Appetite 166 (2021) 105583

Contents lists available at ScienceDirect

Appetite

journal homepage: www.elsevier.com/locate/appet

Identifying Belgian protein consumption typologies by means of clustering and classification to move towards personalized advices for sustainable and nutritious food choices

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ARTICLE INFO

Keywords:
Protein sources
Typologies
Usual intake
Dietary guidelines
Clustering
Classification

ABSTRACT

Protein sources are determinant for the environmental impact and nutritiousness of our food consumption patterns. Dietary advices, in terms of nutritional values and, more recently, the associated environmental impacts, are mostly formulated at nationwide level. However, actual food consumption patterns are variable between individuals within nations, leading to a need for more personalized dietary advices to ensure the feasibility of potential dietary changes. This research addresses the variability within Belgian food consumption patterns by identifying different "protein consumption typologies": consumer groups with different consumption frequencies of different protein sources. Hereto, both statistical clustering and classification were applied to food consumption data, the latter using predefined criteria related to meat consumption. The obtained typologies were further analyzed based on personal characteristics and compliance to nutritional guidelines. Five clusters and five classes were identified, with each survey participant belonging to one cluster and to one class. The clusters differed mainly in milk- and grain product intake, while the classes differed in the intake of meat products from the onset. Both clustering and classification showed that only a small part of the Belgian population frequently adopts plant-based protein sources, that meat products are predominant and that compliances to dietary guidelines are generally low. The typologies are the starting point for more personalized dietary advices to lower environmental impacts while ensuring adequate nutritional value, moving away from nationwide advices.

1. Introduction

Our current food production and consumption patterns are not (sufficiently) sustainable. More specifically, the protein part of our food is in general determinant for its environmental impact (Aiking, 2014). In Belgium, as in most developed countries, meat and dairy are the largest suppliers of protein in food consumption patterns (de Boer, Helms, & Aiking, 2006; Sciensano/WIV-ISP, 2015b), representing respectively 34.6% and 19.0% of the total protein intake on average. Other important protein suppliers are cereals (21.4%), fish and shellfish (6.3%), cakes and cookies (3.9%) and potatoes, tubers and vegetables (5.3%) (Sciensano/WIV-ISP, 2015b).

Animal-based protein sources generally induce higher environmental impacts per kilogram than plant-based protein sources (Nijdam, Rood, & Westhoek, 2012; Poore & Nemecek, 2018). At the same time, meat and other animal-based protein sources are important suppliers of high quality protein and important minerals and vitamins such as iron, zinc and vitamin B12 (FAO, 1992). Changing from animal-based to plant-based protein sources thus has the potential to lower environmental impacts of our food consumption patterns, but at the same time it should be ensured that nutritional needs are met when making these changes. Moreover, dietary changes should be acceptable for consumers to be effectively adopted. Recommended food consumption patterns are more likely to be accepted by individuals when they are as close as possible to current food consumption patterns of individuals (Kanellopoulos et al., 2020).

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https://doi.org/10.1016/j.appet.2021.105583
Received 23 December 2020; Received in revised form 23 April 2021; Accepted 14 June 2021
Available online 1 July 2021

Multiple studies have designed recommended food consumption patterns that consider environmental impacts, nutritional values and acceptability. Willett et al. (2019) defined a global reference diet that respects environmental and nutritional boundaries. The reference diet is however based on a global food system model, while it is important to take diversity in protein consumption into account when assessing the sustainability of protein consumption (de Boer et al., 2006). Broekema et al. (2020) developed a country-specific optimization model to identify food consumption patterns that satisfy environmental and nutritional requirements for Dutch adults, taking acceptability into account by starting from current average food consumption patterns. Chaudhary and Krishna (2019) applied optimization techniques to define diets that satisfy environmental, nutritional and acceptability constraints for multiple countries.

By considering current food consumption patterns in different countries, these studies address the diet variability *between* countries. However, they do not address the variability *within* countries. These variabilities are important, as food choices are influenced by the local food environment (HLPE, 2017), resulting in different food consumption patterns between regions, households and individuals. Acceptability of dietary changes by individuals are therewith also variable, as they are affected by the current food consumption patterns of individuals, among other factors such as culture, religion and social roles (HLPE, 2017).

There is thus a need for studies that take into account the within country variability in food consumption patterns. Several studies have (partly) addressed this need by considering different consumer groups within a country. Brink et al. (2019) formulated food-based dietary guidelines for different sub groups in the Netherlands based on age, gender, activity level and specific food preferences. While Brink and co-authors consider different consumer sub-groups, the groups are not based directly on current food consumption patterns. Other studies identified different groups of consumers, i.e. typologies, based on their food consumption patterns. Baudry et al. (2016) applied clustering techniques to identify typologies in the French population based on their consumption of organic and conventional food products. Vieux et al. (2020) applied clustering and classification techniques to identify typologies in five different countries based on environmental impacts and nutritional quality of current food consumption patterns. de Gavelle, Huneau, and Mariotti (2018) identified different protein source consumption profiles in the French population by means of clustering and assessed the nutritional adequacy of these groups. In a follow-up study, de Gavelle, Huneau, Fouillet, and Mariotti (2019) optimized individual protein consumption patterns in terms of nutritional adequacy, linked to the different protein source consumption profiles defined in the first study.

The goal of this paper was to map the variability within Belgian food consumption patterns by identifying different "protein consumption typologies": consumer groups with different consumption frequencies of different protein sources. The protein consumption typologies are intended to be used in diet optimization models to enhance the acceptability of recommended food consumption patterns, as in de Gavelle et al. (2019), also taking into account environmental impact next to nutritional adequacy. Both an unsupervised and a supervised grouping technique were applied to identify the typologies: (1) clustering, in which consumer groups were formed based on statistical differences in consumption data, and (2) classification, in which consumer groups were predefined based on meat consumption frequency. Clustering was applied to find out if groups could be identified based on statistical differences in protein source consumption and consequently which protein sources cause the distinction between groups. Classification was applied to find out differences between groups based on the consumption of meat products, focusing form the onset on protein sources that are known to have large environmental impacts. Finally, the obtained results of the two applied techniques were combined to find out how predefined groups relate to statistically formed groups. It was further investigated if differences in personal characteristics and nutritional adequacy could be identified.

A first concept of the idea and method development of this research, although not retained in the present paper, was presented at two conferences, one focusing on environmental impacts and one on ethical aspects of dietary changes (Van Mierlo, De Ridder, & Geeraerd, 2019; Van Mierlo, De Tavernier, De Ridder, & Geeraerd, 2019). Preliminary results of this research were presented in a conference abstract (Van Mierlo, De Ridder, Muhammad, & Geeraerd, 2020).

2. Material and methods

2.1. Belgian National Food Consumption Survey

To assess the intake of protein sources within Belgian food consumption patterns, the database of the Belgian National Food Consumption Survey (BNFCS 2014) was consulted. The survey was conducted by the Belgian Institute of Public Health (Sciensano) in 2014 (Sciensano/WIV-ISP, 2015a) and represents the most recent data regarding food consumption in Belgium.

The survey interrogated 3200 Belgian citizens, aged 3–64 years. The sample consisted of approximately 1600 men and 1600 women, distributed over five age classes (approximately 500 younger children, 500 children, 1000 adolescents, 600 young adults and 600 adults) and was stratified over different municipalities throughout the country. The complete methods of the survey are described elsewhere (Bel et al., 2016). In the present study, the adult participants (18–64 years old) of the survey were considered, resulting in an initial sample size of 1222.

The aim of the BNFCS2014 was to map food consumption patterns, both on food product level as on nutrient level and in relation to personal characteristics such as age, gender, education and residency. General information, such as sociodemographic and lifestyle characteristics, were collected by means of oral interviews. The intake of food products was quantified by means of two 24-h dietary recalls during home visits and a written Food Propensity Questionnaire (FPQ). In the dietary recalls, the amounts of all products consumed by the respondents in the past 24 h were quantified. In the FPQ, the consumption frequency of different food groups in the past 12 months was quantified, ranging from 'never' to 'more than 3 times per day'. To assess the intake of nutrients, the intakes of food products were coupled with nutritional databases (Bel et al., 2016).

The 24-h dietary recalls were performed using the GloboDiet® software, which includes a food classification with several levels using structured coding. In the FPQ's, a different food classification is used: a list of 19 specifically chosen food products/product groups, each with a unique code. In the present study, both the GloboDiet® and FPQ classification and codes were followed to identify and characterize the typologies.

The database was obtained by following the procedure of data access as described on the website of the BNFCS 2014 (https://fcs.wiv-isp.be/SitePages/Database.aspx). The obtained database was loaded in the statistical software *R* version 3.6.1 (R Core Team, 2019), in which further analyses were performed.

The BNFCS2014 study was conducted in accordance with the ethical principles for medical research involving human subjects (Declaration of Helsinki) and was approved by the Ethical Committee of the University of Ghent (Reference: 2013/1025) (Belgian Registration number: B670201319129). Written informed consent to participate in the study was obtained from participants.

