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Nutritional scores of milk and plant-based alternatives and their difference in contribution to human nutrition

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A R T I C L E I N F O

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A B S T R A C T

Milk consumption is in decline in developed countries due to changes in lifestyle and habits. Such a reduction is partly due to the expanding plant-based industry which provides attractive alternatives. In this study, the nutritional composition of soya, oat, almond, coconut, and rice-based beverages was compared to that of cow and goat milk by means of 4 commercial nutritional scores (NS). Contribution to the recommended daily intake (RDI) of macro- and micro-nutrients was calculated for comparison. Apart from soya, plant-based beverages (PBB) did not approximate the nutrient profile of cow and goat milk, e.g., they did not provide iodine and contained only limited amounts of calcium, potassium, and magnesium. For several traits important for human health, oat, almond, coconut, and rice-based beverages scarcely contributed to the RDI. Depending on the criteria considered for the score calculation, however, certain PBB achieved better NS than milk. Findings show the difficulty in ensuring coverage of RDI through a non-guided inclusion of PBB as a substitute for milk. Moreover, the inferior contribution of PBB to RDI compared to milk and the high variability in the nutritional scores between the different PBB brands prompts for a standardisation across the plant-based food industry to increase transparency.

1. Introduction

Although the consumption of milk and dairy products is recommended in numerous national dietary guidelines due to their high levels of bioavailable and essential nutrients, their inclusion in the daily diet is declining in Europe and the US. In 2011 the per capita fresh milk consumption was 56.3 kg/yr in Europe but has been estimated to decrease by up to 394 mL/yr by 2031 (EC, 2021). Similarly, in 2013 milk intake in the US had been declining by 820 mL/yr per capita since 1975 (Hayden, Dong, & Carlson, 2013). Milk is the top global dietary source of Ca, vitamin B2, lysine, and fat, providing 49, 24, 18, and 15% of the global nutrient availability, respectively (Smith, Fletcher, Hill, & McNabb, 2022). Moreover, milk has a low energy contribution at just 7% of food energy availability, making it a valuable contributor to global nutrition without concomitantly causing an excessive energy intake (Smith, Dave, & Hill, 2022). Of course, this is not the case for some processed dairy products like cheeses, cream, butter and other dairy-based preparations whose fat content – particularly saturated fatty acids (SFA) – should be taken into account in some circumstances (e.g., special diets) and consumption regulated accordingly (Waldron et al., 2020). As an example, Fox, Uniacke-Lowe, McSweeney, and O'Mahony (2015) reported an average fat content for butter, cheddar, creamed cottage cheese, mozzarella, and parmesan-like cheese of 81.1, 33.1, 4.5, 31.2, and 24.8%, respectively (Fox et al., 2015). As indicated by Fox et al. (2015), the total fat in whole milk ranges between 3 and 5% (w/v), intermediate between butter (81–82%, w/v) and skim milk (0.0–0.1%, w/v) (Fox et al., 2015).

The reduction in fresh milk consumption has partly been replaced by processed derivatives and plant-based beverages (PBB), and has mainly been driven by issues regarding lactose intolerance and milk protein allergies (Aydar, Tutuncu, & Ozcelik, 2023; Mäkinen, Wanhalinna, Zannini, & Arendt, 2016), as well as a growing tendency for certain demographic groups of affluent countries to follow vegan or flexitarian

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Abbreviations

DIAAS	Digestible Indispensable Amino Acid Score
DM	Dry Matter
FA	Fatty Acid
FoPL:	Front of Pack Labelling
HSR	Health-Star Rating
MTL:	Multiple Traffic Light
PBB	Plant-Based Beverages
RDI	Recommended Daily Intake
SFA	Saturated Fatty Acid
TS	Total Score

diets in the belief of improved health and lowered environmental impact (McCarthy, Parker, Ameerally, Drake, & Drake, 2017). However, the nutritional content of PBB vary markedly depending on their plant origin, fortification, and industrial processing, and therefore, the commercial brand, thereby affecting their health profile. In addition, the largely variable composition of PBB available on the market impairs fair nutrient calculation as well as a proper inclusion in the diet to cover dietary requirements. The most popular PBB are of almond, soya, cashew, and coconut or a mix hereof (Vanga & Raghavan, 2018).

Despite marketing strategies aiming to portray such popular products as green (Aydar et al., 2023) and healthy alternatives, PBB have been shown to have a largely variable composition among manufacturers and lower nutrient density than animal milk, often demonstrating poor protein and mineral concentrations but high carbohydrate and sugar contents (Drewnowski, Henry, & Dwyer, 2021; Scholz-Ahrens, Ahrens, & Barth, 2020; Walther et al., 2022). Pérez-Rodríguez, Serrano-Carretero, García-Herrera, Cámara-Hurtado, and Sánchez-Mata (2023) concluded that PBB have their own nutritional profile and functional properties, and they can thus not be considered milk analogues. An example is given by one essential mineral, iodine (I). The mean I content, which is a rate-limiting element for the synthesis of thyroid hormones central in growth and neurological development, especially in children, has been shown to be very low in PBB (Sorrenti et al., 2021). Animal products are the main source of this mineral in developed countries together with salt (Niero et al., 2023). The same applies to nutrients like vitamins (group B in particular), amino acids, Ca, and P which are naturally present in milk harvested from the most common dairy species: cow, goat, sheep, and buffalo. For this reason, commercial PBB must be fortified.

In the quest to efficiently and effectively promote healthier diets, the World Health Organisation has promoted the use of Front of Pack Labelling (FoPL) nutrient systems (World Health Organisation, 2017). Although not complete sources of dietary advice, these labelling systems are recognised as useful and transparent tools aimed at informing consumers about the quality of products and improve nutritional literacy (Volkova & Mhurchu, 2015). FoPL nutrient systems can either be interpretive or informative depending on the information communicated to consumers. Interpretive systems create a profile of the nutritional quality of individual products and display the final result in a simplified visual form. On the contrary, informative labelling systems provide the consumer with a more detailed and descriptive visualisation of the content of pre-selected dietary components. These pre-selected dietary components frequently consist of sugar, fat, SFA, and salt as their excess consumption has been associated with increased risk of chronic diseases such as type 2 diabetes and cardiovascular disease (Martini et al., 2022).

Therefore, the purpose of the current study was to evaluate the nutrient profile of different PBB and how they compare to animal milk. For this reason, several brands of rice, oat, soya, coconut, and almond-based beverages, as well as goat and cow milk were purchased and their nutrient profiles analysed. For this, gross composition was analytically measured and the detailed fatty acid and amino acid composition as well as mineral content quantified. Information on energy, carbohydrate, total sugar, fibre, and fruit and vegetable content was retrieved from the packaging. As a first, the current study applied four different FoPL systems to each brand of said beverages, namely Nutri-Score, NutrInform battery, Multiple Traffic Light (MTL), and Health Star Rating (HSR), and directly compared the beverages by combing their scores for each FoPL into a Total Score (TS). The contribution of each beverage type to the recommended daily intake (RDI) was also explored for different demographic groups of consumers.

