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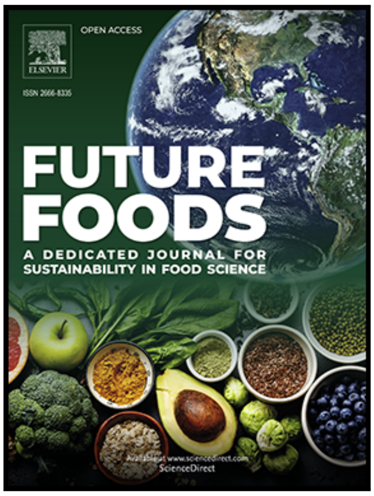

A Clustering Approach To Unravel The Mysteries Of The Food Product “Burger”. Comparison And Classification Of Belgian Market Products Following Three Cooking Methods

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Highlights

- 87 burgers were catalogued from Belgian supermarkets.
- Multivariate analysis can be applied to cluster burgers.
- Among plant-based burgers, only 50% of them can be considered as meat analogue.
- A burger is a food product defined by its appearance and not its texture or nutrition.
- The cooking method has little influence on texture and cooking properties.

A Clustering Approach To Unravel The Mysteries Of The Food Product "Burger". Comparison And Classification Of Belgian Market Products Following Three Cooking Methods

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Keywords: Burger, Meat analogue, Classification, Proteins, Texture, Cooking

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Abstract

Meat analogues are designed to reproduce the sensory and nutritional attributes of meat. Among these products, those labelled as “burgers” constitute a strategic category as they are widely represented on supermarket shelves in Western Europe. However, it remains unclear whether items marketed under this designation share consistent characteristics or effectively emulate meat like properties. In this study, eighty-seven burger products from Belgian supermarkets were catalogued and classified into five groups using multivariate analysis based on their nutritional declaration. Twenty-one products were then randomly selected, cooked using three cooking methods (pan-cooking, oven-baking and sous-vide thermostatic-batch cooking) and subjected to comprehensive physicochemical analyses.
The findings reveal that burgers exhibit consistent physical characteristics, primarily a round or oval shape, a diameter of approximately 9 cm, and a thickness close to 1.8 cm, indicating that their common identity is defined by format and culinary function, rather than by nutritional or textural uniformity. In contrast, lean beef burger remains distinct in both appearance and nutrient composition. Among plant-based products, two categories emerged: (i) burgers with high carbohydrate and low protein contents exhibiting textural properties markedly different from meat products and (ii) formulations, often incorporating extruded proteins, that more closely approximate meat burgers in both texture and nutritional profile. Only products in this second group, representing 50% of the plant-based burgers sampled, fulfil the criteria to be considered true meat analogues. Across cooking methods, neither texture nor cooking

properties were substantially altered, suggesting that cooking techniques does not significantly modify the intrinsic properties of these products.

Introduction

Growing awareness of the environmental consequences of meat production, in combination with health concerns related to processed red meat consumption and increasing public attention to animal welfare, has contributed to the expansion of plant-based food production and consumption (Ketnawa et al., 2024; Kołodziejczak et al., 2024). Although the protein transition remains a complex process influenced by diverse economic, cultural, and political stakeholders (Duluins et al., 2025), it has become increasingly embedded in public discourse and has stimulated significant industrial innovation (Lima Nascimento et al., 2023). Plant-based proteins can be incorporated into the human diet through direct consumption of whole foods such as cooked pulses, nuts, seeds, and cereals, or through their use as ingredients—such as flour, protein concentrates or isolates—in the development of plant-based alternatives to animal products, including especially meat analogues and plant-based milks.

Meat analogues are food products engineered to replicate the sensory and functional attributes of conventional meat—such as texture, flavour, appearance, and cooking behaviour— in order to be commercially successful (Chiang et al., 2019; Schreuders et al., 2021; Shireen and Wright, 2024), for example through the use of plant-derived proteins like soy, wheat gluten, or pea protein and structuring techniques such as extrusion (Kyriakopoulou et al., 2021; Nowacka et al., 2023; Rout et al., 2024). In contrast, meat alternatives refer more broadly to any non-meat foods replacing meat in the diet, including traditional plant based protein sources as well as more technologically advanced analogues (Ray et al., 2024). Consequently, while meat analogues constitute a specific subset of meat alternatives designed to mimic meat's sensory profile, many meat alternatives do not aim to imitate meat but simply provide nutritionally adequate substitutes. This distinction aligns with current literature documenting the classification, technological challenges, and sustainability implications of plant based meat products (Kołodziejczak et al., 2021; Yan et al., 2024).

