), kefir drinks (15/32, 46.9%), tempeh (2/5, 40.0%), kombucha (10/41, 24.4%) and sauerkraut (1/22, 4.5%), with no such information allusion for kimchi and miso. Five products specifically mentioned containing 'probiotics' (3 kombucha, 1 kefir, 1 sauerkraut).

Discussion

Fermented foods have been consumed for millennia, with mass-produced variants now commercially available. The aim of this study was to investigate the availability, cost, ingredient composition, nutritional quality and on-pack claims of selected fermented foods commercially available in the UK. The results showed that that in general fermented foods were widely available and the retail cost of the different categories of fermented foods varied considerably.

Kombucha and kefir (kefir drinks and kefir yoghurts) accounted for almost two thirds (65.7%) of all fermented foods products available in the UK food supply. They were also widely available with on average between five and seven different products were stocked at each retailer. However, despite kimchi and sauerkraut having low numbers of products stocked at each retailer (on average 1.0-2.5), at least one version was stocked by all eight retailers. Therefore even though less selection was available for the fermented vegetables, they could still be widely purchased.

One reason for the greater number of products in the kefir drinks, kefir yoghurts and kombucha categories, could be that they were often sold in different flavours, with each flavour constituting a unique product, whereas kimchi and sauerkraut are rarely prepared in different flavours. Another reason for the wider availability could be explained by consumer perceptions of product familiarity, as kefir (both drinks and yogurts) are similar in format to other dairy products with an established presence in supermarkets, such as live yogurts and yogurt drinks. The least commonly available products were fermented soybean products (tempeh, miso) or fermented vegetable products (kimchi) that have less similar equivalents in the traditional UK diet and therefore may lack consumer familiarity. In addition, these products are typical in diets in Indonesia, Japan and Korea, and yet UK residents of these ethnicities constitute a very small proportion of the UK population ("Asian other" 1.5% of England & Wales) [19], and therefore consumer demand from migrant populations may be low.

The cost of fermented foods depended on how data were calculated. When calculated per 100 g or per 100 mL, those presented as drinks (i.e. kefir drink, kombucha) were the cheapest fermented foods due to their large volume. However, these were actually the most expensive fermented foods when cost was calculated per serving. The higher retail price per serve of kombucha in comparison to most other fermented foods could in part be explained by the high proportion of organic products in this category; organic food reportedly carries an 89% premium in major UK supermarkets [20].

Cost is likely to be an important feature of fermented foods. Although almost no research investigates public perceptions of fermented foods, one survey of attitudes among 264 young adults in Korea demonstrated that beliefs about price (e.g. not expensive, cheap, value for money) was the only factor associated with attitudes towards; satisfaction with; and intention to purchase fermented

foods [21]. Clearly, it is not possible to infer similar beliefs among UK consumers, nor to a wider range of fermented foods, which exposes the need to investigate consumer attitudes to fermented foods in Europe. However, cost may be an important issue in widening access to fermented foods among different groups.

The energy content of some fermented foods was relatively high. A single serving of kefir drink (140 kcal/serve) amounts to a 7% increment in energy intake, based on a 2000 kcal/d diet, which although small is not negligible if it is replacing low energy beverages such as water, teas or coffees. However, despite their energy content, kefir drinks also provide protein and fat, unlike kombucha which as a drink is significantly lower in energy (38.5 kcal/serve) but lacks other nutrients. Nonetheless, calls to include fermented foods into national dietary guidelines [22] should consider the foods they would replace in the diet and account for the impact on energy intake of some products.

Although the fat and saturated fat contents of tempeh, kefir drinks and kefir yogurts did not differ significantly, there were some notable findings. On average, one-fifth of the total fat content of tempeh was saturated fat, compared with two-thirds for kefir drinks and kefir yogurts. Elsewhere, it is reported that three-quarters of the total fat content of tempeh is comprised of unsaturated linoleic and oleic acids [23]. In the UK, and many other countries, dietary guidelines recommend reducing dietary saturated fat and replacing it with unsaturated fat, consistent with evidence of a reduction in blood cholesterol [24]. Interestingly, kefir has been investigated for cholesterol-lowering properties beyond its nutritional composition. However a randomised crossover trial in 13 hypercholesterolaemic males found no effect of kefir drink on plasma cholesterol, although of course this small study may have been vulnerable to type II error [25].