2. Materials and methods

2.1. Samples

A total of 60 PBB, 8 UHT whole cow milk, and 8 UHT whole goat milk cartons were purchased from supermarkets around Vicenza province (Northern Italy). The 60 PBB consisted of different commercial brands, of which 12 samples were available each for rice, oat, soya, almond, and coconut. The animal milk products also originated from different manufacturing plants. None of the products contained mineral or vitamin fortification, but some PBB did contain added sugar which is commonly added for improved palatability. The samples were subsequently analysed between February and March 2022. More details are provided in Sterup Moore et al. (2023).

2.2. Analysis of composition

Samples were analysed for dry mass (DM) (g/100g), ash (g/100g), gross composition (g/100g), fatty acid profile (g/100g), and mineral content (mg/kg beverage or μg/kg beverage) in certified laboratories according to the procedures described below.

2.2.1. Gross composition

Samples were initially freeze-dried so that the mass of the sample thereafter represented only the DM percentage. Crude protein was determined according to Kjeldhal method following AOAC 17th ED. 2000; method 991.20 (AOAC, 2000), while crude lipid content was measured by hydrolysing samples with 4M HCL and adding petroleum ether:diethyl ether (50:50 v/v). The resulting ether extract was extracted and quantified. Fructose and glucose were extracted using 0.1N sulfuric acid solution, while lactose was extracted using Carrez I ($K_4[Fe(CN)_6]x\ 3H_2O$) and Carrez II ($ZnSO_4x7H_2O$) salts. The three sugars were subsequently quantified using high-performance liquid chromatography (HPLC; Jasco Corporation, Tokyo, Japan).

2.2.2. Fatty acids

Briefly, hexane:isopropanol (3:2 v/v) was added to each sample at 110 °C for three extraction cycles, and thereafter dried, firstly under nitrogen flow and subsequently heat dried at 60 °C. The fatty acids were determined by esterification followed by a hexane phase shift as described by Sterup Moore et al. (2023). Through the gas chromatograph GC Agilent 7820 (Agilent Technologies) fatty acids were identified by comparing their retention times to those of a standard (Supelco FAME mixC4-C24 #18919-1AMP; Sigma-Aldrich). Peak areas were calculated using the dedicated software (Agilent Technologies) and expressed as a percentage of total fatty acids. The following SFA were identified according to their saturation and chain length: C4:0, C5:0, C6:0, C7:0, C8:0, C9:0, C10:0, C12:0, C13:0, C14:0, C15:0 iso & anti, C15:0, C16:0, C17:0, C18:0, C20:0, C22:0, C24:0.

2.2.3. Minerals

I, Ca, P, Mg, K, Na, and S were quantified analytically. Briefly, samples were mineralised to release inorganic minerals via microwave acid-digestion. They were thereafter dissolved in demineralised water and quantified using inductively coupled plasma optical emission spectroscopy (ICP-OES) SPECTRO ARCOS (SPECTRO Analytical Instruments GmbH, Kleve, Germany). The method for the determination of minerals followed the method described in Poitevin E. (2016) (Poitevin, 2016). Accuracy and precision were evaluated by a blank solution, a low level control solution (recovery limits ± 30%), and a medium level control solution (recovery limits ± 10%). The measured values were in excellent agreement for all minerals. For the case of I, the mineralised sample was diluted in ammonia solution (0.6% v/v) and quantified via inductively coupled plasma mass spectrometry (ICP-MS; 20).

2.3. Scores definition

The R software (v. 4.2.2, R Core Team, 2022) was used for data visualisation, elaboration, and handling. To compare the analysed samples, four FoPL nutritional scores were calculated for each brand of PBB and animal milk, of which:

i) two were informative scores, namely MTL and NutrInform Battery (Italian Ministry of Health, 2022; The Department of Health and The Food Standard Agency, 2016),
ii) two were interpretive scores, namely Nutri-Score and HSR (Australian Government, 2023; Chauliac, 2018).

Briefly, MTL rates the amounts (g/100 mL) of the major unhealthy items, namely sugars, fat, SFA, and salt and gives each category a green (best), amber, or red (worst) score. Moreover, it also depicts the amount of energy provided by 100 mL of product. The thresholds for each item are:

- Fat: green ≤1.5g/100 mL; amber >1.5g to ≤8.75g/100 mL; red >8.75g/100 mL;
- SFA: green ≤0.75g/100 mL; amber >0.75g to ≤2.5g/100 mL; red >2.5g/100 mL;
- Sugars: green ≤2.5g/100 mL; amber >2.5g to ≤11.25g/100 mL; red >11.25g/100 mL;
- Salt: green ≤0.3g/100 mL; amber >0.3g to ≤0.75g/100 mL; red >0.75g/100 mL.

Similarly, the NutrInform Battery considers the amounts (g/100 mL) of sugars, fat, SFA and salt provided. Unlike the MTL, however, this score relies on the portion size, which - for the sake of the current study - was conventionally set at 250 mL, corresponding to one glass. The rating is displayed in the form of percentage of the RDI for an adult male obtained from one portion.

The Nutri-Score puts emphasis on both unhealthy and healthy food components, thus it considers energy (kJ/100 mL), sugars (g/100 mL), SFA (g/100 mL), and salt (g/100 mL) as negative traits, but protein (g/100 mL), fibre (g/100 mL), and the percentage of vegetables, fruits, and nuts as positive traits. The level of each of these traits is considered to achieve a score between −15 (most healthy) and +40 (least healthy). This score is then reduced to a final overall score of 5 classes (A, B, C, D and E), with A reflecting the highest nutritional quality. For this study, an online open access service (https://nutrirechner.xyz/en/) was used for the calculation of the Nutri-Score for each product following the original score guidelines where the sub-category “solid-foods”, i.e. not “beverage”, must be used for PBB and milk. Specifications are available online at: https://www.santepubliquefrance.fr/content/download/150263/file/2021_07_21_QR_scientifique_et_technique_V41_EN.pdf.

Finally, the HSR considers various nutrients depending on the food category and yields a final score expressed in number of stars, with 5 stars representing the maximum/best. Points are given (+) for healthy nutrients while points are deducted (−) for unhealthy nutrients. According to the HSR criteria (Craig, Brothers, & Mangels, 2021), for all products except non-dairy beverages, the healthy nutrients considered include: fibre (g/100 mL), protein (g/100 mL), concentrated fruit and vegetable (%), and non-concentrated fruit, vegetable, nuts, and legumes (%). The unhealthy items, instead, are: SFA (g/100 mL), sugars (g/100 mL), Na (g/100 mL), and the amount of energy (kJ/100 mL). For non-dairy beverages, only the percentage of non-concentrated fruit, vegetable, nuts, and legumes is considered within the healthy traits, and sugars and amount of energy within the unhealthy traits.