Meat alternatives encompass a broad range of products designed to replace conventional meat, including plant-based items such as plant-based meat analogues (PBMAs) (Shireen and Wright, 2024), cultured meat, insect-based alternatives, and fermentation-derived products which replace the piece of meat in a meal (Caparros Megido et al., 2016). The latter category includes foods produced through biomass or precision fermentation, using microorganisms such as fungi (mycoprotein), bacteria, or yeasts (Cedeno et al., 2025; Knychala et al., 2024; Martin and Chan, 2024) as these new source present many advantages in terms of nutrition and productivity making them convenient to design meat analogues (Muazzam et al., 2025). Nevertheless, consumer acceptance remains the main bottleneck in the development of these next-generation meat alternatives, and a technological market analysis could help in designing more effective strategies.

In Western Europe, PBMAs currently represent the most widely consumed category of meat alternatives and are available in a variety of formats that replicate traditional meat products (Shireen and Wright, 2024). Common examples include meatballs, ready sliced products, ground meat, nuggets, sausages, and burgers (Andreani et al., 2023; Rout et al., 2024; Vila-Clarà et al., 2024). Those products are typically often inspired by products originally manufactured from comminuted meat (Pierre et al., 2024). Other plant derived products, such as seitan, tofu, and tempeh, can also serve as substitutes for meat. However, these foods are not classified as meat analogues. Instead, they are considered first generation meat alternatives, predating the development of modern extruded plant protein matrices (Vila-Clarà et al., 2024). These traditional products differ from PBMAs in their formulation, processing techniques, sensory properties, and their limited intent to mimic meat's structure or organoleptic profile.

Plant-based meat analogues rely on a wide diversity of ingredients, among which water typically represents the predominant component, while vegetable proteins constitute the key macronutrient (Vila-Clarà et al., 2024). Proteins sourced from pulses—particularly pea and soy—are commonly incorporated in the form of isolates or concentrates and may undergo various degrees of texturization depending on the processing technology applied. Their functional properties, including solubility, gelling capacity, and emulsification, are strongly influenced by the specific processing conditions (Vila-Clarà et al., 2024). To reproduce the fibrous structure characteristic of animal muscle, extrusion remains the most widely used structuring technology. High moisture extrusion involves processing proteins with 50–70% water to directly form structured products, whereas low moisture extrusion produces dried protein matrices requiring hydration prior to final preparation. These dehydrated matrices, known as textured vegetable proteins (TVPs), are frequently employed to imitate minced meat products due to their ability to mimic the fibrillar architecture of muscle tissue (Dubey et al., 2024). TVPs may also be blended with animal meat to produce hybrid products that maintain high consumer acceptance while reducing the proportion of animal-derived ingredients (Singh and Sit, 2022). Despite these technological advances, fully plant-derived meat alternatives still encounter several challenges, notably concerning nutritional quality, textural fidelity, and consumer acceptance (Zhu et al., 2024). Unlike conventional meat, PBMAs often contain substantial amounts of carbohydrates—including dietary fibre—which contribute to texture, binding capacity, and overall product consistency. Although total fat content may be comparable between meat products and PBMAs, their fatty acid profiles typically differ due to the predominance of plant-based lipid sources. Additional formulation components include hydrocolloid binders such as plant gums or cell wall derivatives to stabilize water and lipid phases and improve texture. Spices, essential oils, meaty flavourings, seasonings, and colorants are frequently incorporated to approximate the sensory attributes—flavour, aroma, and colour—of conventional meat products.

Burgers rank among the most widely consumed processed meat products globally, particularly in Western countries (Cristian Adrian et al., 2024; Tarjuelo et al., 2023), and their continued popularity is largely attributed to their versatility (Mercês et al., 2024). A traditional patty is typically composed of minced beef, salt and spices (Moll et al., 2023). In western Europe, the burger model is frequently used by the food industry as a vehicle for incorporating new or less common ingredients like nuts, seeds, legumes or pulses.

Moreover, in March 2026, the European Union decided to retain the controversial designation "burger" for plant-based products, while prohibiting the use of terms such as "steak" and other animal-related descriptors, including "breast" or "drumstick" (Pinto, 2026). To date, there is no official or legal definition of the products referred to as "burgers" in Belgium, nor more broadly within the European Union, which may partly explain the ongoing debate surrounding this terminology. In the context of the protein transition, where consumers are encouraged to reduce meat consumption for environmental reasons, clear and accessible communication grounded in scientific evidence is essential to support the maintenance of a high-quality diet.