Tempeh was the richest source of fibre (4.1 g/serving). Fibre plays a major role in the maintenance of gastrointestinal health [26], despite which there are relatively low intakes of fibre in the UK (19 g/d) compared to the reference nutrient intake (30 g/d) [27], it is unlikely that tempeh could make a major contribution to fibre intakes at the population level due to its low availability and current low intakes.

The sugar content of kefir drinks and kefir yogurts may be partly attributed to naturally occurring lactose. However, of 13 unsweetened kefir products, seven exceeded the 3.8 g /100 mL or 100 g limit for lactose set out in the UK sugar reduction programme [28]. Artificial sweeteners (e.g. erythritol, steviol glycosides) were added to some kefir drinks, kefir yogurts and kombucha to facilitate ‘no sugar’ or ‘sugar-free’ claims. A review of the safety of erythritol in foods raised no concerns [29] and

there is preliminary evidence that steviol glycosides reduce postprandial glucose and insulin in comparison to sucrose [30].

Food additives were present in almost one third of fermented food products, although all must be approved for safety by the European Food Safety Authority prior to inclusion in food supply. Accordingly, fermented foods that contain food additives would be classified as ultra-processed, although the broad definition of 'ultra-processed foods' has its limitations [31]. There is well-documented consumer distrust of food additives [32], however, it is unclear whether consumers understand that food additives are used in a wide range of fermented foods.

The salt content of miso, sauerkraut and kimchi may be a cause for concern. In the current study, a single serving of miso provides more than one-quarter of the maximum 6 g/d salt recommended by SACN to achieve a population-wide reduction in blood pressure [33]. Interestingly, increases in systolic blood pressure were shown to be attenuated in rats fed miso soup for eight weeks compared to those fed a sodium chloride solution [34], although effects in humans and any underlying mechanisms are unclear. Therefore, in the context of a Western diet and without further research in humans, it remains important for fermented foods to be consumed with consideration for national dietary guidelines.

Although little is known regarding the perceptions towards fermented foods among the public, any perceived health benefit may in part be driven by on-pack claims. Nutrition claims can either promote the presence of nutrients (e.g. protein, fibre) or the reduction or absence of energy or nutrients (e.g. fat, sugar), and research indicates that foods carrying 'presence claims' are perceived as healthier and tastier than those with 'absence claims' [35]. This may underpin the predominance of presence claims on fermented foods, including the use of protein claims on the majority of kefir drinks, kefir yogurts and tempeh.

A potential incentive for consumers may be the presence of bacteria, the benefits of which were implied on 39 products, including five that explicitly used the term probiotic. The Committee of Advertising Practice cautions against using the term 'probiotic' [36] and, what is more, the majority of fermented foods do not fulfil the classification of being a probiotic fermented food [1]. Consumers should therefore be wary of assertions that commercially available fermented foods will yield a 'probiotic benefit' unless evidence of such an effect is available.

Strengths of this study include the comprehensive data collection, allowing comparisons to be made across major categories of fermented foods. The inclusion of eight retailers, accounting for nearly

three-quarters of the total grocery market, allowed for a relatively complete assessment of the fermented foods widely available to UK consumers.

Limitations of the study were the exclusion of retailers without a substantial online presence as well as small, independent health food stores and stores tailored to specific cultural diets (e.g. independent Japanese or Polish supermarkets), some of whom may stock fermented foods not available in the major supermarkets and online stores. Inconsistencies in labelling practices meant that comparisons between nutrients not legally required on pack (e.g. fibre) were limited. Finally, the lack of tempeh and kimchi products, as well as the application of a 'conservative' Bonferroni correction [37], may have increased the risk of type II error, masking potential differences between fermented foods.