2.2. Protein source groups

The following protein source groups were included: beef, pork, poultry, processed meat, fish and shellfish, cheese, milk and milk products, eggs, meat replacers, milk (product) replacers, legumes and grain products. Table S1 in the supplementary material shows in detail the included protein source groups with corresponding GloboDiet and

FPQ codes and –names. The selection of the protein source groups was based on their protein content (European Commission, 2020) and their contribution to the intake of protein in the Belgian food consumption pattern (Sciensano/WIV-ISP, 2015b) (in total representing 82% of the protein intake, not accounting for protein intake from food products such as snacks and vegetables). Processed meat (e.g. salami, hamburger), was considered as a separate group because it is consumed regularly by a large part of the population and has a distinct composition compared to unprocessed meat products (e.g. chicken filet). Dairy products were divided into "cheese" and "milk and milk products", since cheese has a considerably different composition than milk (products), i.e., high in fat and salt (Sciensano/WIV-ISP, 2015b). Butter was not included because it is regarded as a lipid source (Sciensano/WIV-ISP, 2015b). Grain products are considered since they contribute considerably to the protein intake of the Belgian consumption (21.4%) (Sciensano/WIV-ISP, 2015b). The groups "meat replacers" (including tofu), "legumes" (e.g. chickpeas) and "milk and milk products replacers" (e.g. soymilk and –cream) were included to identify consumers that are moving towards more plant-based protein consumption.

2.3. Identifying protein typologies

To identify typologies with similar characteristics regarding protein source consumption, both statistical clustering and classification of food intake data were applied, as in (Vieux et al., 2020). Cluster analysis is an unsupervised learning technique to identify groups in data by seeking (dis)similarities in the data. Classification is a supervised learning technique in which groups are predetermined and data are assigned based on the group characteristics (Han, Kamber, & Pei, 2012). Both methods were applied to the FPQ data. Participants that did not fill in the FPQ were removed from the sample, resulting in a final sample size of 1201.

Although FPQ's do not supply information on the consumption *amounts*, they reflects the long term consumption *frequency* of the protein sources on individual level. 24-h recalls reflect the consumption amounts, but only concern the consumption on two consumption days and therefore do not reflect the long term consumption. Several statistical methods exist to estimate these long term consumption amounts on population level (Dekkers, Verkaik-Kloosterman, van Rossum, & Ocké; Harttig, Haubrock, Knüppel, & Boeing, 2011; Tooze et al., 2006), and some of these methods include functionalities to estimate usual intakes on individual level (Harttig et al., 2011; Tooze et al., 2006). However, these individual usual intakes are not suitable to identify groups in a population (National Cancer Institute, 2019). Therefore, FPQ information was selected to identify the typologies and the usual intakes of protein sources for each typology were determined to characterize the typologies (as elaborated on in section 2.4.1).

2.3.1. Cluster analysis of FPQ data

Prior to applying cluster analysis, missing values in the FPQ dataset were replaced by applying multiple imputation (Rubin, 1986) with the *mice* function (Buuren & Groothuis-Oudshoorn, 2011) in *R* version 3.6.1 (R Core Team, 2019). Consequently, the *k*-means approach, a partitioning clustering method (Han et al., 2012), was applied to identify typologies. To determine the optimal number of clusters, the silhouette method was applied, which assesses graphically (1) how compact the clusters are and (2) how well the clusters are spread out. The number of clusters associated with the highest silhouette value (going from −1 to 1) is optimal, as the observations within each clusters are close to each other and the observations between the clusters are far from each other. (Rousseeuw, 1986).

The original FPQ values are categorical, with for example a value of four corresponding to a consumption frequency of one time per week. To be able to combine different FPQ values of different products (for example for yoghurt and milk, which both belong to the protein source group "milk products"), the values were transformed to numerical values in times per day, as in Haubrock et al. (2011). For example, as the original FPQ value of four corresponds to one time per seven days, it equivalently corresponds to one seventh times per day. Table S2 in the supplementary material shows the original FPQ values, the calculations steps and converted FPQ values.

For each protein source group, the corresponding FPQ value or a combined FPQ value was considered, e.g. the sum of FPQ values representing "fresh or frozen fish", "smoked fish", "crustaceans and shellfish" and "sushi" for the group "fish and shellfish". Table S3 in the supplementary material shows the combinations of FPQ values for each protein source group (the third column represents the codes which were used for clustering).

2.3.2. Classification of FPQ data

Classification was applied to the converted FPQ values with assignment criteria based on meat consumption frequency, as meat is known to have high environmental impacts among protein sources (Nijdam et al., 2012; Poore & Nemecek, 2018).

To determine each person's consumption frequency of meat, the FPQ values beef, pork, poultry, horse, meat preparations, rabbit and other game, offal and processed meat were summed, resulting in "FPQ_MEAT" (Table S3, column 4, in supplementary material). Five groups were defined: "eating meat very frequently", "eating meat frequently", "eating meat regularly", "eating meat occasionally" and "never eating meat". For each group, ranges of FPQ_MEAT were tested as assignment criteria. For example, FPQ_MEAT larger than 2, 2.5, 3, …up to 5 times per day were tested as assignment criteria for the class "eating meat very frequently". The results of the different assignment criteria were evaluated in terms of class sizes and differences in protein source intakes. Based on this, the final criteria values were defined.

2.4. Characterization of the identified protein typologies

The identified typologies, i.e., the clusters and classes, were characterized in terms of usual intake of protein sources, compliance to the most recent Belgian Food Based Dietary Guidelines (FBDG) (Superior Health Council of Belgium, 2019) and nutritional guidelines (Superior Health Council of Belgium, 2016) and personal characteristics.

2.4.1. Usual intake protein sources

The "Multiple Source Method" (MSM) (Harttig et al., 2011) was applied to estimate the usual intake distributions (in g/day) of the protein source group for each typology, based on the 24-h and FPQ information. The MSM first estimates the consumption probability by applying logistic regression and the consumption amounts on consumption days by applying linear regression, for each individual. These two values are combined to obtain the usual intake for each individual. The usual intake distribution is then estimated from the individual usual intakes. The MSM is available through a web-based tool (https://nugo.dife.de/msm).

FPQ information was added in the MSM model to identify "never-consumers". In this way, consumers that never consume a product were distinguished from the consumers that had an intake of zero in both 24-h recalls, but do consume the concerning product on the long term. The FPQ information was also added as a covariate in the regression models, together with sample weights, age, gender, province, season and day of the week of the interview.

2.4.2. Compliance to FBDG's and nutritional guidelines

For each typology, the consumption of protein sources and intake of nutrients were compared with the FBDG's (Superior Health Council of Belgium, 2019) and nutritional guidelines (Superior Health Council of Belgium, 2016), respectively. The compliance to the FBDG's and the nutritional guidelines were determined by quantifying the percentage of the consumers within each typology that complies with the guidelines.

The FBDG's include recommended consumption amounts or frequencies for red meat, processed meat, fish and shellfish (lean and fat separately), milk and milk products, legumes and meat replacers and whole grain products. The minimum and/or maximum recommended amounts of these products were compared with the intake of the products for each typology to assess their compliance to the FBDG's. Table 1 shows the recommended amounts and the values in g/day used in this analysis.

The intake of protein sources corresponding to the FBDG's were assessed by combining FPQ values with the average portion size of each typology based on the 24-h recalls. The portion size was determined by considering the mean of the 24-h recalls of the corresponding protein source within each cluster. This approach was followed because the FPQ classification matches the protein groups of the FBDG's more precisely than the GloboDiet classification. Table S3 in the supplementary material, column 5, shows the combined FPQ values to assess the intake of the protein sources. Some products were excluded from the previously used FPQ values, e.g. ice cream, which was included in "FPQ_MILK" for the clustering but was not included in "FPQ_DAIRY_REC" to assess the compliance to the FBDG's.

The nutritional guidelines (Superior Health Council of Belgium, 2016) provide recommended daily intakes of nutrients, which are shown in Table 2. The nutrients protein, iron, vitamin B12 and zinc were included. These recommendations concern all minimum intake amounts. The usual intake of these nutrients, estimated by means of the MSM, were compared with the recommended amounts to determine the nutritional adequacy for each typology. For reasons of completeness, the nutrient intakes are based on the consumption of *all* food products; not only of protein sources. The nutritional adequacy was assessed separately for male and female participants, as the recommended amounts of some nutrients differ for men and women. For example; pre-menopausal women require a higher intake of iron than men (Superior Health Council of Belgium, 2016). Post-menopausal women require the same amount of iron as men (Superior Health Council of Belgium, 2016) and where therefore considered separately, assuming that women over 50 years old are in the post-menopausal stage.

2.4.3. Personal characteristics

The personal characteristics age, gender, educational level, employment, nationality, country of birth, province, Body Mass Index (BMI), self-perceived health and perceived importance of nutrition for health were included to further characterize the typologies.

2.5. Statistical analyses

Statistically significant differences between the clusters and classes were tested with χ^2 tests and analysis of variance ANOVA with a two-tailed significance level of 0.05. The analyses were performed using the stats package in *R* version 3.6.1 (R Core Team, 2019). For the compliance to FBDG's and nutritional guidelines and for personal characteristics except age, χ^2 tests were performed and for age and usual intakes of protein sources, ANOVA was performed.

Table 1
Recommendations for protein sources provided in the Food Based Dietary Guidelines (FBDG's) and converted to recommended amounts in g per day.

Product	Recommendation in FBDG	Recommendation (g/day)
Red meat: beef, pork, horse, sheep, goat, meat preparations (eg. minced meat, sausage)	<300 g/week	<42.9
Processed meat: cold cuts, obtained by cooking, smoking, drying, etc., eg., ham, salami	<30 g/week	<4.3
Fish & shellfish (fat)	1×/week	21.4–42.9[a]
Fish & shellfish (lean)	1×/week	
Milk & milk products, including cheese, yoghurt, etc., excluding butter, cream and plant-based "milk"	250–500 ml/day	250–500
Legumes & meat replacers	>1×/week	>21.4[a]
Whole grain (product)s	>125 g/day	125

[a] *Assuming a portion size of 150 g.*

Table 2
Recommended daily intakes for the included nutrients.