Plant-based burgers, considered as meat analogue, are designed to replicate the texture, protein content and flavour profile of conventional meat burgers (Mercês et al., 2024). However, other vegetable-based patties (often referred to as “veggie burgers”) may not always be considered as PBMAs for unclear reasons, which can lead to confusion among consumers regarding product categorization (Shireen and Wright, 2024). These items nonetheless represent a major segment of the new generation of plant-based meat alternatives. Burgers are particularly popular among young consumer, driven by factors such as taste, convenience and social influence (Asha et al., 2025) making them a strategic format for the introduction of novel food ingredients. In retail settings, burgers are commercialized in various preservation states, including frozen, refrigerated or “refreshed” (refrigerated after thawing). On top, some of the products are sold pre-cooked or pre-fried, further enhancing their convenience and accessibility.

In 2025, the market for plant-based alternatives in Belgium was valued at approximately €60 million, representing 2.5% of the total meat market. Indeed, Belgium, as a relatively small country characterized by two distinct communities (Wallonia and Flanders), a high population density, a cosmopolitan population, and a well-developed food industry, represents a particularly relevant case study for conducting a technological market analysis of burger alternatives. In Belgium, as for many other European countries, price and in-store presentation remain significant barriers for consumers (Dereymaeker, 2026). Moreover, a study examining the nutritional aspects of ready-to-eat meat alternatives on the Belgian market showed that plant-based burgers are widely available and can be categorized into several groups, such as breaded versus non-breaded products, or those containing vegetables, legumes, nuts, or seeds. These categories are primarily based on ingredient composition rather than nutritional profile (Mertens et al., 2024). Regional differences in consumption patterns have also been observed: consumers in Wallonia, the French-speaking region of Belgium, appear slightly less inclined to consume alternative protein products compared to those in Flanders, the Dutch-speaking region (Zaleskiewicz et al., 2024). In 2020, 51% of Belgian consumers reported that existing plant-based alternatives adequately met their needs. At the same time, national dietary guidelines, including the food pyramid, have been designed to encourage reduced meat consumption for both health and environmental reasons (Bryant and Sanctorum, 2021; Geeraerts et al., 2020).

Traditional in-home cooking methods applied by consumers play a crucial role in determining the appearance, sensory attributes, and texture of plant-based meat alternatives (PBMAs) (Yoganarasimhaswamy et al., 2025). Cooking conditions, particularly time and temperature, influence the internal temperature of the product and promote interactions between proteins and other ingredients, including Maillard reactions as well as structural modifications within the matrix. In conventional meat systems, for instance, the thermal denaturation of actin and myosin in beef leads to fluid loss and increased hardness (Vu et al., 2022; Yoganarasimhaswamy et al., 2025). However, as plant-based burgers differ substantially from meat burgers in terms of protein types and manufacturing processes, it remains unclear whether their cooking behavior follows similar mechanisms. From a consumer perspective, minimal shrinkage and uniform browning are considered desirable cooking characteristics for PBMAs. Common household cooking methods for these products rely on dry heat techniques, such as oven baking, roasting, grilling, and pan-frying (Yoganarasimhaswamy et al., 2025).

The rapid expansion of alternative burger products in retail outlets, combined with the wide range of ingredients and manufacturing approaches used to produce them, raises the question of whether these strategically important and controversial food product shares any consistent

defining characteristics. Moreover, as already mentioned, plant-based burgers are frequently categorized as a meat analogue, yet the degree to which they effectively replicate meat-like attributes remains uncertain and warrants clarification for consumers.
Thus, the primary objective of this local technological study is to provide a detailed characterization of these products by examining their nutritional profiles, physical appearance, textural properties, and cooking behaviour. The aim is to determine whether a common pattern can be identified across products or whether this category is composed of distinct groups with differing characteristics. In this context, an important question arises: does this market correspond to a homogeneous model, or does it encompass multiple, differentiated product profiles?
This work could enable industry stakeholders to better understand product performance and behaviour, thereby supporting the development of more effective strategies for the design of next-generation burger alternatives, particularly in terms of formulation, processing, and cooking performance.
Beyond its contribution to food innovation, this study may also assist policymakers in establishing a clearer legal framework grounded in quantitative data on the physical and nutritional properties of these products. Such an approach would enhance transparency for consumers, foster greater acceptance, and ultimately support a more informed and effective protein transition.