In conclusion, the commercially-produced fermented foods are widely available in the UK, but are diverse in their cost, nutritional quality, ingredients and use of on-pack claims. Kombucha, for which there are currently no controlled clinical trials investigating its effects on human health, is limited in nutritional content. Meanwhile, tempeh is low in sugar and rich in protein and fibre, making it among the most nutritionally favourable fermented food in this study, albeit the least available. The 'health halo' surrounding fermented foods is open to exploitation and they are promoted for their bacteria-related benefits, despite limited evidence of such outcomes from human clinical trials. High quality studies of the impact of fermented foods on health are warranted, and investigation of the availability, cost, nutritional quality, ingredients and health claims should be repeated as the fermented foods market in the UK develops.

References

1. Marco ML, Sanders ME, Gänzle M, Arrieta MC, Cotter PD, De Vuyst L, Hill C, Holzapfel W, Lebeer S, Merenstein D, Reid G, Wolfe BE, Hutkins R. The International Scientific Association for Probiotics and Prebiotics (ISAPP) consensus statement on fermented foods. Nat Rev Gastroenterol Hepatol. 2021 Jan 4. doi: 10.1038/s41575-020-00390-5. Epub ahead of print.
2. Tamang JP, Cotter PD, Endo A, Han NS, Kort R, Liu SQ, Mayo B, Westerik N, Hutkins R. 2020. Fermented foods in a global age: East meets West. Comprehensive Reviews in Food Science and Food Safety, 19, 184-217.
3. Prado MR, Blandon LM, Vandenberghe LP, Rodrigues C, Castro GR, Thomaz-Soccol V, Soccol CR. 2015. Milk kefir: composition, microbial cultures, biological activities, and related products. Frontiers in Microbiology, 6, 1177.
4. Patra JK, Das G, Paramithiotis S, Shin HS. 2016. Kimchi and Other Widely Consumed Traditional Fermented Foods of Korea: A Review. Frontiers in Microbiology, 7, 1493.

5. Peñas E, Martinez-Villaluenga C, Frias J. 2017. Sauerkraut: Production, Composition, and Health Benefits. *In:* Frias J, Martinez-Villaluenga C, Peñas E. (eds.) *Fermented Foods in Health and Disease Prevention*. London: Academic Press.
6. Murooka Y, Yamshita M. 2008. Traditional healthful fermented products of Japan. Journal of Industrial Microbiology and Biotechnology, 35, 791-798.
7. Nout MJ, Kiers JL. 2005. Tempe fermentation, innovation and functionality: update into the third millenium. Journal of Applied Microbiology, 98, 789-805.
8. Jayabalan R, Malbaša RV, Lončar ES, Vitas JS, Sathishkumar M. 2014. A Review on Kombucha Tea-Microbiology, Composition, Fermentation, Beneficial Effects, Toxicity, and Tea Fungus. Comprehensive Reviews in Food Science and Food Safety, 13, 538-550.
9. Rezac S, Kok CR, Heermann M, Hutkins R. 2018. Fermented Foods as a Dietary Source of Live Organisms. Frontiers in Microbiology, 9, 1785.
10. Marco ML, Heeney D, Binda S, Cifelli CJ, Cotter PD, Foligne B, Ganzle M, Kort R, Pasin G, Pihlanto A, Smid EJ, Hutkins R. 2017. Health benefits of fermented foods: microbiota and beyond. Current Opinion in Biotechnology, 44, 94-102.
11. Dimidi E, Cox SR, Rossi M, Whelan K. 2019. Fermented Foods: Definitions and Characteristics, Impact on the Gut Microbiota and Effects on Gastrointestinal Health and Disease. Nutrients. 11: 1806.
12. Aloulou A, Hamden K, Elloumi D, Bou Ali M, Hargafi K, Jaouadi B, Ayadi F, Elfeki A, Ammar E. 2012. Hypoglycemic and antilipidemic properties of kombucha tea in alloxan-induced diabetic rats. BMC Complementary and Alternative Medicine, 12. 63.
13. Kapp JM, Sumner W. 2019. Kombucha: a systematic review of the empirical evidence of human health benefit. Annals of Epidemiology, 30, 66-70.
14. Food Ingredients 1st. 2020. "Not just a gut reaction": Kefir sales rocket at UK Tesco [Online]. Available: https://www.foodingredientsfirst.com/news/not-just-a-gut-reaction-kefir-sales-rocket-at-uk-tesco.html [Accessed 09/02/2021].
15. Research And Markets. 2019. Global fermented food and ingredients market: focus on food type, ingredient type and distribution channel - analysis and forecast (2018-2023) [Online]. Available: https://www.researchandmarkets.com/reports/4763864/global-fermented-food-and-ingredients-market#pos-0 [Accessed 09/02/2021].
16. Moore JB, Horti A, Fielding BA. 2018. Evaluation of the nutrient content of yogurts: a comprehensive survey of yogurt products in the major UK supermarkets. British Medical Journal Open, 8, e021387.
17. Kantar World Panel. 2020. *Grocery Market Share (12 weeks ending)*. Available: https://www.kantarworldpanel.com/en/grocery-market-share/great-britain [Accessed 09/02/2021].