	Recommended daily intake			
	Protein (g/day)	Iron (mg/day)	Vitamin B12 (μg/day)	Zinc (mg/day)
Men	62	9	4	11
Women	52	15 (<50 years old) 9 (>50 years old)	4	8

3. Results

3.1. Cluster identification and characterization

The Silhouette method (Rousseeuw, 1986) showed the largest average silhouette value for two clusters (0.31) and the second largest for five clusters (0.26). A five cluster solution was selected, because it reveals the overall variability in protein source consumption of the population better than a two cluster solution. The first execution of the cluster analysis detected an outlier, which formed a cluster on its own. The outlier was removed, resulting in a sample size of 1200. The five resulting clusters are elaborated upon below.

Cluster 1: high in milk (products) and pork, low in grain products (n = 204, 17.0% of sample)

Cluster 1 consumers showed the highest usual intake of milk products and pork among clusters, and the lowest usual intake of grain products (Fig. 1 and Table S4 in the supplementary material). Looking at the compliance to the FBDG's (Fig. 2 and Table S5 in the supplementary material), cluster 1 showed the highest compliance for milk and milk products among clusters, with 79.4% of the cluster members complying to the recommendation. Male members of cluster 1 showed the highest compliance in terms of vitamin B12 among clusters, with 90.9% of the male members showing a vitamin B12 intake higher than the recommended intake (Fig. 3 and Tables S6 and S7 in the supplementary material). Looking at personal characteristics (Table 3), cluster 1 consisted of more women than men (62.3% and 37.7% respectively) and was a somewhat older group compared to the other clusters, together with cluster 4.

Cluster 2: high in poultry and grain products, low in red meat (n = 61, 5.1% of sample)

Consumers in cluster 2 showed the highest usual intake of poultry and grains among clusters, and high mean intakes of legumes and meat replacers. They further had a low usual intake of beef, pork and processed meat. Cluster 2 thus moves both towards more sustainable meat consumption and more plant based protein consumption. The usual intake of cheese and milk (products) was rather high (Fig. 1 and Table S4 in the supplementary material). Looking at the compliance to the FBDG's (Fig. 2 and Table S5 in the supplementary material), cluster 2 showed the highest compliance of the FBDG for grains among clusters, with 93.4% of cluster members complying to the recommendation. Male members of cluster 2 showed the lowest adequacy for vitamin B12 among clusters, with 67.7% of male member having a vitamin B12 intake higher than the recommended amount. On the other hand, female members of cluster 2 showed the highest adequacy for vitamin B12 among clusters, with 50.0% of female members having a higher intake

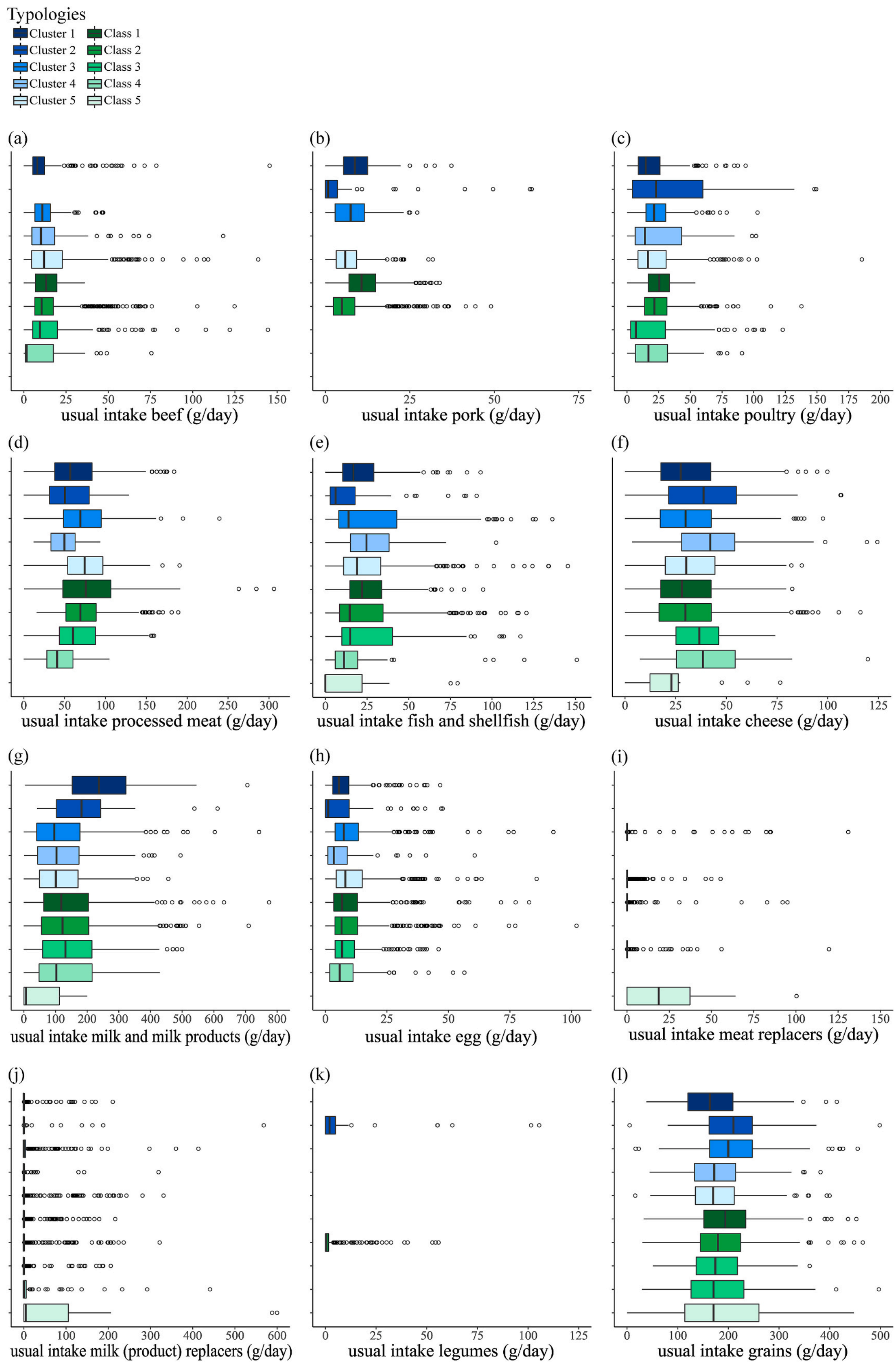

Fig. 1. Usual intake (g/day) of protein sources. (a) Beef, (b) pork, (c) poultry, (d) processed meat, (e) fish and shellfish, (f) cheese, (g) milk and milk products, (h) eggs, (i) meat replacers, (j) milk (product) replacers, (k) legumes, (l) grain products. If no boxplot is displayed, the usual intake of the concerning protein source could not be estimated by the MSM, because the typology did not have any subject with more than one positive intake in the 24-h recalls. For visibility reasons, a small number of outliers are hidden on the graph (<2%).