The first phase involved compiling a comprehensive list of burgers available in supermarkets and classifying them according to relevant theoretical data. In a second phase, a representative subset of products was selected based on this classification then cooked using three preparation methods commonly applied to traditional meat products namely oven baking, pan cooking and sous-vide cooking in a thermostatic bath to determine if one cooking mode performs better than others in mimicking meat products characteristics. Measurements were collected on both raw and cooked samples, enabling analysis across three complementary data categories: theoretical product information, properties of raw burgers, and properties of cooked burgers, including cooking performance. Together, these datasets support a more rigorous comparison and classification of plant-based and conventional burger products.

2. Materials and Methods

2.1. Listing strategy

All products included in this study were sourced from local supermarkets in the Wallonia region of Belgium and were purchased in 2024 or 2025. Only items stored either refrigerated or frozen, and all contain the term “burger” or “steack” on the front of packaging, were considered. In total, 87 products met the inclusion criteria (plant-based and animal-based items combined). For each product, the following information were collected: the nutritional declaration (energy, proteins, lipids, fibres, carbohydrates, salt and water - calculated by difference), the recommended cooking method and conditions (time and temperature), the product’s shape, the portion weight and the protein source.

According to EU labelling regulations nutritional declaration must include nutritional value, total fat, saturated fat, carbohydrates, sugar, protein and salt expressed for 100g or 100 ml of product. Optional elements, such as polyunsaturated fatty acids, fibres, vitamins and minerals may also be provided. It is thus important to note that fibre content is not included in the total carbohydrate value. In addition to the nutritional declaration, the full list of ingredients must be displayed for all prepacked food, with ingredients are listed in descending order of weight.

It is worth mentioning that the nutritional declaration may be calculated based on the composition of the ingredients used rather than being exclusively determined through laboratory analyses in accordance with EU labelling rules (Nutrition declaration - EU labelling rules).

2.2. Classification

Multivariate statistical approach was applied to classify products, combining principal component analysis (PCA) with ascending hierarchical classification (AHC). PCA was conducted using only the variables of the nutritional declaration, without considering the biological origin of the proteins. The coordinates of each product on the first five dimensions were then used to construct a proximity matrix based on squared Euclidean distances. This matrix served as the input for the AHC, performed via Ward's minimum-variance method. The resulting hierarchical structure was visualized through a similarity dendrogram to facilitate interpretation and to explore clustering patterns in a two-dimensional perspective. A dendrogram, by definition, displays hierarchical relationships between observations, and similar approaches have been used successfully in previous studies to group food products according to nutritional similarities and to assess recipe-related environmental impacts (da Silva Torres et al., 2006; Patras et al., 2011).

The optimal number of clusters—corresponding to the cut height in the dendrogram—was determined using the inertia jump curve, which represents within-cluster variance. This height cut-off method was applied consistently across all classifications based on theoretical data, as well as on measurements collected from raw and cooked burgers. The first phase of analysis therefore consisted of clustering the 87 burgers using their theoretical nutritional declaration.

Even if not mentioned on pack, some of the products were probably pre-cooked for storage or ease of processing purposes. Nevertheless, the nutritional declaration remains based on sold products, meaning post pre-cooking.

2.3. Sampling procedure

A total of 3,4 or 5 burgers products were randomly selected from each previously defined cluster, with the number sampled proportional to the size of the group. This procedure yielded a final sample of 21 products, which can be considered representative of the "burger" market in the Walloon region in Belgium during 2024 and 2025. The biological origin of the proteins (meat, fish or plant-based) was then not a direct criterion for the selection. For each product and for each cooking method applied (pan cooking, oven baking and sous-vide cooking in a thermostatic bath), three independent burgers were prepared. In addition, whenever feasible, three replicate measurements were performed per burger, ensuring robust quantitative assessment across cooking modes.

2.4. Cooking methods applied

For oven baking (dry heating oven from Rational®) and pan-cooking (Tillreda induction HOB), the recommended cooking time provided on the product packaging was followed whenever available. The baking temperature was always 180°C for the oven and the power of the baking tray for the pan cooking was always 6. When cooking time was not available, the conditions applied of a similar product were used. The burgers were always flipped halfway through cooking. Parchment paper was used for both cooking method to standardize surface contact conditions and minimize sticking.