18. European Commission. 2016. EU Register on nutrition and health claims [Online]. Available: https://ec.europa.eu/food/safety/labelling_nutrition/claims/nutrition_claims_en [Accessed 09/02/2021].
19. United Kingdom Government. Population of England and Wales, Census 2011. https://www.ethnicity-facts-figures.service.gov.uk/uk-population-by-ethnicity/national-and-regional-populations/population-of-england-and-wales/latest. [Accessed 09/02/2021]
20. Beer E. 2016. *UK shoppers pay 89% more for organic food: survey* [Online]. Foodnavigator.com. Available: https://www.foodnavigator.com/Article/2016/01/28/UK-shoppers-pay-89-more-for-organic-food-survey#:~:text=UK%20consumers%20are%20paying%20an,think%20they%20pay%20too%20much [Accessed 09/02/2021].
21. Kim SA, Hong WS. The effect of food choice motive on consumption attitude, satisfaction, and purchase intention for traditional fermented foods in the twenties (Mediating Effect of Attitude and Satisfaction). *J Korean Soc Food Sci Nutr*. 2019; 48(4): 482–493.
22. Chilton SN, Burton JP, Reid G. 2015. Inclusion of fermented foods in food guides around the world. Nutrients, 7, 390-404.
23. Murata K, Ikehata H, Miyamoto T. 1967. Studies on the Nutritional Value of Tempeh. *Journal of Food Science,* 32**,** 580-586.
24. Scientific Advisory Committee On Nutrition (SACN). 2019. Saturated fats and health [Online]. Available: https://www.gov.uk/government/publications/saturated-fats-and-health-sacn-report [Accessed 09/02/2021].
25. St-Onge MP, Farnworth ER, Savard T, Chabot D, Mafu A, Jones PJH. 2002. Kefir consumption does not alter plasma lipid levels or cholesterol fractional synthesis rates relative to milk in hyperlipidemic men: a randomized controlled trial. BMC Complementary and Alternative Medicine, 2, 1.
26. Gill SK, Rossi M, Bajka B, Whelan K. Dietary fibre in gastrointestinal health and disease. Nat Rev Gastroenterol Hepatol. 2021; 18: 101-116.
27. Public Health England, F.S.A. 2018. National Diet and Nutrition Survey Results from Years 7 and 8 (combined) of the Rolling Programme (2014/2015 to 2015/2016) [Online]. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/699241/NDNS_results_years_7_and_8.pdf [Accessed 09/02/2021].
28. Public Health England. 2019. *Fermented (yogurt) drinks. A supplementary report to the sugar reduction guidelines, outlining the drinks included and separate guidelines.* [Online]. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/773818/Fermented_yogurt_drinks_supplementary_report_to_sugar_reduction_guidelines.pdf [Accessed 09/02/2021].