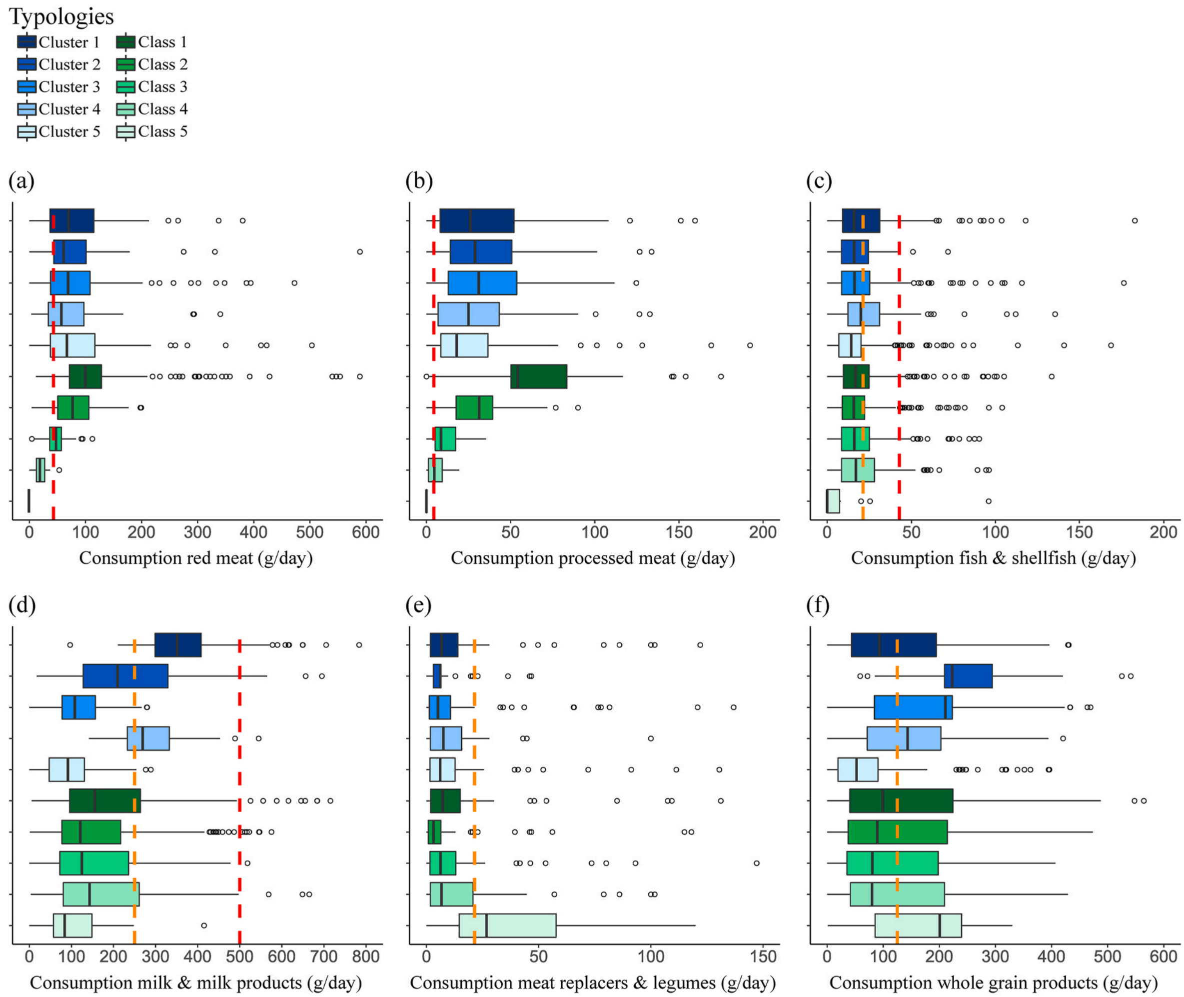

Fig. 2. Consumption amounts (g/day) of protein sources in relation to Belgian food based dietary guidelines (FBDG's). (a) Red meat, (b) processed meat, (c) fish and shellfish, (d) milk and milk products, (e) meat replacers and legumes, (f) whole grain products. Yellow dashed lines represent minimum recommended amounts, red dashed lines maximum recommended amounts.

than the recommended amount, although the difference of the latter is (marginally) not statistically significant ($p = 0.06$) (Fig. 3 and Tables S6 and S7 in the supplementary material). Looking at personal characteristics (Table 3), cluster 2 was a rather young group and had the highest percentage of people with a non-Belgian nationality (19,6%) and a country of birth outside Belgium (22,9%) compared to other clusters.

Cluster 3: average in all protein sources (n = 383, 31.9% of sample)

Cluster 3 represented consumers with average usual intakes of all protein sources compared to other clusters. They showed a rather high usual intake of processed meat, (shell)fish and eggs and relatively low usual intakes of cheese and milk (products) among clusters (Fig. 1 and Table S4 in the supplementary material), which was reflected in the low compliance for the FBDG for milk and milk products compared to other clusters, with only 2.6% of the cluster members complying to the recommendation (Fig. 2 and Table S5 in the supplementary material). For whole grain (product)s they showed a relatively high compliance among cluster, with 62.7% of cluster members complying to the recommendation. Male members of cluster 3 showed a relatively high adequacy for vitamin B12 among clusters, with 76.9% of male member having a vitamin B12 intake higher than the recommended amount (Fig. 3 and Tables S6 and S7 in the supplementary material). Looking at personal characteristics (Table 3), cluster 3 showed an even distribution of men and women and an average age compared to other clusters.

Cluster 4: high in cheese and fish and shellfish, low in processed meat (n = 83, 6.9% of sample)

Cluster 4 consumers showed the highest usual intake of cheese and fish and shellfish and the lowest usual intake of processed meat among clusters (Fig. 1 and Table S4 in the supplementary material). Looking at the compliance to the FBDG's (Fig. 2 and Table S5 in the supplementary material), cluster 4 showed the highest compliance for fish and shellfish, with 36.1% of cluster members complying to the recommendation and a relatively high compliance for milk and milk products, with 59% of the cluster members complying to the recommendation. Looking at personal characteristics (Table 3), cluster 4 consisted of more women than men (61.4 and 38.6% respectively). They were the oldest group and included a rather high percentage of people with birth countries outside Belgium (16.8%), among clusters.

Cluster 5: high in beef, processed meat and eggs, low in milk (products) (n = 469, 39.1% of sample)

Cluster 5 consumers showed the highest usual intake of beef, processed meat and eggs and the lowest usual intake of milk (products) among clusters (Fig. 1 and Table S4 in the supplementary material). Looking at the compliance to the FBDG's (Fig. 2 and Table S5 in the supplementary material), they showed relatively low compliances for all included FBDG's. In particular for milk and grain (products), for which

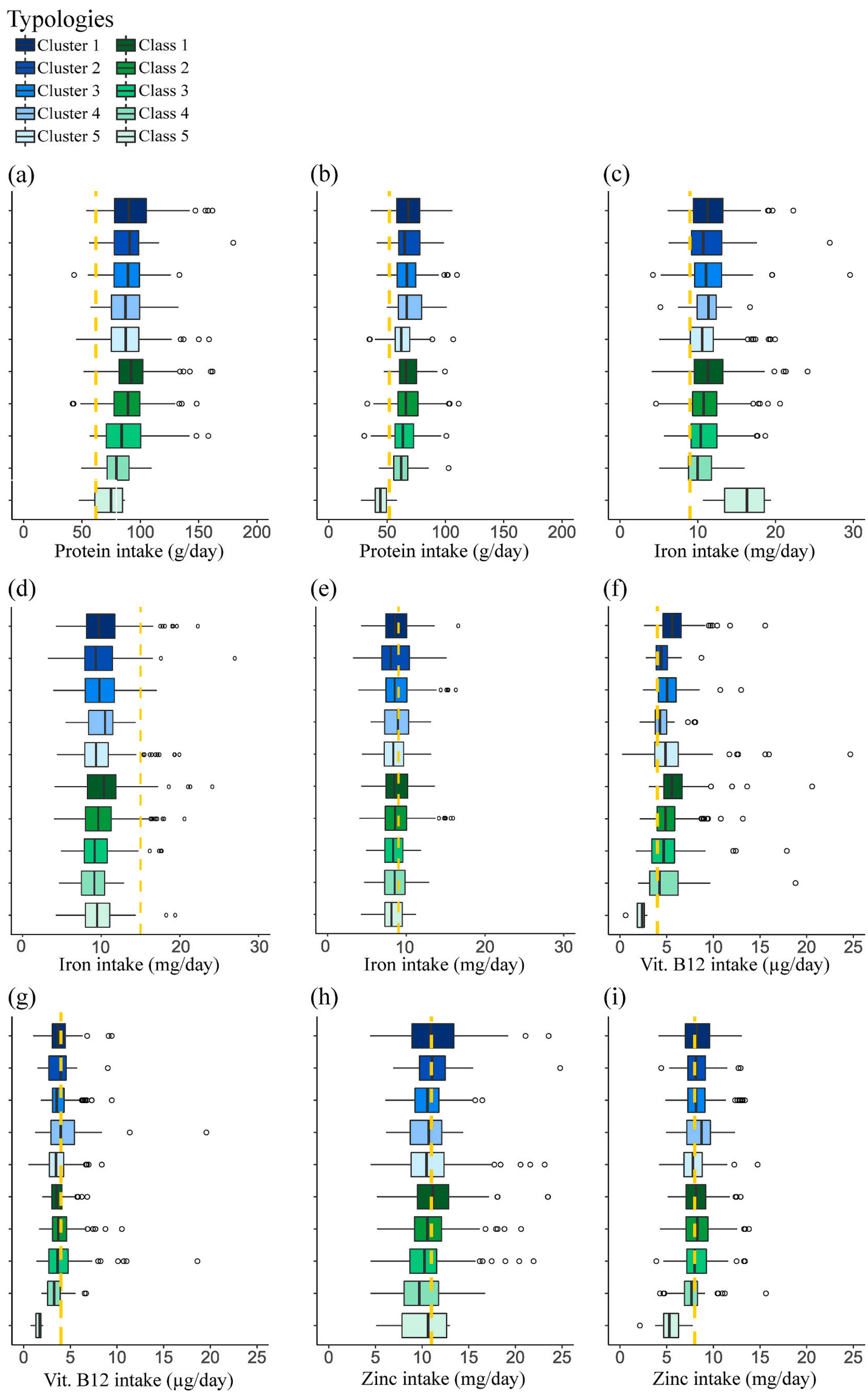

Fig. 3. Nutrient intake in relation to Belgian nutritional guidelines. (a) Protein - men, (b) protein - women, (c) iron - men, (d) iron - women < 50 years old, (e) iron – women > 50 years old (post-menopausal), (f) vitamin B12 - men, (g) vitamin B12 - women, (h) zinc - men, (i) zinc - women. Yellow dashed lines represent minimum recommended intakes.

Table 3
Personal characteristics of typologies.