Because plant-based burgers are sometimes pre-cooked and typically contain lower moisture levels than conventional meat patties, a gentler cooking method, like sous-vide cooking in thermostatic bath, was also included to evaluate whether it could yield different textural outcomes and reduce water loss (Penalver et al., 2025; Zhou et al., 2021). Sous-vide cooking was carried out using an Anova Precision® Cooker in a water bath. Plant-based and fish burgers were cooked at 60°C for 1 hour, whereas meat containing burger were cooked at 70°C for 1 hour to ensure compliance with food safety requirements.

2.5. Measurements

2.5.1 Weight, moisture and dimensions

Dry matter content was determined using a gravimetric method, whereby samples were dried in an air oven at 130°C for 3 hours. The moisture content and moisture loss were subsequently calculated according to the formula described by Chen. (2003):

$$Moisture\ (\%) = 100 - Dry\ Matter\ (\%)$$

$$Moisture\ loss\ (\%) = 100 * ((Water\ content\ raw\ product - Water\ content\ cooked\ product)/Water\ content\ raw\ product)$$

The cooking loss was calculated using the following equation (Ayalew et al., 2024):

$$Cooking\ loss\ (\%) = 100 * (1 - (weight\ after\ cooking/weight\ before\ cooking))$$

Product dimensions (diameter and thickness) were measured with a calliper. Surface and volume were estimated by assuming burgers were cylinder and applying the corresponding mathematical formulas. The absolute dimensional changes due to cooking including variation in thickness, surface and volume were determined by subtracting the measurements on the cooked product from those of the raw product.

Unless otherwise specified, all percentages are expressed on weight basis.

2.5.2 Instrumental colour

CIELAB colour space $L*$ (lightness/brightness) $a*$ (redness/greenness) $b*$ (yellowness/blueness) was used to express the instrumental colour. The equipment used was a ColorFlex EZ spectrophotometer from HunterLab with CIE standard illuminant D65.

The colour change due to cooking for each dimension ($\Delta L*$, $\Delta a*$ and $\Delta b*$) and the total colour change (ΔE) have been calculated as described by Mandliya et al. 2022.

$$\Delta L* = (L* \text{cooked} - L* \text{raw})$$

$$\Delta a* = (a* \text{cooked} - a* \text{raw})$$

$$\Delta b* = (b* \text{cooked} - b* \text{raw})$$

$$\Delta E = \sqrt{\Delta L*^2 + \Delta a*^2 + \Delta b*^2}$$

2.5.3 Instrumental texture

Texture Profile Analysis (TPA), a widely used instrumental method for characterising the textural properties of solid food products, was used to assess the textural attributes of the cooked burger samples. TPA relies on a bi-cyclic compression of a sample to derive mechanical parameters commonly associated with human sensory perceptions. All measurements were performed using a TA.XTPlus texture analyzer (Ametek TA1 Lloyd). For each burger, three cylindrical sub-samples (24 mm diameter), were prepared and equilibrated to ambient temperature prior to testing. A cylindrical probe (50.8 mm diameter and 50 mm height) was used at a speed of 2.5 mm/s with a preload of 1N. Samples were compressed to 40% of their initial height. The textural parameters considered most relevant for meat analogue product, hardness, chewiness, cohesiveness, resilience, and springiness, were recorded (Souppez et al., 2025; Vu et al., 2022). As all these parameters are known to be highly correlated, a PCA was subsequently applied to the resulting dataset (6 textural attributes from the TPA) to derive a dimensionless textural attribute, referred to as “Dimensions 1” gathering more than 80% of variability. This parameter has no physical sense but is a good assumption to relatively compare texture of products.

2.6. Statistical analysis

Three independent replicates were performed for each condition, and three measurements were taken per replicate whenever possible. Because repeated measurements within the same product and cooking condition could not be considered statistically independent, a linear mixed model (LMM) was employed to evaluate the effects of the nutritional group, cooking method, and their interaction. Random effects have been associated with the sampling of burgers within each group and with individual cooking processes. Estimated marginal means were calculated and pairwise contrasts were used to identify significant differences between groups. For variables based on independent measurements, a two-way analysis of variance (ANOVA) was applied followed, when assumptions were met, by Tukey’s HSD or Games-Howell post-hoc test if homoscedasticity was not respected (p-value < 0.05). All the statistics analysis and data processing were performed with the statistical software RStudio (R version 4.4.1).