To compute the score for each brand of PBB and animal milk, a publicly available HSR calculator was used: http://www.healthstarrating.gov.au/internet/healthstarrating/publishing.nsf/Content/excel-calculator. Following the guidelines of usage (Australian Department of Health, 2023), cow and goat milk were considered as category “1D”, whereas rice, oat, almond, and coconut-based beverages as non-dairy beverages, and soya as category “2D”.

Thus, both the lab-determined content of fat, SFA, protein and Na was used for the score calculation and the salt (NaCl) content was calculated starting from the measured Na as follows (Okuda et al., 2014), considering the atomic weight of both Na (23.0) and Cl (35.5): Salt (g/100 mL) = Na (g) × 2.54 × 100 mL. As regards energy, total sugar content, fibre, percentage of nuts, fruits, vegetables, and legumes, and fruit and vegetables concentrates, the values were retrieved from the declared ingredient list on the packaging.

To allow easy comparison between beverage type and brand, a TS was developed using the four individual scores investigated. The TS was calculated so that each score had an equal weight of 5; the maximum score achievable for a beverage was consequently 20. For each deduction in one of the individual scores, the TS was reduced as described in Table 1.

3. Results and discussion

3.1. Nutritional profiles

Mean, standard deviation, and median of traits for each PBB and milk are presented in Table 2. As indicated by Sterup Moore et al. (2023), most of the investigated features were not normally distributed, so the medians comparison is provided and discussed. Regardless of the animal species, milk was characterised by the highest energy content, with 275 and 259 kJ/100 mL for cow and goat milk, respectively. These were immediately followed by rice (253 kJ; Table 2), whose protein (0.12 g/100g) and lipid (0.39 g/100g) contents were not concomitant with the high energy content. Instead, the high energy content derived from an elevated carbohydrate content of 12.6 g/100 mL, of which two thirds, 8.25 g/100 mL, was sugar. These values coincide with energy, protein, fat, and carbohydrate contents reported by Walther et al. (2022), who also found rice to be the most protein-poor PBB. In the present study, rice also had the highest DM, which reflects the total nutrient content of

Table 1
The scoring scheme used to obtain the Total Score.

Score or condition	Point reduction
Multiple Traffic Light	
Green	0
Amber	0.5
Red	1
250 ≤ kJ < 300	0.5
kJ ≥ 300	1
Nutri-Score	
A	0
B	1
C	2
D	3
E	4
NutrInform Battery	
6 ≤ % < 10	0.5
% ≥ 10	1
Health Star Rating	
Half star reduction	0.5
Full star reduction	1

Table 2
Mean ± standard deviation and median of gross composition traits and mineral content for different plant-based beverages[a] and animal milk[b]. Superscript letters within trait refers to the medians comparison[c] (P).

Trait	Rice		Soya		Coconut		Oat		Almond		Cow		Goat		P
Energy[d], kJ/100 mL	258 ± 43	253	167 ± 19	165	156 ± 82	124	209 ± 34	196	216 ± 156	145	276 ± 8	275	256 ± 9	259	
Dry matter, g/100g	12.18 ± 1.45	12.31^{b}	8.07 ± 1.03	7.78^{b}	6.20 ± 3.39	4.14^{b}	10.51 ± 1.41	10.02^{b}	8.73 ± 5.61	6.60^{b}	12.18 ± 0.20	12.22^{a}	11.89 ± 0.61	11.84^{a}	<0.001
Ash, g/100g	0.09 ± 0.03	0.09^{b}	0.46 ± 0.09	0.45^{b}	0.19 ± 0.04	0.19^{b}	0.18 ± 0.0	0.18^{b}	0.15 ± 0.07	0.16^{b}	0.72 ± 0.02	0.72^{a}	0.79 ± 0.15	0.82^{a}	<0.001
Total protein, g/100g	0.12 ± 0.05	0.12^{b}	3.35 ± 0.48	3.47^{b}	0.23 ± 0.09	0.23^{b}	0.70 ± 0.26	0.69^{b}	0.99 ± 0.47	0.85^{b}	3.39 ± 0.10	3.42^{a}	3.02 ± 0.50	3.25^{a}	<0.001
Fat, g/100g	0.45 ± 0.24	0.39^{b}	1.30 ± 0.54	1.60^{b}	1.84 ± 0.79	1.73^{b}	0.76 ± 1.12	0.37^{b}	2.04	1.99^{b}	3.58 ± 0.14	3.55^{a}	3.71 ± 0.61	3.72^{a}	<0.01
Saturated fatty acids, g/100g	0.08 ± 0.03	0.07^{b}	0.26 ± 0.16	0.27^{b}	1.83 ± 0.60	1.51^{b}	0.12 ± 0.08	0.07^{b}	0.23 ± 0.13	0.19^{b}	2.53 ± 0.04	2.59^{a}	2.82 ± 0.22	2.69^{a}	<0.001
Carbohydrates[d], g/100 mL	12.7 ± 2.01	12.6	1.78 ± 1.14	1.55	3.18 ± 2.36	1.95	7.95 ± 1.28	8.00	7.80 ± 6.02	8.20	4.90 ± 0.08	4.90	4.35 ± 0.05	4.35	
Total sugar[d], g/100 mL	8.20 ± 2.46	8.25	1.20 ± 1.17	0.80	2.30 ± 3.02	0.95	4.70 ± 1.07	4.25	7.20 ± 5.46	7.90	4.90 ± 0.08	4.90	4.30 ± 0.10	4.35	
Lactose, g/100g	0.00 ± 0.00	0.00^{b}	0.00 ± 0.00	0.00^{b}	0.00 ± 0.00	0.00^{b}	0.00 ± 0.00	0.00^{b}	0.00 ± 0.00	0.00^{b}	4.70 ± 0.18	4.72^{a}	4.45 ± 0.42	4.31^{a}	<0.001
Glucose, g/100g	3.86 ± 2.16	3.12^{a}	0.50 ± 0.45	0.33^{a}	0.83 ± 0.98	0.37^{a}	1.42 ± 1.44	1.04^{a}	1.98 ± 2.20	0.97^{a}	0.09 ± 0.09	0.01^{b}	0.02 ± 0.02	0.00^{b}	<0.001
Fructose, g/100g	0.07 ± 0.05	0.06^{a}	0.69 ± 1.01	0.33^{a}	0.62 ± 0.72	0.26^{a}	0.12 ± 0.15	0.06^{a}	1.79 ± 1.96	1.02^{a}	0.04 ± 0.06	0.02^{b}	0.02 ± 0.01	0.02^{b}	<0.001
Salt, g/100 mg	0.06 ± 0.02	0.07	0.09 ± 0.04	0.08	0.10 ± 0.01	0.10	0.09 ± 0.03	0.10	0.07 ± 0.03	0.07	0.11 ± 0.00	0.11	0.23 ± 0.02	0.23	
Fibre[d], g/100 mL	0.12 ± 0.20	0.00	0.98 ± 1.10	0.65	0.32 ± 81.96	0.00	0.40 ± 0.40	0.46	0.41 ± 0.35	0.50	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00	
Minerals															
I, μg/kg	0 ± 0	0^{b}	0 ± 0	0^{b}	0 ± 0	0^{b}	0 ± 0	0^{b}	10 ± 23	0^{b}	249 ± 122	242^{a}	537 ± 394	377^{a}	<0.001
Ca, mg/kg	140 ± 60	125^{b}	258 ± 53	260^{b}	153 ± 45	133^{b}	151 ± 66	139^{b}	230 ± 90	214^{b}	1,049 ± 70	1,067^{a}	925 ± 280	882^{a}	<0.001
P, mg/kg	81 ± 23	84^{b}	499 ± 117	471^{b}	54 ± 19	58^{b}	155 ± 44	138^{b}	147 ± 68	131^{b}	926 ± 75	930^{a}	971 ± 270	1,000^{a}	<0.001
Mg, mg/kg	1,403 ± 2,434	0^{a}	188 ± 60	184^{a}	1,672 ± 3,183	15^{a}	3,452 ± 4,129	9^{a}	843 ± 2,712	65^{a}	87 ± 10	88^{a}	115 ± 24	117^{a}	ns
K, mg/kg	192 ± 120	0^{b}	1,364 ± 391	1,394^{b}	343 ± 167	337^{b}	324 ± 59	323^{b}	254 ± 123	218^{b}	1,396 ± 81	1,408^{a}	1,656 ± 121	1,636^{a}	<0.001
Na, mg/kg	250 ± 121	228^{b}	337 ± 155	325^{b}	376 ± 65	367^{b}	358 ± 127	381^{b}	258 ± 110	253^{b}	415 ± 38	405^{a}	888 ± 118	878^{a}	<0.001
S, mg/kg	1.6 ± 5.1	0^{b}	201 ± 47	212^{b}	0 ± 0	0^{b}	14 ± 17	5^{b}	4.6 ± 10.8	0^{b}	241 ± 30	241^{a}	224 ± 51	234^{a}	<0.001