	Population	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	p[a]	Class 1	Class 2	Class 3	Class 4	Class 5	p[a]
N	1201	204	61	383	83	469		295	556	248	87	15	
%		17.0	5.1	31.9	6.9	39.1		24.6	46.3	20.6	7.2	1.2	
Gender													
Male	48.0	37.7	50.8	50.9	38.6	51.4	0.004	58.0	47.3	42.7	37.9	26.7	<0.001
Female	52.0	62.3	49.2	49.1	61.4	48.6		42.0	52.7	57.3	62.1	73.3	
Age													
Mean	40.6	43.4	39.5	41.1	44.9	38.3	<0.001	39.7	40.4	42.2	40.3	35.2	0.15
s.d.	14.0	13.9	14.5	14.1	13.3	13.6		13.1	13.9	14.7	15.6	10.2	
Educational level													
Other	1.5	1.0	1.6	0.8	1.2	2.3	0.42	0.7	0.9	2.8	4.6	0.0	0.05
Secondary or lower	51.6	57.8	50.8	53.3	43.4	49.0		56.3	51.3	51.2	42.5	33.3	
Higher education short type	25.6	22.1	24.6	25.1	34.9	26.0		23.4	26.3	23.8	33.3	26.7	
Higher education long type	21.3	19.1	23.0	20.9	20.5	22.6		19.7	21.6	22.2	19.5	40.0	
No answer	0.1	0.0	0.0	0.3	0.0	0.0		0.0	0.2	0.0	0.0	0.0	
Employment													
Unemployed	35.0	37.3	36.1	33.7	39.8	34.1	0.11	31.2	31.5	44.0	46.0	33.3	0.01
Unskilled manual worker	2.8	5.9	0.0	3.1	4.8	1.3		2.0	3.6	2.4	1.1	6.7	
Half-skilled or unskilled manual worker	3.2	3.9	4.9	2.9	2.4	3.0		5.1	2.5	2.8	2.3	0.0	
Skilled manual worker	6.4	6.9	3.3	6.5	7.2	6.4		6.8	7.4	4.4	4.6	6.7	
Leading manual worker	1.8	3.4	1.6	2.1	1.2	1.1		2.0	2.3	0.8	1.1	0.0	
Self-employed and/or leading farmer	0.6	2.0	0.0	0.0	1.2	0.4		0.7	0.4	1.2	0.0	0.0	
Self-employed without personnel	3.3	2.5	4.9	1.8	3.6	4.7		6.4	2.0	2.8	3.4	0.0	
Self-employed with less than 10 Personnel	1.4	0.5	1.6	1.0	0.0	2.3		1.0	2.2	0.8	0.0	0.0	
Half- and unskilled non-manual work	7.9	6.9	8.2	7.3	8.4	8.7		8.1	9.2	6.9	2.3	6.7	
Skilled non-manual work	30.7	27.9	32.8	32.4	25.3	31.1		26.8	33.5	27.0	34.5	40.0	
Self-employed higher grade professionals	2.0	1.5	1.6	3.1	1.2	1.5		3.1	0.9	2.8	2.3	6.7	
Management, academics	4.8	1.5	4.9	5.7	4.8	5.3		6.8	4.5	4.0	2.3	0.0	
Nationality													
Belgium	92.1	92.6	80.3	93.2	94.0	92.1	0.01	95.6	93.2	87.1	87.4	93.3	0.01
Other EU member state	5.4	6.4	9.8	4.7	3.6	5.3		2.0	5.0	8.9	9.2	6.7	
Not a EU member state	2.5	1.0	9.8	2.1	2.4	2.6		2.4	1.8	4.0	3.4	0.0	
Birth country													
Belgium	88.3	85.8	77.0	90.1	83.1	90.4	0.006	91.5	90.8	82.3	80.5	80.0	<0.001
Other EU member state1	6.0	7.8	9.8	3.7	12.0	5.5		3.4	5.2	8.9	9.2	20.0	
Not a EU member state1	5.7	6.4	13.1	6.3	4.8	4.1		5.1	4.0	8.9	10.3	0.0	
Province													
Antwerp	16.0	18.6	11.5	17.8	8.4	15.4	0.671	18.6	16.2	14.1	9.2	26.7	0.01
Flemish Brabant	8.7	4.4	11.5	8.9	12.0	9.4		9.2	9.4	7.7	6.9	0.0	
West Flanders	12.6	15.2	9.8	13.1	9.6	11.9		12.9	13.5	10.9	10.3	13.3	
East Flanders	12.5	14.2	16.4	13.1	10.8	11.1		16.9	11.5	9.7	9.2	26.7	
Limburg	8.0	7.8	3.3	7.0	10.8	9.0		6.8	8.5	9.3	6.9	0.0	
Brussels-Capital region	7.2	6.4	13.1	6.5	7.2	7.5		4.4	5.4	12.1	13.8	13.3	
Walloon Brabant	2.8	2.9	1.6	2.6	4.8	2.6		2.7	2.7	2.0	4.6	6.7	
Hainaut	11.0	11.3	8.2	9.7	13.3	11.9		8.8	10.3	13.3	18.4	0.0	
Liège	12.4	11.8	18.0	13.1	15.7	10.9		11.9	12.4	14.1	11.5	6.7	
Luxembourg	2.7	2.9	1.6	2.3	0.0	3.4		2.0	2.9	3.2	1.1	6.7	
Namur	6.2	4.4	4.9	6.0	7.2	7.0		5.8	7.4	3.6	8.0	0.0	
Self-perceived health													
No answer	2.7	2.0	1.6	3.9	1.2	2.3	0.09	2.4	2.5	4.0	2.3	0.0	0.06
Very good	21.0	13.2	24.6	23.8	20.5	21.7		22.7	20.7	19.0	21.8	26.7	
Good	55.2	57.8	55.7	53.0	48.2	56.9		55.6	55.6	52.8	57.5	53.3	
Fair	18.6	23.0	18.0	17.0	24.1	17.1		18.6	19.4	17.7	16.1	13.3	
Bad	2.0	2.9	0.0	1.8	3.6	1.7		0.3	1.6	4.8	1.1	6.7	
Very bad	0.6	1.0	0.0	0.5	2.4	0.2		0.3	0.2	1.6	1.1	0.0	
Importance of nutrition for your health (%)													
Very important	50.6	51.0	49.2	50.7	59.0	49.0	0.86	46.1	49.8	51.2	63.2	80.0	0.04
Important	46.4	46.6	49.2	46.5	38.6	47.3		49.2	47.7	46.4	34.5	20.0	
Not important	3.0	2.5	1.6	2.9	2.4	3.6		4.7	2.5	2.4	2.3	0.0	
Body Mass Index (BMI)													
Not applicable	1.4	1.5	4.9	0.8	1.2	1.5	0.39	1.4	1.3	1.2	2.3	6.7	<0.001
Missing	0.5	1.0	0.0	0.0	0.0	0.9		1.0	0.2	0.4	1.1	0.0	
Underweight	2.4	2.5	1.6	1.8	0.0	3.4		1.4	3.2	0.8	2.3	20.0	
Normal	45.6	49.5	37.7	45.2	44.6	45.4		43.1	43.7	48.8	55.2	53.3	
Overweight	31.4	27.0	36.1	31.3	30.1	33.0		31.2	33.1	31.0	25.3	13.3	
Obese	18.7	18.6	19.7	20.9	24.1	15.8		22.0	18.5	17.7	13.8	6.7	

[a] *p*-values determined with χ^2 test for categorical variables and ANOVA for continuous variables.

only 0.6% and 7.2% of cluster members complied to the recommended intakes, respectively. Cluster 5 thus represented a rather “unhealthy” repartition of protein sources. Looking at personal characteristics (Table 3), cluster 5 consisted of slightly more men (51.4%) than women (48.6%), and represented the youngest cluster.

3.2. Class identification and characterization

The following classification criteria were applied, as they had the most favorable class sizes and differences in protein source intakes distribution of the participants over the classes: the meat consumption frequency (FPQ_MEAT) of the class “eating meat very frequently” was larger than 2 times per day, for “eating meat frequently” between 1 and 2, for “eating meat regularly” between 0.5 and 1, for “eating meat occasionally” between 0 and 0.5 and for “never eating meat” equal to zero. For meat products, i.e. beef, pork, poultry and processed meat, the usual intake was in general highest for class 1, followed by class 2, and so on. The usual intake of the other protein sources varied, as elaborated upon below.

Class 1: very frequent meat eaters (n = 295, 24.5% of sample)

Class 1 consumes meat more than two times per day. Within meat products, they showed the highest median usual intake of beef, pork, poultry and processed meat among classes. Class 1 also showed the highest median usual intake of fish and shellfish and grains among classes. They showed a rather low usual intake of cheese but a high usual intake of milk (products) compared to the other classes. They showed a low usual intake of meat replacers, milk (product) replacers and legumes (Fig. 1 and Table S4 in the supplementary material). Looking at the compliance to the FBDG’s (Fig. 2 and Table S5 in the supplementary material), class 1 showed the lowest compliance for red meat and processed meat among classes, with 9.8% and 2.4% of cluster members complying to the recommended amounts. Male member of class 1 showed the highest adequacy for protein and vitamin B12, with 97.7% and 87.7% of male members complying to the recommended amounts, respectively. Female members of class 1 showed the highest adequacy for protein among classes, with 96.0% of female members complying to the recommended amount, a relatively high adequacy for zinc and a relatively low adequacy for vitamin B12 (Fig. 3 and Tables S6 and S7 in the supplementary material). Looking at personal characteristics (Table 3), class 1 consisted of more men (58%) than women (42%) and they showed the highest percentage of obesity among classes.

Class 2: frequent meat eaters (n = 556, 46.3% of sample)

Class 2 consumes meat one to two times per day. Consumers in this class showed a lower median usual intake for all meat products than class 1. They showed a relatively low usual intake of cheese but a relatively high median intake of milk (products) among classes. They showed low usual intakes of meat replacers, milk (product) replacers and legumes (Fig. 1 and Table S4 in the supplementary material). Looking at the compliance to the FBDG’s (Fig. 2 and Table S5 in the supplementary material), class 2 showed low compliances for red meat and processed meat among classes, with 20.5% and 6.1% complying to the recommended amounts, respectively, and the lowest for legumes and meat replacers, with 2.7% of cluster member complying with the recommendation. In terms of nutritional adequacy (Fig. 3 and Tables S6 and S7 in the supplementary material), male member of class 2 showed lower adequacies for protein and vitamin B12 than class 1. Female members also showed lower adequacies for protein than class 2 but the largest adequacies for vitamin B12 and zinc. Looking at personal characteristics (Table 3), class 2 consisted of slightly more women (52.7%) than men (47.3%) and showed average personal characteristics compared to the other classes.