29. European Food Safety Authority. 2015. Scientific Opinion on the safety of the proposed extension of erythritol (E968) as a food additive. Available: https://efsa.onlinelibrary.wiley.com/doi/epdf/10.2903/j.efsa.2015.4033 [Accessed 09/02/2021].
30. Anton SD, Martin CK, Han H, Coulon S, Cefalu WT, Geiselman P, Williamson DA. 2010. Effects of stevia, aspartame, and sucrose on food intake, satiety, and postprandial glucose and insulin levels. *Appetite,* 55**,** 37-43.
31. Gibney MJ, Forde CG, Mullally D, Gibney ER. 2017. Ultra-processed foods in human health: a critical appraisal. American Journal of Clinical Nutrition, 106, 717-724.
32. Van Gunst A, Roodenburg AJC. 2019. Consumer Distrust about E-numbers: A Qualitative Study among Food Experts. Foods, 8, 178.
33. Scientific Advisory Committee On Nutrition (SACN). 2003. Salt and Health. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/338782/SACN_Salt_and_Health_report.pdf [Accessed 09/02/2021].
34. Yoshinaga M, Toda N, Tamura Y, Terakado S, Ueno M, Otsuka K, Numabe A, Kawabata Y, Uehara Y. 2012. Japanese traditional miso soup attenuates salt-induced hypertension and its organ damage in Dahl salt-sensitive rats. Nutrition, 28, 924-931.
35. André Q, Chandon P, Haws K. 2019. Healthy Through Presence or Absence, Nature or Science?: A Framework for Understanding Front-of-Package Food Claims. Journal of Public Policy & Marketing, 38, 172-191.
36. Committee Of Advertising Practice (CAP). 2019. *Food: Probiotic claims, advice online* [Online]. Available: https://www.asa.org.uk/advice-online/food-probiotic-claims.html [Accessed 09/02/2021].
37. Streiner DL. 2015. Best (but oft-forgotten) practices: the multiple problems of multiplicity-whether and how to correct for many statistical tests. *American Journal of Clinical Nutrition,* 102**,** 721-728.

Table 1. Availability and cost of fermented foods in the United Kingdom

	Kefir drink	**Kefir yogurt**	**Kimchi**	**Kombucha**	**Miso**	**Sauerkraut**	**Tempeh**	**P value[1]**
Availability								
Number of products in UK, n (% of total 143)	32 (22.4)	21 (14.7)	8 (5.6)	41 (28.7)	14 (9.8)	22 (15.4)	5 (3.5)	-
Number of products per retailer (8 retailers), median (IQR)	7.0 (9) [g]	5.0 (8.5)	1.0 (0.75)	5.5 (11.5)	2.0 (3.5)	2.5 (2.0)	1.0 (2.5) [a]	0.016
Number of retailers stocking at least one product, n (%)	7/8 (87.5)	7/8 (87.5)	8/8 (100)	6/8 (75)	7/8 (87.5)	8/8 (100)	6/8 (62.5)	0.321
Cost, median (IQR)	**(n=32)**	**(n=21)**	**(n=8)**	**(n=41)**	**(n=14)**	**(n=22)**	**(n=5)**	
Cost per 100 g or per 100 mL (£)	0.54 (0.31) [ceg]	0.83 (0.57) [ce]	1.30 (1.03) [abdf]	0.73 (0.19) [ce]	1.56 (0.55) [abdf]	0.83 (0.82) [ce]	1.50 (0.14) [a]	<0.001
Price per serving (£)	1.27 (0.70) [def]	0.77 (0.72) [d]	0.91 (0.72) [e]	1.99 (0.14) [abef]	0.20 (0.03) [acd]	0.66 (0.66) [ad]	0.99 (0.08)	<0.001

[1]*P*-value for continuous data (median, IQR) represents the comparison between categories following a Kruskal-Wallis test, and for categorical data (n, %) represents the comparison between categories following a Fishers exact test.