[a] 12 samples from 6 brands.
[b] 8 samples from 4 brands.
[c] Adapted from Sterup Moore et al. (2023). When available, the *P*-value of the contrast plant-based beverages vs animal milk is reported.
[d] Values taken from package labelling.

foodstuff. However, this high DM in rice was most likely due to the elevated carbohydrate content; similarly, Pérez-Rodríguez et al. (2023) found rice to have on average very high energy (55.5 kcal/100 mL which corresponds to 232 kJ/100 mL), sugar, and carbohydrate contents but low protein (0.36 g/100 mL). Therefore, rice represents an energy-dense but nutrient-poor beverage.

Cow and goat milk on the other hand, had a concomitantly high protein (3.42 and 3.25 g/100g, respectively) and lipid (3.55 and 3.72 g/100g, respectively) content as well as DM (Table 2). The carbohydrate content was low, consisting almost exclusively of lactose (4.72 and 4.31 g/100g, respectively). In accordance with numerous studies (Craig et al., 2021; Smith, Dave, & Hill, 2022; Walther et al., 2022), soya-based beverages had high contents of protein at 3.47 g/100g, even surpassing that of milk. Although with a high DM (7.78 g/100g), soya-based beverages did not have a high carbohydrate content (Table 2). Moreover, soya also demonstrated the highest fibre content amongst all the beverages. Craig et al. (2021) demonstrated that pea-based beverages had just as high protein content as soya-based beverages, underlining the potential the legume family holds as an alternative source of protein for dairy milk.

Almond was the PBB with the highest lipid content (1.99 g/100g), but not SFA (0.19 g/100g). Instead, coconut had the highest SFA content, with median and mean of 1.51 and 1.83 g/100g, respectively. The same PBB also had the highest fat content (mean = 1.84 g/100g; median

= 1.73 g/100g). Median of both SFA and fat content was the lowest in oat-based beverages (Table 2), being highly similar to rice. These two traits, however, were quite variable across the oat brands (Table 2). Aydar et al. (2023) reviewed literature on PBB and reported average total SFA of 0 g/100g for both almond and rice beverage and 0.2, 0.42, and 2.08 g/100g for those made with soya, oat, and coconut. Regarding mineral content, both animal milk greatly surpassed all PBB, while soya milk approximated that of milk, but nonetheless only had higher levels of Mg (88–117 vs. 184 mg/kg; Table 2). The I was exclusively found in animal milk, with cow milk containing 242 mg/kg and goat milk 377 mg/kg. Besides being present in animal milk (242 and 234 mg/kg), S was also present in both soya (212 mg/kg) and oat-based beverages (5 mg/kg), although the latter in just trace amounts. In general, rice was the PBB with the overall poorest content of minerals, providing no I, Mg, K, nor S (Table 2).

Goat and particularly cow milk were both less variable in terms of composition compared to PBB (Table 2), except for glucose and fructose content whose mean and median were not far from zero in the case of animal milk. Glucose and fructose were, in fact, only found in trace amounts in a limited number of samples, probably due to minor contamination either at dairy plant or laboratory level in the case of fructose, and due to hydrolysis of lactose into its monosaccharides in the case of glucose. The scarcely variable composition of animal milk demonstrates the standardisation imposed on the dairy industry in terms of product processing, nutritional content, and quality, and which is still lacking in the PBB industry. Indeed, PBB cannot be considered as a unique family: according to the review of Fructuoso et al. (2021), the energy content can vary dramatically within and across PBB, with a minimum of 6 kcal/100 mL (~25 kJ/100 mL) and a maximum of 183 kcal/100 mL (~766 kJ/100 mL). Carbohydrate and protein contents can be zero or even achieve concentrations up to 22.29 and 12.43g/100 mL, respectively (Fructuoso et al., 2021). The same can be said for minerals, e.g. concentration of Ca can range from 0 to 1,252.94 mg/100 mL, likely due to presence or absence of fortification (Fructuoso et al., 2021). Ensuring that PBB are similar with regard to nutrition content, particularly within beverages of similar plant origin, and not inferior to milk is a matter of public health concern and should be considered by regulatory agencies for future programmes (Drewnowski et al., 2021; Fructuoso et al., 2021). Indeed, many consumers wrongly believe PBB to offer the same nutritional value as milk, simply without lactose and with lower contents of SFA (Castaneda & Howley, 2023; Khandpur, Martinez-Steele, & Sun, 2021; Vanga & Raghavan, 2018).

By using part of the data of this study, Sterup Moore et al. (2023) tested the difference in terms of composition traits (Table 2) between animal milk and PBB, among fruit- and crop-based PBB, between monocot- and dicot-based PBB, and between cereal-based and legume-based PBB. Except for Mg, all the minerals were significantly different when comparing cow or goat milk with the vegetal alternatives. The same can be said for most of the gross composition traits, namely total protein, lipids, and sugars (Table 2).