Class 3: regular meat eaters (n = 248, 20.7% of sample)

Class 3 consumes meat one time per one to two days. They showed a lower median usual intake for all meat products than class 2 and the lowest usual intake of poultry. They showed a relatively high usual intake of cheese and the highest usual intake of milk and milk products among classes. They showed a higher usual intake of meat replacers, milk (product) replacers and legumes than class 1 and 2, but still rather low (Fig. 1 and Table S4 in the supplementary material). Looking at the compliance to the FBDG’s (Fig. 2 and Table S5 in the supplementary material), class 3 showed higher compliances for red and processed meat than class 1 and 2, higher compliance for meat replacers and legumes than class 2 and lower compliances for whole grain products than class 1 and 2. Looking at nutritional adequacy (Fig. 3, Tables S6 and S7 in the supplementary material), male members of class 3 showed a lower adequacy for protein and vitamin B12 than class 1 and class 2. Female members showed a lower adequacy than class 1 and 2 for protein and zinc, and for vitamin B12 it showed a lower adequacy than class 2 but a higher adequacy than class 1. Looking at personal characteristics (Table 3), class 3 consisted of more women (57.3%) than men (42.7%) and consisted of the highest percentage of persons with a non-Belgian nationality (12.9%) and a relatively high percentage of persons with non-Belgian birth countries (17.8%) among classes.

Class 4: occasional meat eaters (n = 87, 7.2% of sample)

Class 4 consumers eat meat less than one time per two days. They showed a higher median usual intake of poultry than class 3, but not as high as class 1 and 2. They showed the highest median usual intake of cheese and a rather low usual intake of milk and milk products, fish and shellfish and meat replacers among clusters. They showed a notably higher usual intake of milk (product) replacers and legumes than class 1, 2 and 3 (Fig. 1 and Table S4 in the supplementary material). Looking at the compliance to the FBDG’s (Fig. 2 and Table S5 in the supplementary material), class 4 showed a very high compliance for red meat, with 98.9% of cluster members complying to the recommended amount, and a relatively high compliance for processed meat, with 46.0% of cluster members complying to the recommended amount. Looking at nutritional adequacy (Fig. 3 and Tables S6 and S7 in the supplementary material), class 4 showed a lower adequacy for protein, vitamin B12 and zinc than class 1, 2 and 3, except for female members for protein. Looking at personal characteristics (Table 3), class 4 consisted of more women (62.1%) than men (37.9%), has the highest percentage of unemployment (46.0%) and consists of a relatively high percentage of non-Belgian nationalities (12.6%) and countries of birth (19.5%) among classes.

Class 5: no meat eaters (n = 15, 1.2% of sample)

Class 5 never consumes meat. They showed the highest usual intake of meat replacers, milk (product) replacers and legumes among classes. They showed a low usual intake of fish and shellfish, cheese and milk and milk products (Fig. 1 and Table S4 in the supplementary material). Looking at the compliance to the FBDG’s (Fig. 2 and Table S5 in the supplementary material), class 5 showed the highest compliance for red meat and processed meat among classes, with (evidently) 100% of class members complying with the recommended amounts, and the highest compliance for legumes and meat replacers and whole grains products among classes, with 66.7% of class members complying to the recommended amounts for both. Looking at nutritional adequacy (Fig. 3 and Tables S6 and S7 in the supplementary material), female members of class 5 showed the lowest adequacy for protein, vitamin B12 and zinc, and for vitamin B12 and zinc even 0% of the class members complied with the recommendations. Among male members of class 5, 0% showed an adequate intake of vitamin B12, but a relatively high percentage (50%) showed an adequate intake of zinc. Looking at personal characteristics (Table 3), class 5 consisted of more women (73.3%) than men (26.7%), had the highest percentage of non-Belgian birth countries (20%), the highest occurrence of underweight and lowest percentage of obesity among classes.

3.3. Associations between clusters and classes

Each survey participant belonged to one cluster and to one class. Fig. 4 shows the distribution of participants over the clusters, classes and subgroups at the intersection of clusters and classes. The distribution is represented by percentages of the (sub)groups in the total sample and “weighted ratios”, which reveal relative differences in the distribution of clusters within classes and classes within clusters, compared to the whole sample. Weighted ratios higher than 1 indicate a relatively high overlap between a cluster and a class, and weighted ratios lower than 1 indicate a relatively low overlap between a cluster and class.

Fig. 4 shows that large subgroups (>5% of sample) can be distinguished mostly within the two largest clusters; cluster 3 and 5. Class 1, 2 and 3 represent the largest part within these clusters. The two largest groups in the population are at the intersection of class 2 and cluster 3 and 5, representing 16.2% and 18.1% of the population respectively. This means that the largest part of the population eats meat frequently, i.e. one to two times per day, and that their consumption is evenly distributed over all protein sources, or that they have a high consumption of beef, processed meat and eggs, and a low consumption of milk (products). The same holds for the relatively large subgroups at the intersection of class 1 with cluster 3 and 5 and at the intersection of class 3 with cluster 3 and 5, while their meat consumption is more than two times per day and once in one to two days, respectively. A relatively large group, at the intersection of class 2 and cluster 1, eats meat one to two times per day and has a high intake of milk products and pork and a low intake of grain products. Small subgroups (<1%) can be distinguished mainly within the smallest classes: class 4 and 5, which occasionally or never consume meat. This indicates that only a small part of the Belgian population limits its meat consumption to less than one time per two days. However, a relatively large subgroup at the intersection of class 4 and cluster 5 can be distinguished, representing consumers that consume meat less than one time per two days, but have high intakes of beef and processed meat. The smallest subgroup, representing one consumer, is situated at the intersection of class 5 and cluster 2, indicating a group that never consumes meat and has a high intake of grain products, legumes and meat replacers. No consumers were identified that never consume meat and have a high intake of cheese and fish and shellfish.

When comparing the weighted ratios, large and small overlaps between classes and clusters can be distinguished. Somewhat surprisingly, a relatively high overlap exists between class 1, which shows very frequent meat consumption, and cluster 2, which has a high intake of poultry and grain products and a low intake of beef, pork and processed meat. Indeed, Fig. 1 shows that both cluster 2 and class 1 have a high intake of grain products. While cluster 2 is indicated as a group that is moving towards more sustainable meat consumption and more plant based protein sources, they apparently contain a large part that has a very frequent meat consumption, mostly represented by poultry. However, cluster 2 also has a large overlap with class 5, indicating a group that never consumes meat and has a high intake of grain products, legumes, meat replacers and milk (products). While this appears to be the desired consumption pattern in term of environmental impact, only one

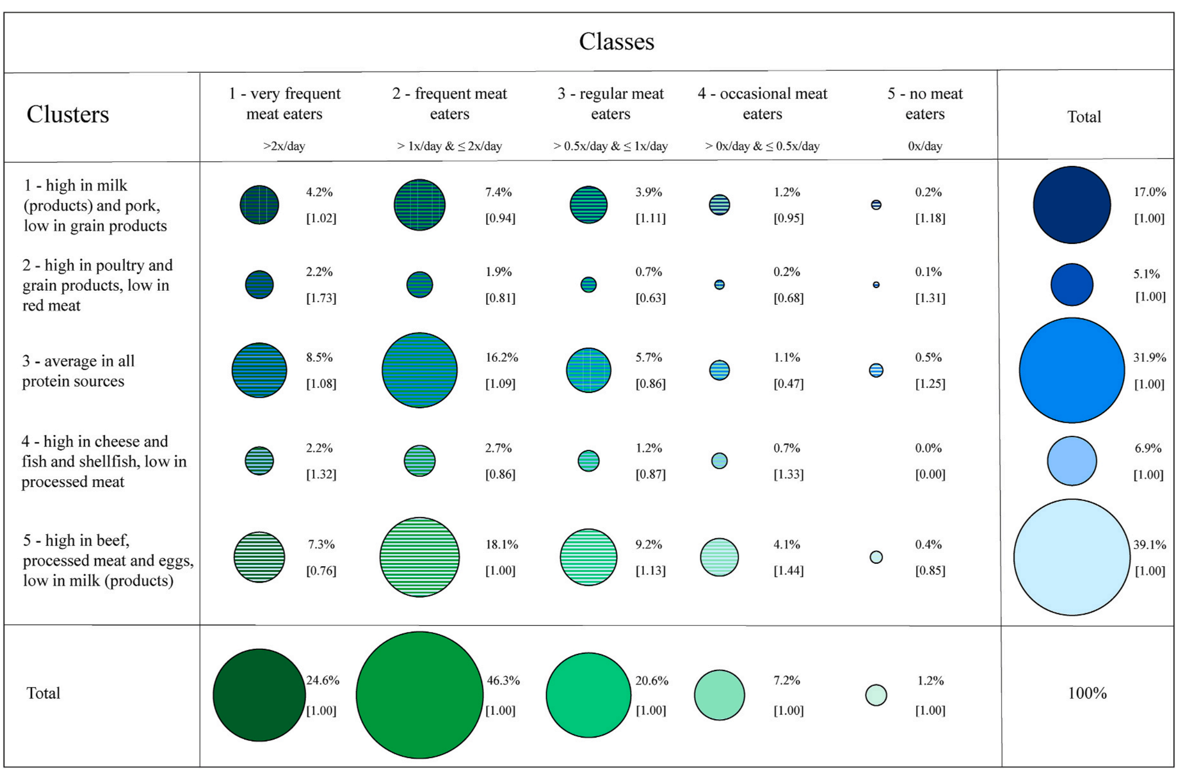

Fig. 4. Distribution of survey participants over clusters, classes and subgroups at the intersection of clusters and classes. The surface of the spheres, as well as the percentages next to the spheres represent the share of the sample belonging to each (sub)group. For example, the subgroup at the intersection of class 1 and cluster 3 contains 8.5% of the total sample. The values between brackets [...] represent “weighted ratios”, which reveal relative differences in the distribution of clusters within classes and classes within clusters, compared to the whole sample. The weighted ratios are determined by dividing the fraction of a certain class in a cluster by the fraction of that class in the total sample. The same result is obtained by dividing the fraction of a certain cluster in a class by the fraction of that cluster in the total sample. For example, the weighted ratio of 1.08 for the subgroup at the intersection of class 1 and cluster 3 is obtained by dividing (8.5%/31.9%) by 24.6%, equal to (8.5%/24.6%)/31.9%. Values higher than 1 indicate a relatively high overlap between a cluster and a class, and values lower than 1 indicate a relatively low overlap between a cluster and class.