Superscript letters indicate a significant difference ($P<0.05$) following paired comparisons with Bonferroni *post hoc* correction compared with: (a) kefir drink; (b) kefir yogurt; (c) kimchi; (d) kombucha; (e) miso; (f) sauerkraut; (g) tempeh

Table 2. Nutritional composition of fermented foods per 100 g / 100 mL and per serve available in the United Kingdom

Median (IQR)	Kefir drink (n=32)	Kefir yogurt (n=21)	Kimchi (n=8)	Kombucha (n=41)	Miso (n=14)	Sauerkraut (n=22)	Tempeh (n=5)	P value[1]
Per 100g								
Energy (kJ)	245.0 (66.5) [def]	366.0 (87.0) [cdf]	109.0 (42.5) [beg]	62.0 (37.0) [abeg]	783.5 (159.0) [acdf]	82.0 (36.0) [abeg]	768.0 (141.0) [cdf]	<0.001
Energy (kcal)	58.5 (16.0) [def]	87.0 (21.0) [cdf]	26.0 (10.0) [beg]	14.0 (8.0) [abeg]	187.0 (38.0) [acdf]	20.0 (9.0) [abeg]	184.0 (34.0) [cdf]	<0.001
Fat (g)	2.6 (1.5) [df]	1.9 (2.5) [df]	0.5 (0.3) [eg]	0.0 (0.1) [abeg]	5.5 (3.4) [cdf]	0.2 (0.2) [abeg]	9.7 (2.9) [cdf]	<0.001
Saturated fat (g)	1.7 (0.9) [cdf]	1.3 (1.7) [df]	0.1 (0.1) [a]	0.0 (0.1) [abeg]	0.9 (0.5) [df]	0.0 (0.1) [abeg]	1.9 (1.8) [df]	<0.001
Carbohydrates (g)	5.0 (2.7) [def]	7.6 (2.8) [cdf]	3.3 (3.4) [be]	3.3 (2.3) [abe]	18.0 (5.6) [acdf]	2.4 (2.2) [abe]	3.5 (8.5)	<0.001
Sugars (g)	4.8 (2.5) [cdef]	6.2 (2.5) [cdfg]	1.1 (1.5) [abe]	3.2 (2.4) [abe]	11.8 (4.9) [acdfg]	1.2 (2.9) [abe]	0.5 (0.4) [be]	<0.001
Fibre (g)	0.1 (0.1) [g] (n=2)	0.5 (0.0) (n=1)	1.8 (1.2) (n=5)	0.1 (0.3) [efg] (n=24)	4.1 (1.1)[d] (n=11)	2.5 (0.4) [d] (n=10)	6.1 (0.9) [ad] (n=5)	<0.001
Protein (g)	3.0 (0.5) [bde]	10.2 (6.4) [acdf]	1.3 (0.5) [beg]	0.0 (0.2) [abefg]	10.3 (3.1) [acdf]	1.0 (0.4) [bdeg]	19.0 (4.5) [cdf]	<0.001
Salt (g)	0.1 (0.1) [cdef]	0.1 (0.1) [de]	1.7 (1.2) [ad]	0.0 (0.0) [abcef]	11.5 (1.0) [abdg]	1.7 (1.2) [ad]	0.0 (1.1) [e]	<0.001
Calcium (mg)	112.5 (12.0) (n=20)	164.0 (74.9) (n=19)	-	-	-	-	-	0.056
Phosphorus (mg)	81.2 (15.2) [b] (n=13)	131.9 (10.9) [a] (n=12)	-	-	-	-	-	0.002
Vitamin B2 (ug)	145.6 (47.0) [b] (n=20)	185.6 (19.9) [a] (n=12)	-	-	-	-	-	0.005
Vitamin B12 (ug)	0.3 (0.3) (n=20)	0.5 (0.4) (n=12)	-	-	-	-	-	0.226
Per serving								
Energy (kJ)	590.4 (203.5) [cdef]	500.0 (147.0) [cdef]	76.3 (29.8) [abg]	165.0 (83.5) [abfg]	100.9 (34.9) [abg]	65.6 (28.4) [abdg]	583.0 (82.2) [cdef]	<0.001
Energy (kcal)	140.3 (49.3) [cdef]	119.0 (34.0) [cdef]	18.2 (7.2) [abg]	38.5 (19.0) [abfg]	24.0 (8.3) [abg]	16.0 (7.2) [abdg]	139.0 (18.8) [cdef]	<0.001
Fat (g)	5.4 (3.7) [cdf]	2.9 (2.7) [df]	0.3 (0.2) [a]	0.0 (0.1) [abeg]	0.7 (0.5) [d]	0.2 (0.1) [abg]	6.9 (1.6) [df]	<0.001
Saturates (g)	3.6 (2.6) [cdef]	1.3 (1.8) [df]	0.1 (0.1) [a]	0.0 (0.1) [abg]	0.1 (0.1) [a]	0.0 (0.0) [abg]	1.4 (0.9) [df]	<0.001