3.2. Nutritional requirements

The relative contribution to the RDI of the two essential fatty acids, α-linolenic acid (C18:3n3) and linolenic acid (C18:2n6), the minerals Na, K, Mg, I, and Ca, and the gross protein from one glass differed greatly among beverages (Fig. 1). Of the PBB, soya approximated milk with its nutritive contribution to the daily intake. Soya was a greater source of the omega-6 and omega-3 fatty acids α-linolenic acid and linolenic acid, and the mineral Mg than either of the two milk. Indeed, disregarding I, which was exclusively found in milk and in great amounts, soya provided a greater total amount of nutrients than milk. It is evident that rice was the poorest source of nutrients, providing no protein, I, nor Mg, and only trace amounts of α-linolenic acid and linolenic acid (Fig. 1).

As expected, a glass of milk contributed less to the RDI of adult males than females for the studied nutrients. Indeed, in comparison to women, men require 39% more protein, 17% more Mg, 45% more α-linolenic acid, and 42% more linolenic acid. Therefore, due to the extremely low content of protein and Mg, and the almost complete absence of α-linolenic acid in all PBB except for soya, findings suggest that PBB provide much less of the nutrients investigated in this study to the adult male consumer compared to milk (Fig. 1). A lower percentage of the RDI is covered by a glass of milk for pregnant and for lactating women than nonpregnant and non-lactating adult females, primarily due to their higher requirement of protein, I, and α-linolenic acid. Both pregnant and lactating women require on average 54% more protein and 33% more I than women in non-special conditions, and 27 and 18% more α-linolenic acid, respectively. Therefore, the complete absence of I makes PBB a poor choice for pregnant and lactating women, while their reduced protein content exacerbates the issue. An elderly female obtains a greater amount of her RDI of studied nutrients from a glass of any beverage than an adult, pregnant, or lactating female. Regardless of the demographic group, cow and particularly goat milk provided the greatest total amount of the studied nutrients (Fig. 1).

Linoleic acid has been associated with reduced cardiovascular risk, improved long-term glycaemic control, and insulin resistance (Marangoni et al., 2019) and higher consumption of this omega-6 fatty acid can therefore be believed to be beneficial. However, linoleic acid has been demonstrated to act as a precursor to the pro-inflammatory fatty acid (FA) Arachidonic acid, and elevated intakes are therefore commonly believed to promote inflammation (Innes & Calder, 2018). One glass of a soya-based beverage provided about 15% of the RDI of linoleic acid, therefore making it unlikely a consumer may obtain excessive amounts of this FA from consumption of soya-based beverages alone. α-linolenic acid, on the other hand, which was more abundant in the soya beverages than linolenic acid, has shown to possess neuroprotective properties. A glass of soya beverage provided roughly 25% of the RDI of α-linolenic acid.

3.3. Nutritional scores

The various PBB and animal milk scored differently between each other (Fig. 2). This is mainly due to the profound difference in terms of gross and fine composition (Aydar et al., 2023). Although contributing less to the RDI of different demographic groups (Fig. 1), and although in general being nutrient-poor (Table 2), PBB generally scored better FoPL nutritional scores than milk. Amongst the PBB soya-based beverages scored the highest across-board MTL scores with particularly brand I and V scoring only green. When considering the Nutri-Score, soya also scored an optimal A for all brands. Rice demonstrated the poorest HSR, with all brands scoring only half a star, except brand II which scored one full star, whereas soya scored 5 full stars for all brands. Both cow and goat milk scored overall poorer MTL scores and had higher NutriInform battery percentages, particularly for SFA, than the PBB. However, milk continuously scored HSR ratings ranging from 3.5 to 4 stars out of 5. Within animal milk, goat contained greater amounts of salt (3.4–4.1 % of RDI vs 1.8% of RDI; Fig. 2), greater than any other beverage, but also more SFA than cow milk (12.2–14.5% of RDI vs. 12.4–13.2% of RDI; Fig. 2). Sugar was generally high in all beverage types, the only exception being coconut. Almond had several brands of high sugar content, with a portion providing up to 13.7% of the RDI (brand I) (Fig. 2). Milk provided between 4.7 and 5.6% of the RDI for sugar. However, it is evident from Fig. 3 that the composition of sugars between animal and PBB are not equal nor comparable. Although the overall total amount of sugar between PBB and milk was similar (4.7 and 4.6 g, respectively; Fig. 3), the sugar content between the different PBB was highly variable and their mean value is thus moderated by the extremely low content in soya and coconut (Table 2). Almost all the sugar in cow and goat milk consisted of lactose, a disaccharide synthesised in the mammary gland from glucose and galactose (Costa et al., 2019), while 36.2 and 14.9% of sugar in PBB consisted of glucose and fructose, respectively, and the remaining 48.9% consisted of other sugar species (Fig. 3), namely