participant of the sample belongs to it. Another large overlap exist between class 1 and cluster 4, representing a subgroup with very frequent meat consumption and high intakes of cheese and fish and shellfish and low intakes of processed meat. Also somewhat surprisingly, a small overlap exists between class 1 and cluster 5, while a high intake of beef and processed meat is observed in this cluster. Class 4, representing occasional meat consumption, has a relatively high proportion of cluster 4, representing occasional meat consumers with a high intake of cheese and fish and shellfish and low intakes of processed meat. The usual intake of cheese is indeed high for class 4 (Fig. 1), and apparently a small part of this class also has high intakes of fish and shellfish. A large overlap exists between class 4 and cluster 5, representing consumers that do not consume meat frequently, but have high intakes of beef and processed meat. Class 5, representing no meat eaters, has large overlaps with cluster 1 and cluster 3, indicating that consumers that do not eat meat have high intakes of milk products and low intakes of grain products, or average intakes of other protein sources.

4. Discussion and conclusion

In order to enhance acceptability of recommended food consumption patterns, this study assessed the variability in Belgian protein source consumption. Ten protein consumption typologies were identified – five by means of clustering and five by means of classification, with each individual consumer belonging to one cluster and to one class.

The typologies were characterized, first in terms of usual intakes of protein sources. While the classes showed large differences in meat consumption, as predefined in the classification, the clusters showed large differences in milk (products) and grain (products), which indicates that these protein sources are determinant in the variability of Belgian food consumption patterns. Subgroups at the intersection of clusters and classes refined the characterization of the classes by revealing protein source consumption within the predefined groups based on meat consumption.

4.1. About 7 out of 10 consumers in Belgium (typology class 1 and 2) eat meat more than once per day and consume either a variety of all protein sources or has high intakes of beef, processed meat and eggs

The typologies identified by means of classification showed a decrease in the usual intake of separate meat products with decreasing meat consumption frequency used for the classification. The usual intake of milk (products) followed the decreasing intake of meat: it was the highest for very frequent meat eaters and decreased to the lowest intake for no meat eaters. The usual intake of plant-based protein sources increased with a decreasing usual intake of meat. Similarly, the usual intake of cheese increased with a decreasing usual intake of meat, except for no meat eaters, which showed the lowest usual intake of cheese. A large group (cluster 5, 39.1% of the population) was identified with a high usual intake of beef, processed meat and eggs. This group showed a less recommended eating behavior with very low compliances to the Belgian FBDG's (with <30% of cluster members complying for each guideline). This group shows a relatively high overlap with occasional meat eaters (intersection of cluster 5 and class 4, 4.1% of the population), forming a subgroup that limits its meat consumption but has high intakes of unsustainable meat types. 70.8% of the Belgian population eats meat more than once per day (class 1 and 2). Within these groups, large subgroups are formed with consumers with average protein consumption (cluster 3) and consumers with high intakes of beef, processed meat and eggs (cluster 5). However, relative to the whole sample (weighted ratios), large overlaps can be observed between very frequent meat eaters and consumers with low intakes of beef, and high intakes of poultry and grain products (cluster 2) and consumers with low intakes of processed meat and high in cheese and fish and shellfish (cluster 4). For frequent meat eaters, the percentages of clusters are more in line with the weighted ratios, meaning that cluster 3 and 5 form large subgroups within this class, both absolutely and relative to the whole sample.

4.2. A small minority, about 1 out of twenty consumers (cluster 2), moves towards plant-based protein sources

A small group of the population (5.1%) was identified that is moving towards more plant-based protein consumption (cluster 2) and an even smaller group (1.2%) that is completely vegetarian (class 5), indicating that only a small part of the Belgian population frequently adopts plant-based protein sources in its food consumption pattern. Moreover, only one consumer is vegetarian *and* is moving towards more plant-based protein consumption (intersection of cluster 2 and class 5). Consumers in class 5 rather have average intakes of protein sources other than meat, indicated by the high percentage and high weighted ratio of the subgroup between class 5 and cluster 3. The group that is moving towards plant-based protein consumption (cluster 2) shows a large overlap (weighted ratio) with very frequent meat eaters. This group thus has a high meat consumption frequency, represented mostly by poultry, and has a relatively high intake of plant-based protein sources.

The fact that only a small group in the Belgian population adopts plant-based protein sources in their food consumption patterns was also observed by Lin et al. (2011), when they assessed the intake of plant-based and animal-based protein sources in Belgian, based on the Belgian National Food Consumption Survey of 2004: they found that the largest part of the protein intake came from animal-based sources. Although not specific for the Belgian context, studies have shown that despite the raising awareness about the benefits of eating less meat (Siegrist, Visschers, & Hartmann, 2015), the adoption of more plant-based food consumption patterns is hampered by, for example, negative taste experiences, negative associations with social image and limitations in food choices (Graça, Oliveira, & Calheiros, 2015). Promoting the consumption of plant-based protein sources can however be increased by responding to ethical, health and naturalness concerns that are already established in some consumer segments (Graça, Truninger, Junqueira, & Schmidt, 2019).

Specific to the Belgian situation, Vanhonacker at al. (2013) studied motives of Flemish consumers related to more sustainable food choices and meat alternatives. Five consumer segments were identified based on the consumers' self-evaluated environmental impacts of their food consumption, and the importance of environmental impacts in their decision process when purchasing food. They found that in general, the environmental impact of meat production is underestimated, and that the willingness to adopt meat alternatives is low. Higher willingness was observed for consuming less meat and more sustainable types of meat. By looking at different consumer segments, they highlight the importance of a targeted approach to stimulate consumers to lower their meat consumption. The consumer segments ranged from the "active", which indicated a high importance of environmental impacts in purchasing decisions and estimate their own environmental impact to be small, to the "unwilling", which do not take into account environmental impacts when purchasing food and estimate their environmental impact to be high. Three intermediate groups, i.e. the "conscious", with high importance of environmental impact and a high self-evaluated environmental impact, the "ignorant", with low importance of environmental impact and a low self-evaluated environmental impact, and the "uncertain", with intermediate values for both factors.

Trying to link the five identified consumer segments related with their willingness to adopt meat alternatives and our typologies, some (as of yet unproven) hypotheses can be formulated. The very frequent and frequent meat eaters identified in this study are likely to contain "unwilling" consumers as described by Vanhonacker and colleagues. However, also the "conscious" consumers, which have high consumption frequencies of meat, could be present in these classes. More specifically, the conscious segment, which evaluate meat sorts with lower impacts as good alternatives, is probably present mainly in the subgroup at the intersection of class 1 and cluster 2, which shows very frequent meat consumption, high intakes of poultry and low intakes of red meat. The “active” consumers could probably be present in the occasional and no meat eaters, apparently needing less convincement to make changes in their food consumption patterns. As indicated by Vanhonacker at al. (2013), it is easier to convince the active and conscious consumers to lower their meat consumption than the unwilling and ignorant, and therefore they require different, targeted approaches. The different typologies identified in this study may be interesting starting points for such approaches, as elaborated on in the subsection “Future research” below.

4.3. The Belgian population showed low compliances (less than 40%) to food based dietary guidelines while some of the identified typologies showed higher compliances

The typologies were further characterized in terms of compliance to FBDG’s. In general, the Belgian population showed low compliances to the FBDG’s: the highest compliance was 38.5% of the population for the FBDG for whole grain products. If the different typologies are considered, however, larger compliances can be observed. Nevertheless, even the typologies that show a movement towards the recommended consumption of legumes and meat replacers (class 4 and class 5) include a large part that do not comply with the guidelines. The general incompliance to the FBDG’s is in line with the conclusions of the study of Bel et al. (2019) (Bel et al., 2019), in which usual intakes of food products were assessed based on the BNFCS2014 and compared to Belgian FBDG’s. The authors concluded that a large part of the Belgian population did not comply with the FBDG’s (note that in the study by Bel et al. (2019) a previous version of the FBDG’s was used while the present study consulted the most recent version of the FBDG’s (Superior Health Council of Belgium, 2019). Main differences between clusters in the compliance to the FBDG’s were observed for milk products and for whole grain products. Main differences between classes in the compliance the FBDG’s were observed for red meat, processed meat, legumes and meat replacers and whole grains and grain products. The identified typologies with a high consumption of meat products showed low compliances for the FDBG’s of red meat and processed meat. The identified typologies with a low consumption of meat showed high compliances to the FBDG of legumes and meat replacers.