Carbohydrates (g)	11.9 (7.2) [cef]	12.1 (8.5) [cef]	2.3 (2.4) [ab]	9.6 (5.2) [ef]	2.5 (0.7) [abd]	1.9 (1.8) [abd]	2.1 (6.1)	<0.001
Sugars (g)	10.3 (7.1) [cefg]	9.9 (6.1) [cefg]	0.7 (0.9) [ab]	8.3 (5.7) [f]	1.8 (0.9) [ab]	1.0 (2.3) [abd]	0.4 (0.2) [ab]	<0.001
Fibre (g)	0.2 (0.3) (n=2)	0.8 (0.0) (n=1)	1.3 (0.7) [d] (n=5)	0.1 (0.3) [cfg] (n=24)	0.6 (0.4) [g] (n=11)	2.0 (0.3) [d] (n=10)	4.1 (0.6) [de] (n=5)	<0.001
Protein (g)	7.3 (1.7) [df]	7.2 (10.1) [cdf]	0.9 (0.3) [bg]	0.0 (0.3) [abefg]	1.4 (0.5) [d]	0.8 (0.3) [abdg]	13.0 (1.0) [cdf]	<0.001
Salt (g)	0.1 (0.2) [def]	0.2 (0.2) [def]	1.2 (0.9) [d]	0.0 (0.0) [abcef]	1.6 (0.4) [abd]	1.4 (0.9) [abd]	0.0 (0.8)	<0.001
Calcium (mg)	279.0 (50.0) [b] (n=20)	197.0 (92.4) [a] (n=19)	-	-	-	-	-	0.001
Phosphorus (mg)	200.0 (10.0) (n=13)	204.5 (37.0) (n=12)	-	-	-	-	-	1.000
Vitamin B2 (ug)	343.5 (81.0) [b] (n=20)	297.0 (36.5) [a] (n=12)	-	-	-	-	-	0.029
Vitamin B12 (ug)	0.6 (0.2) (n=20)	0.7 (0.7) (n=12)	-	-	-	-	-	0.347

Median (IQR) values are for the number (n) of products shown in the column header, unless otherwise indicated

[1]*P*-value represents the difference between categories following a Kruskal-Wallis test

Superscript letters indicate significant differences ($P<0.05$) following paired comparisons with Bonferroni *post hoc* correction compared with: (a) kefir drink; (b) kefir yogurt; (c) kimchi; (d) kombucha; (e) miso; (f) sauerkraut; (g) tempeh.

Table 3. Fermented foods in the United Kingdom carrying regulated nutrition claims, n (% of column total)

Nutrition claim	**Kefir drink (n=22)**	**Kefir yogurt (n=21)**	**Kimchi (n=0)**	**Kombucha (n=14)**	**Miso (n=5)**	**Sauerkraut (n=5)**	**Tempeh (n=5)**
Any nutrition claim	22/32 (68.8%)	21/21 (100%)	0/8 (0%)	14/41 (34.1%)	5/14 (35.7%)	5/22 (22.7%)	5/5 (100%)
Energy	2 (9.1%)	0 (0)	0 (0)	6 (42.9%)	0 (0)	4 (80.0%)	0 (0)
Fat or saturated fat	1 (4.5%)	7 (33.3%)	0 (0)	0 (0)	3 (60.0%)	0 (0)	1 (20.0%)
Sugar	3 (13.6%)	5 (23.8%)	0 (0)	8 (57.1%)	0 (0)	0 (0)	0 (0)
Protein	18 (81.8%)	21 (100%)	0 (0)	0 (0)	3 (60.0%)	0 (0)	5 (100%)
Fibre	0 (0)	0 (0)	0 (0)	0 (0)	1 (20.0%)	5 (100%)	4 (80.0%)
Calcium	16 (72.7%)	14 (66.7%)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Phosphorus	0 (0)	4 (19.0%)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Vitamin B_2	18 (81.8%)	6 (28.6%)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Vitamin B_{12}	18 (81.8%)	6 (28.6%)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