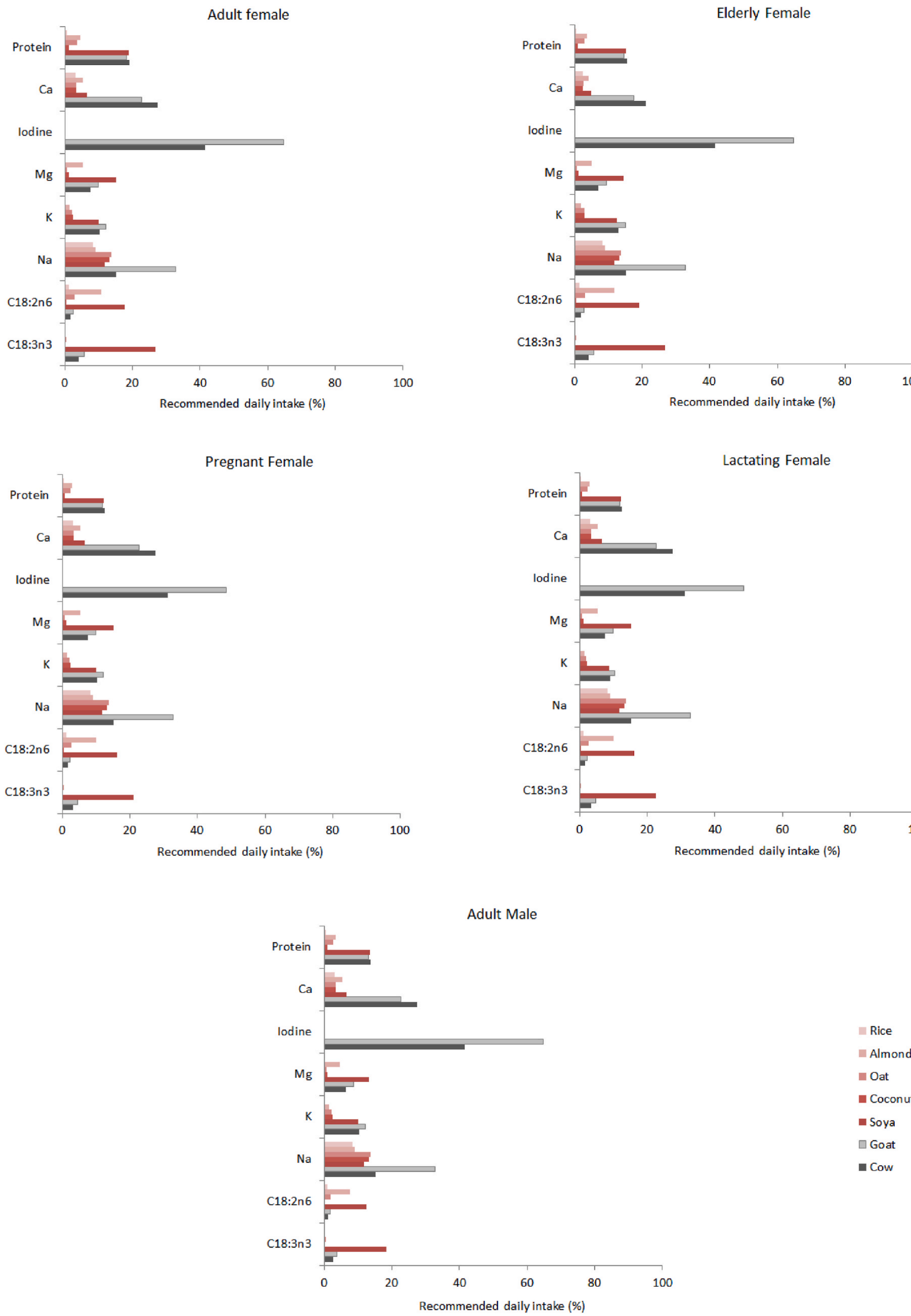

Fig. 1. The relative recommended daily intake (%) of a selection[1] of dietary nutrients obtained from a glass (250 mL) of plant-based beverage or milk for different demographic groups[2].

[1] Essential elements and/or traits related to human health.

[2] Adult is defined as 25–70 years of age; elderly as >70 years of age.

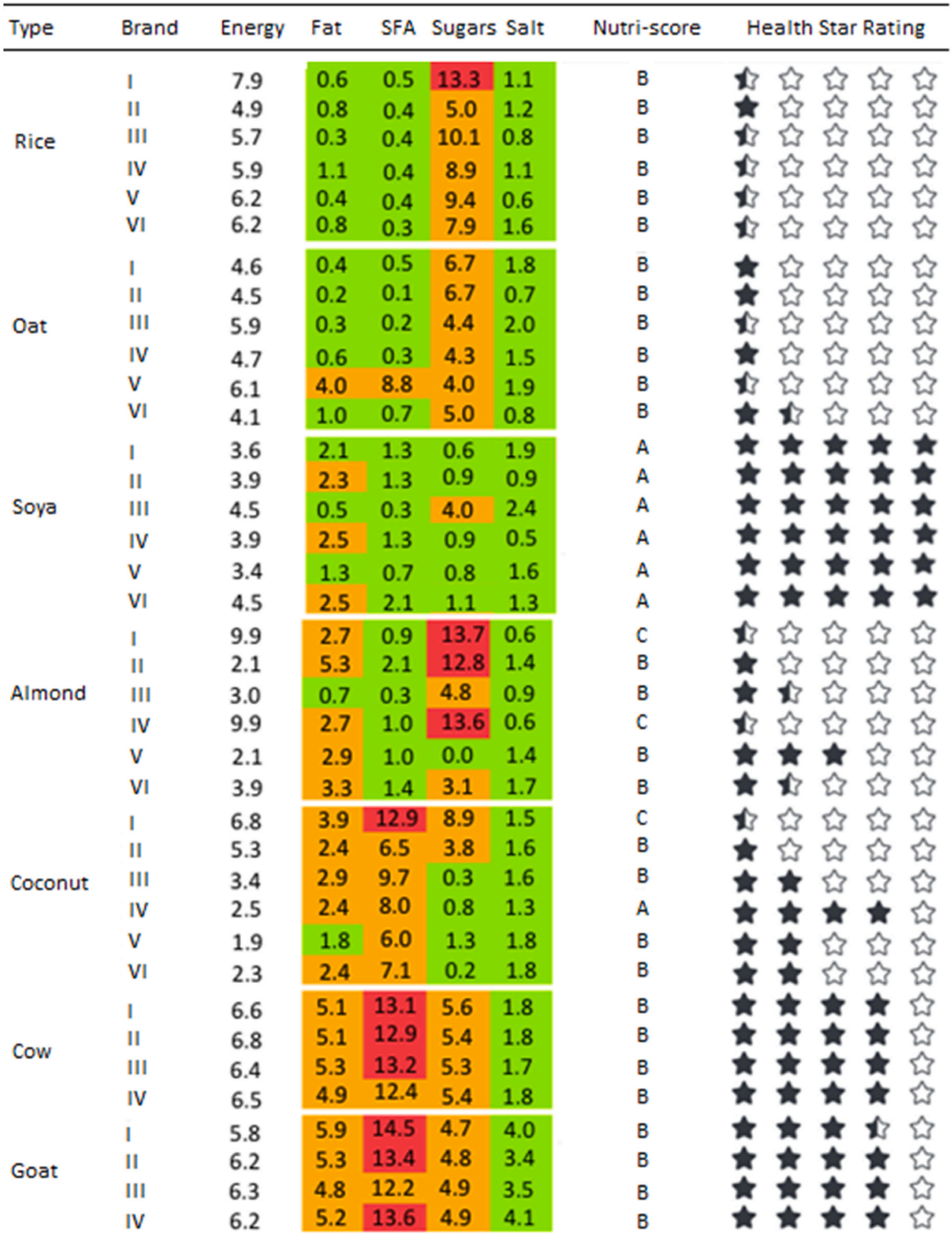

Fig. 2. The rating of four different nutrition scores - Multiple Traffic Light, NutrInform battery, Nutri-Score, and Health Star Rating – for each brand[1] of plant-based beverages and animal milk. Coloured cells indicate Multiple Traffic Light score, while the numbers inside them refer to the NutrInform battery percentage.
[1] Anonymised names. Commercial brands differ among the categories.

sucrose, maltose, and xylose. Glucose, fructose, and other sugars occurring in the PBB may have been added for palatability, particularly sucrose (McClements, Newman, & McClements, 2019). The glycaemic index of glucose and sucrose, however, is 110 and 65, respectively, while that of lactose is just 46, and as a result, induces a lower glycaemic response (Qi & Tester, 2020; Romero-Velarde et al., 2019). In other words, although bovine and caprine milk contain greater amounts of sugar than soya, coconut, and oat-based beverages, upon ingestion, they do not induce the same metabolic response. As reviewed by Qi and Tester (2020), elevated fructose and sucrose consumption has been linked to an increased risk of several health disorders including but not limited to hypertriglyceridemia, cancer, type 2 diabetes, and