4.4. The Belgian population showed low nutritional adequacies, except for protein. For females, classes show differences in protein, vitamin B12 and zinc adequacy levels, with class 2 showing the most optimal levels

Characterization in terms of nutritional adequacy has shown that the Belgian population showed inadequacies also on nutrient level. For protein, the adequacy on population level was rather high, 95.5% for men and 90.2% for women. The female members of the typology “no meat eaters” (class 5) however showed very low adequacies for protein; only 27.3% of female class 5 members showed an adequate intake. For the other included nutrients the adequacies on population level were lower. For iron, 78.9% of men and only 14% of women showed an adequate intake. For vitamin B12, 76.7% of men and 36.4% of women showed an adequate intake. For zinc, 42.9% of men and 53.1% of women showed an adequate intake. It is striking that the differences between the classes and clusters at the level of nutrients are less outspoken than the differences in the compliance to the FBDG’s. The fact that the complete food intake (and not only the protein sources) is taken into account for this assessment is important in this respect. It turns out that between clusters, only vitamin B12 differs significantly for male participants. For females, all nutritional adequacies are similar, yet the difference for vitamin B12 is only marginally insignificant with cluster 3 females showing the lowest values. Considering the classes, male participants show an even larger outspoken difference for vitamin B12, with the adequacy decreasing for increasing class numbers. The same trend can be observed for protein. For females, classes are interestingly showing differences at protein, vitamin B12 and at zinc levels, with class 2 showing the most optimal levels.

4.5. Consumers that move towards more plant-based protein consumption (class 4 and 5) showed high proportions of consumers with a non-Belgian Nationality and/or birth country compared to the other typologies and a higher percentage of highly educated consumers

Characterization in terms of personal characteristics has shown that multiple associations exist between clusters and between classes. The clusters showed significant differences for gender ($p = 0.004$), age ($p = 0.001$), nationality ($p = 0.01$) and birth country ($p = 0.006$). The classes showed significant differences for gender ($p < 0.001$), educational level ($p = 0.05$), employment ($p = 0.01$), nationality ($p = 0.01$), birth country ($p < 0.001$), province ($p = 0.01$), importance of nutrition for health ($p = 0.04$) and BMI ($p < 0.001$). As with the nutritional adequacy, the classes subdivision seems to be more capable of identifying clear distinctions between groups in society.

Younger consumers in the Belgian population appeared to choose for a healthy/more plant-based food consumption pattern (cluster 2), or for the opposite; an unhealthy/high meat food consumption pattern (cluster 5). Older consumers appeared to choose less processed/expensive protein sources (cluster 4). Male consumers appeared to adopt a food consumption pattern with very frequent meat consumption. Female consumers appeared to adopt less processed protein sources and the identified vegetarian group consisted mainly of women. This is in line with the findings of Lin et al. (2011), stating that male Belgian consumers consume more animal-based protein sources than female Belgian consumers, and with Michel, Hartmann, and Siegrist (2021), who observed a higher meat consumption frequency for men than for women (in Germany). Cluster 2 and class 4 and 5, which represent consumers that move towards more plant-based protein consumption, showed high proportions of consumers with a non-Belgian Nationality and/or birth country compared to the other typologies. This is in line with the findings of Desbouys, Ridder, Rouche, and Castetbon (2019), in which socio-economic characteristics were coupled to food consumption in adolescents and young adults based on the BNFCS 2014. They have found that consumers that were born outside Belgium had a healthier food consumption patterns compared to consumers born in Belgium (Desbouys et al., 2019). Highly educated consumers were mainly found in class 4 and class 5, typologies that move towards more plant-based protein consumption. The study of Mosier and Rimal (2019) shows similar findings: consumers with higher education levels are more likely to adopt plant-based food consumption patterns. The highest percentage of unemployment occurs in class 3 and 4, which have a lower meat consumption than the other classes. Inhabitants of the Brussels-Capital region are more represented in the classes with moderate/low meat consumptions (class 3–5). Class 1, high in meat products and low in plant-based protein sources, showed the highest percentage of obesity. The percentage decreased when moving from class 1 to class 5, together with a decrease in meat consumption and an increasing consumption of plant-based protein sources. This is supported by the study of Lin et al. (2011), which found a negative relationship between BMI and the intake of plant-based protein sources.

4.6. Limitations of the present study

While this study has developed a solid framework to identify protein consumption typologies, some limitations have to be underlined. Protein consumption frequencies were used for the identification of typologies, which do not reflect the consumption *amounts*. Usual intakes reflects both the consumption frequency and amounts, however, they cannot be used for identifying groups in a population, as elaborated on in the materials and methods section. Usual intakes of the protein sources are however determined in the characterization of the typologies to map also the consumption amounts of the included protein sources. While the "Multiple Source Method" (MSM) was chosen to estimate usual intakes, as described above, other possibilities were tested as well, including the "National Cancer Institute" (NCI) method (Tooze et al., 2006) (version 2.1) and the "Statistical Program to Assess Dietary Exposure" (SPADE) (Dekkers et al., 2014) (version 3.2) (results not shown). The usual intake of some protein sources could not be determined for each typology with the MSM (as shown in Fig. 1) due to the small sample sizes of some of the typologies and a lack of positive intakes. The minimum amount of participants with two positive intakes needed to estimate the usual intake differs between the tested methods due to differences in modeling: SPADE and the NCI require more participants with two positive intakes compared to MSM. Nevertheless, the mean intakes obtained by the different methods were similar, confirming more extensive comparisons of the methods (Souverein et al., 2011; Verly-Oliveira, Fisberg, & Marchioni, 2016). It was decided to report on the MSM results because it allows a more elaborate comparison between the typologies, while keeping in mind that the results on small sample sizes are (probably) only a rough approximation. Another limitations is related to the compliance to the FBDG's, for which the intakes of protein sources were assessed by combining the FPQ values with the average portion size of each typology based on the 24-h recalls. These values are less precise than the usual intakes determined by the MSM and therefore sometimes (slightly) different, but were used because the FPQ classification matches the protein groups of the FBDG's more precisely than the GloboDiet classification.

4.7. *Future research: towards the optimization of food consumption patterns in terms of environmental impact and nutritional adequacy at typology level*

Compared to studies taking into account average, nationwide food consumption patterns, the identified typologies allow to optimize food consumption patterns in terms of environmental impact and nutritional adequacy on a more individual level. These optimized diets can be translated into more personalized dietary advices compared to general advices. An example of a diet optimization study taking into account differences in food consumption patterns is the study of Horgan, Perrin, Whybrow, and Macdiarmid (2016), who optimized individual food consumption patterns in terms of greenhouse gas emissions (GHGE) and nutritional recommendations, based on current food consumption patterns in the UK. Similar to the findings in this study, they found that there are incompliance to most nutritional and food based dietary guidelines. They formulated food consumption patterns that were (1) healthy and (2) sustainable by minimizing the changes to current food consumption for each individual. For some individuals, the intake of products with high GHGE's had to increase to meet the nutritional constraints, showing the possible trade-off between environmental impact and nutritional value.

While dietary advices based on minimal changes from current food consumption patterns are more likely to be acceptable (Kanellopoulos et al., 2020), it is imaginable that these changes will not be acceptable for all individuals. Moreover, there will always be consumers that are not willing to change their current food consumption pattern, as shown by Vanhonacker, Van Loo, Gellynck, and Verbeke (2013). In future research, the acceptability of dietary changes for the different protein source typologies should be validated. This can be done by for example organizing focus groups, a qualitative research method in which a group of people discusses a certain topic (Bryman, 2012). Specifically, the acceptability of changes in protein consumption patterns based on maximal changes (e.g. 10%) from the current food consumption patterns can be discussed, as in Austgulen, Skuland, Schjøll, and Alfnes (2018). The classification criteria would be the basis to form different focus groups; participants can easily identify themselves with a class by indicating how frequently they consume meat. In this sense, the classification approach presented in this research is more recommended than the clustering approach to use in future diet optimization methods. However, the clustering approach can be used to refine the formed classes, for example during the focus group to find out to which subgroup (Fig. 4) the participants belong. By consequently optimizing the food consumption pattern of each protein consumption typology separately, with the corresponding acceptability constraints, targeted advices can be formulated for each typology.

4.8. *Conclusion*

This study has shown that both statistical clustering and classification with predefined grouping criteria can be used to identify protein source consumption typologies in the Belgian population. While clustering revealed that milk and grain products are determinant for the variability in Belgian protein consumption, classification revealed that meat is predominant in Belgian protein consumption patterns. The combination of the two techniques revealed detailed protein consumption subgroups in the Belgian population. The typologies and/or subgroups are the starting point for more personalized dietary advices to lower environmental impacts while ensuring adequate nutritional values.

Acknowledgments

The BNFCS2014 results from a collaboration between Sciensano, the Belgian Federal Public Service Health, Food Chain Safety and Environment and the European Food Safety Authority (EFSA)

The authors would like to thank Niels Demaître for his assistance in the visualization of Fig. 4, Matthias Naets for his assistance in data management, Naeem Muhammad for his coding efforts and Johan De Tavernier for his ongoing interest in the research topic. The authors further wish to explicitly thank the anonymous reviewers for their helpful, constructive comments.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.appet.2021.105583.

Author contributions

Klara Van Mierlo: conceptualization, methodology, software, validation formal analysis, investigation, data curation, writing – original draft, writing - review & editing, visualization. Karin De Ridder: resources, data curation, writing - review & editing. Annemie Geeraerd: conceptualization, methodology, validation, resources, writing - review & editing, supervision, funding acquisition. Each author has approved the final version of the manuscript.

Funding

This work was supported by the Science, Engineering and Technology Group at KU Leuven for the Expertise Centre Ethics@Arenberg.

Declaration of interest

None.

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