Figure titles and legends

Figure 1. Number of fermented food products per retailer

Data are presented as the number of fermented foods available at eight retailers and are presented as boxplots for each fermented food category. The bar represents the median value, the lower and upper boxes represent Q1 and Q3 values, and the lower and upper lines represent minimum and maximum values. The number of products available at eight retailers was significantly different between fermented food categories following a Kruskal Wallis test (P=0.016), with kefir drink and tempeh being significantly different following a pairwise comparison with Bonferroni correction for multiple testing (P=0.024).

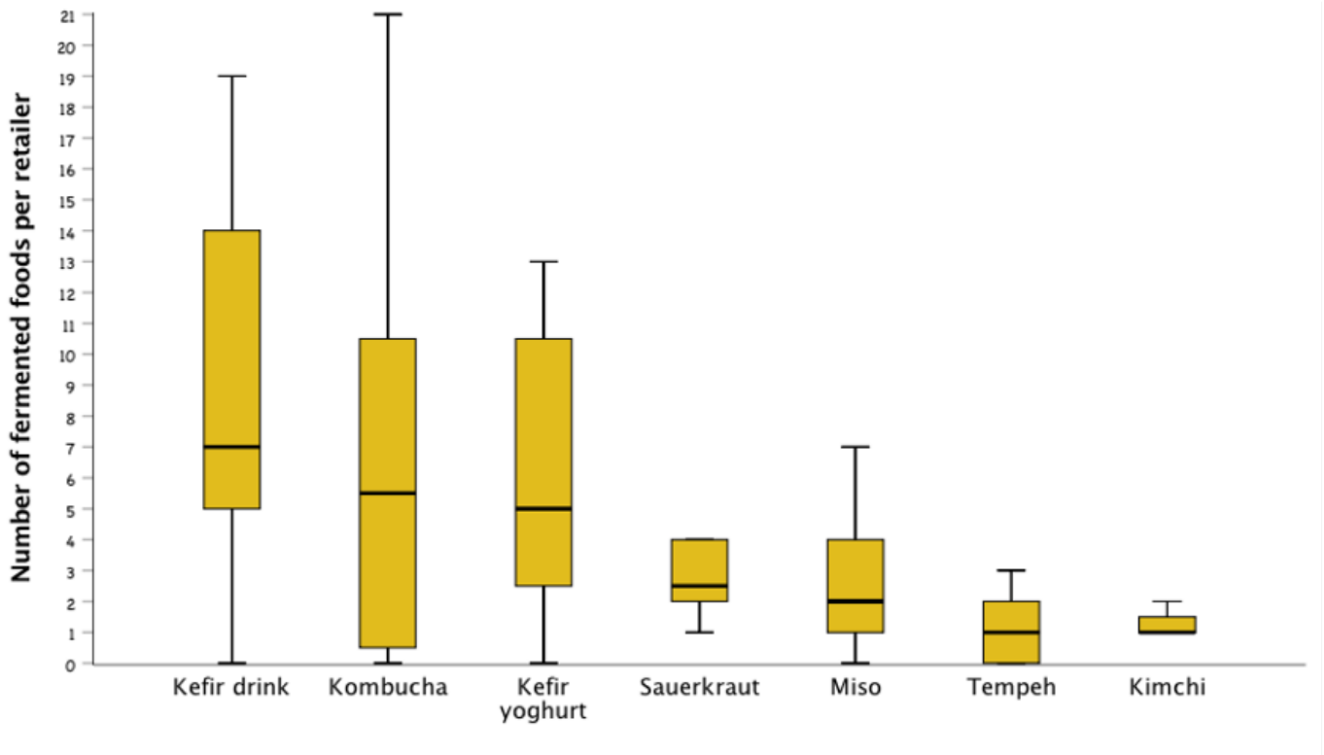

Figure 2. Fermented foods displaying information relating to bacterial content, strains and bacteria-related health outcomes, n (% of all 143 fermented foods)