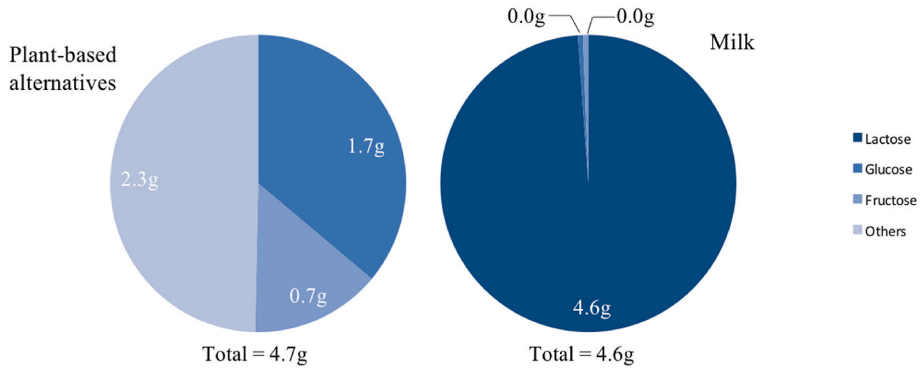

Fig. 3. Average distribution of sugars (g/100 mL) in plant-based beverages vs animal milk.

non-alcoholic related fatty liver.

The greatest within-beverage variance was found in both almond and coconut-based beverages, where the score differed greatly among brands. For example, the coconut brand I scored: i) 1 green, 2 amber, and 1 red for MTL, ii) a Nutri-Score equal to III, iii) only a half HSR and iv) generally high NutrInform battery percentages. Brand IV of coconut instead scored: i) 2 green and 2 amber for MTL, ii) a Nutri-Score of A, iii) 4 health-star in the HSR rating, and iv) generally low NutrInform battery values (Fig. 2). This high variance amongst brands is also evident in the TS (Fig. 4), where particularly almond and coconut stood out as PBB with high within-brand variance. As foreshadowed in Fig. 3, both animal milk showed very little variability in TS among the different brands (Fig. 4) due to physiological constraints but also due to the standardisation of the bulk mass usually carried out in the plant before cartons are filled and delivered. Brands of milk showed moderately high values between 14 and 14.5 points. The beverages with the absolute highest scores were soya brand I and V, both with 20 points, while brand I of coconut had the absolute lowest with 9 points. Out of all the beverages, soya was the beverage with the generally highest TS across brands ranging from19.5 to 20 (Fig. 4).

It is evident that there is little accordance between the different nutritional scores, probably stemming from the fact that each consider various dietary components differently. Indeed, interpretive FoPL process the nutrient profile via an algorithm to obtain a final easy-to-understand score (i.e. Nutri-Score A-E) obscuring the details behind the outcome of the score. Here the mean by which various dietary components influence the algorithm has a huge impact on the result, and is subject to manipulation depending on where emphasis is wished to be placed (i.e. healthy vs unhealthy components). On the contrary, informative FoPL offer a more detailed and descriptive labelling system where only eventual thresholds are subject to subjective interpretation (i.e. thresholds for MTL colouring). As an example, Nutri-Score, an interpretive FoPL, has been criticised for its emphasises on foodstuff's "unfavourable" effects. Up to 40 negative points are given to unhealthy or negative components while a maximum of only 15 positive points to healthy or positive components. As such, the Nutri-Score can be said to advertise what foodstuff not to eat rather than what consumers are advised to eat (Carruba, 2022) and would consequently yield completely different results from a labelling system focusing more on "favourable" effects. Among the 15 most significant dietary risk factors affecting health of populations worldwide, 10 refer to insufficient intakes (i.e. low fruit, low legume, low seafood diets) while only 5 to foodstuff consumed in excess (i.e. high Na, high SFA, high added-sugar diets) (GBD 2017 Diet Collaborators, 2019). What is more, GDB (2019) has calculated that the excess consumption of these components is a small percentage (0.86%) of diet-related deaths in western Europe, with the exception of high Na consumption. On this basis, it is possible that a focus on the "favourable" components of a beverage, rather than on its "unfavourable" and unhealthy components is more important in promoting health in western European countries. In fact, contrary to the general perception of the western consumer, a reduction in SFA intake, which is a major negative trait in the calculation of several of the FoPL nutritional scores, is not promoted by the GBD as a component to be reduced for improved health (GBD 2017 Diet Collaboraters, 2019). Furthermore, the other interpretive FoPL, namely the HSR, which categorise PBB according to their Ca content and plant-origin prior analysis (Australian Department of Health, 2023), was greatly amenable according to which category a beverage was considered. Soya-based beverages received 5 out of 5 stars if considered in "Category 2D" as guidelines instruct, but only 1–2 stars when considered in the category "Non-dairy alternatives" like the other PBB (data not shown). This was due to the difference in which nutrients and variables are considered by the algorithm between the two categories.

None of the FoPL consider necessary micronutrients such as vitamins and minerals, and as foodstuff should be evaluated in their complexity to form a holistic perception of its impact on health, they may innately provide consumers with inaccurate and biased views of products. Indeed, although coconut beverages scored better overall TS than milk, their contribution to a pregnant woman's elevated protein, I, and α-linolenic acid requirement is either non-existent or very poor. If these dietary requirements are not met from other sources, it puts the health of both the pregnant woman and the foetus at risk. Therefore, consumers must consider a rational combination of foods and their frequency of consumption. As such, food products with high nutrient density in relation to their energy content, like that of milk, should be favoured over high-energy, nutrient-poor foods.

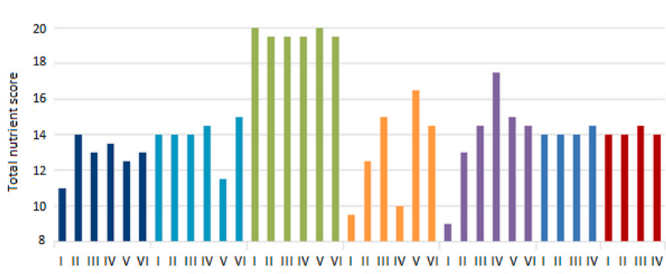

Fig. 4. Total nutrient score[1] of plant-based beverages and animal milk calculated for each brand[2].
[1] where the four scores considered (Multiple Traffic Light, NutrInform battery, Nutri-Score, and Health Star Rating) contribute to a maximum of 5 points each. The maximum value achievable is 20 (optimal). [2] Anonymised names on the x-axis. Commercial brands differ among the categories.

3.4. Protein quality and bioavailability

As an alternative source to the high protein content of milk, soya represents a great candidate, providing about the same percentage of RDI in terms of total protein. However, studies into the quality of the protein content of various foodstuff have found slight differences between milk and soya-sourced proteins. The Digestible Indispensable Amino Acid Score, usually abbreviated as DIAAS, recognises the presence of each amino acid as an individual nutrient and evaluates its digestibility which varies among proteins (Bailey & Stein, 2019). Walther et al. (2022) assessed the score for cow's milk protein to be 1.45 while that of protein from soya-based beverages only 1.08. Similarly, coconut, oat, rice, and almond-based beverages were given a score of 0.72, 0.59, 0.43, and 0.39, respectively. Therefore, although a glass of soya-based beverage appears to provide similar percentage of RDI as milk (20%; Fig. 1), a consumer does not benefit equally from this protein. Similarly, the other PBB did not approximate the protein content of animal milk, and their low DIAAS score further aggravates their poor contribution of this nutrient.

With a complete substitution of animal milk with PBB, consumers risk reducing their mineral intake, particularly that of I and Ca. Despite its importance in growth and neurological development (Sorrenti et al., 2021), I deficiency is on the rise in continental Europe and Australia and is believed to be due to the decline in the use of iodophors in the dairy industry (Censi et al., 2020; Zimmermann, 2010). Indeed, this demonstrates the importance of dairy products in providing populations with adequate I; a glass of milk provides up to 60% of the RDI, while a glass of PBB none (Fig. 1). Although being highly concentrated in milk, particularly cow's milk, Ca is not exclusive to milk like I. The PBB which contributes the most to the RDI of Ca is soya, with about 5% per glass. Of the PBB, soya also provided the highest percentage of K (~8%), comparable to that of milk, and greater amounts of Mg (~15%) than milk (~5%) (Fig. 1). Mg is essential in numerous and highly diverse enzymatic reactions and physiological processes (De Baaji, Hoenderop, & Bindels, 2015). Hypomagnesemia is common throughout the world and is often the results of skewed renal Mg balancing due to disease and drug use, and therefore not from limited dietary intake (Van Laecke, 2019). Hypomagnesemia and Mg deficiency has been linked to cardiovascular disease, vascular calcification, and endothelial function (Van Laecke, 2019). Ca on the other hand, is essential for skeletal structure, muscle movement, and neuronal signalling (Institute of Medicine, 2011; Weaver & Peacock, 2011). As 99% of the Ca in the human body is found in the bones and teeth, Ca deficiency is the leading cause of reduced bone mass and osteoporosis (Cashman, 2002). Among the PBB, almond and particularly soya represent the two plant origins with the highest potential to contribute to the RDI of minerals. However, the presence of phytates may hinder the absorption of these minerals, making them less bioavailable than in the milk matrix. Phytates are plant storage compounds for P and inositol and form soluble complexes with divalent cations under acidic environments like that of the digestive tract. Phytates thus sequester Zn, Fe, and Ca, inhibiting their absorption in monogastrics due to their lack of the phytase enzyme (Dersjant-Li, Awati, Schulze, & Partridge, 2015; Schlemmer, Frølich, Prieto, & Grases, 2009). Since they are thermostable (Davies & Reid, 1979), they are not broken down during the processing steps of the PBB, and their concentration in soya-based beverages has been quantified to be 0.106g/100g (Raghavendra, Ushakumari, & Halami, 2011). However, of the PPB, only soya PBB has been tested for bioavailability of Ca (Zhao, Martin, & Weaver, 2005). If fortified with $CaCO_3$, the Ca was absorbed equally well as when sourced from cow's milk, but not if fortified with $Ca_3(PO_4)_2$. Other PPB are yet to be studied; thus these beverages may not represent satisfactory substitutes for milk as a source of Ca or other essential nutrients. Although neither hydrosoluble nor liposoluble vitamins were analysed in the present study, it is widely known that PBB are frequently fortified or enriched with synthesised or natural substances (Pérez-Rodríguez et al., 2023). Milk and dairy foods are important providers of group B vitamins, especially B2, and therefore, to maximise transparency to the consumer, the percentage of vitamin B2 provided by one portion as compared to bovine milk could be reported together with other important non-mandatory nutrition facts.

Finally, it is worth mentioning that the commercial PBB purchased for this study belong to a single country of origin. Thus, it is not possible to evaluate whether the PBB recipes follow cultural preferences nor if there are country-related differences in certain components such as added sugars.

The PBB investigated in the present study represent the most popular items available on the Italian market. This consequently excludes other PBB which nonetheless demonstrate a market demand, and which offer potential alternative sources of certain nutrients such as PBB made from cashew nut, hazelnut, millet, or quinoa (Fructuoso et al., 2021).

4. Conclusions

The chemical and declared composition of two types of beverages, PBB and animal milk, were used in the current study to compare their nutritional scores. Although the PBB generally achieved elevated FoPL scores, their contributions to the RDI of macro and micronutrients were poorer compared to animal milk. In particular, the PBB offered no I, and very low amounts of Ca, K, and Mg. The only exception was given by soya-based beverages which contributed more essential fatty acids and Mg than milk, but no I. Vitamins were not explored in the present study, but with milk's importance as a dietary source of vitamins like the B2, it is a point for further investigation. Studies focused on PBB vitamins could provide a more comprehensive image of the nutritional value of different commercially available PBB types, improving transparency to the consumers. All PBB except for soya were also poor contributors of protein, but elevated in sugar species with high glycaemic indices, i.e., glucose and sucrose. Due to issues regarding bioavailability and protein quality, consumers switching from milk to soya-based beverages may not benefit to the same extent from the nutrients in soya-based beverages as nutrients sourced from milk. The inferior contributions of PBB to RDI and the high variability in FoPL nutritional scores between brands of PBB prompts for a standardisation across the PBB industry to promote consumer trust and assurance while ensuring public health is not compromised due to poor nutrient literacy. Authors recommend interpreting the findings with caution as data refer exclusively to Italian PBB and milk commercially available. Indeed, more insights into the nutrient differences related to culture-driven country-specific recipes are advisable in further investigations.

Authors' contributions

S. Sterup Moore: Data analysis, methodology, writing -original draft, reviewing and editing. A. Costa: Conceptualisation, methodology, supervision, writing-reviewing and editing. M. Pozza: Lab.

Analysis, writing -reviewing. C.M. Weaver: writing –reviewing and editing. M. De Marchi: Conceptualisation, methodology, supervision, writing-reviewing and editing.

CRediT authorship contribution statement

Selina Sterup Moore: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Formal analysis, Data curation. **Angela Costa:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Methodology, Investigation, Data curation, Conceptualization. **Marta Pozza:** Writing – review & editing, Project administration, Formal analysis. **Connie M. Weaver:** Writing – review & editing, Writing – original draft, Visualization, Conceptualization. **Massimo De Marchi:** Writing – review & editing, Supervision, Resources, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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