3. Results and Discussion

3.1. Initial classification based on theoretical data

The macronutrients composition reported in the nutritional declaration of the 87 listed burgers from supermarkets exhibited substantial variability (Table 1). Fat and energy contents were strongly correlated and inversely associated with water content which emerged as the most discriminating variable among products (Fig. 1). Carbohydrates and proteins were also negatively associated, indicating that products with lower protein levels tended to contain higher carbohydrate amounts meaning carbohydrates are more abundant when protein content is low and vice versa. Protein content, typically considered a defining characteristic of meat-based products, showed considerable fluctuation across the dataset, suggesting that protein level is not a consistent common attribute of the “burger” food product in the region studied. In contrast, salt and fibre contents displayed comparatively limited variation.

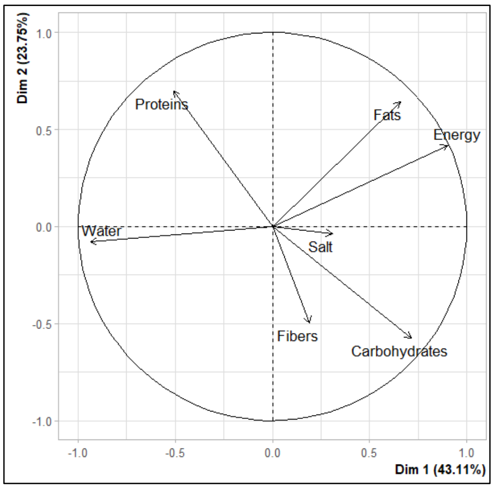

Fig. 1. Score plot of the first two principal components derived from PCA performed on the nutritional declarations of 87 burgers available in Belgian supermarkets in 2024–2025.

Overall, a representative approximation of the nutritional profile of burgers marketed in Wallonia during 2024--2025 is shown in Table 1, showing that fats, proteins and carbohydrates are present in roughly similar proportions, each averaging around 11-12%.

Table 1. Average theoretical nutritional declaration of a "burger" in Belgian supermarkets. Values are expressed as mean ± standard deviation.

Energy (Kcal/100g)	203.83 ± 46.19
Fats (g/100g)	10.79 ± 4.61
Proteins (g/100g)	12.85 ± 5.7
Carbohydrates (g/100g)	12.57 ± 9.03
Fibers (g/100g)	2.67 ± 2.33
Water (g/100g)	59.26 ± 9.06
Salt (g/100g)	1.11 ± 0.37

The ascending hierarchical classification (AHC) applied to the 87 listed burgers revealed several plausible clustering structures (Fig. 2). The most pronounced drop in within-cluster inertia occurred when the dataset was partitioned into two groups (Fig. 3). The first cluster comprised 53 burgers, predominantly containing meat and plant-based formulations, while the second cluster grouped 34 burgers made primarily from fish or plant-based protein sources. Protein origin (plant, fish or meat), was not used as a classification criterion, the dendrogram naturally reflected this distinction, with products sharing the same protein sources tending to cluster together. This pattern indicates that protein origin contributes substantially to similarities in nutritional composition.

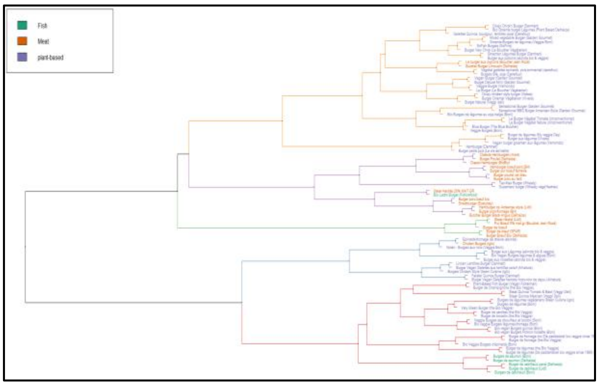

Fig. 2. Resulting dendrogram of ascending hierarchical classification applied on nutritional declaration of 87 listed burgers from PCA coordinates.

Five clusters were defined arbitrarily from the 87 burgers present in the dendrogram (Table 2), as this partition accounted for more than 50% of the total inertia (Fig. 3). These clusters are represented by colour-coded branches in the dendrogram (Fig. 2) and are referred to as Group 1 through 5. Generating more than seven clusters offered no additional interpretative value, as further divisions contributed minimally to the explained inertia.

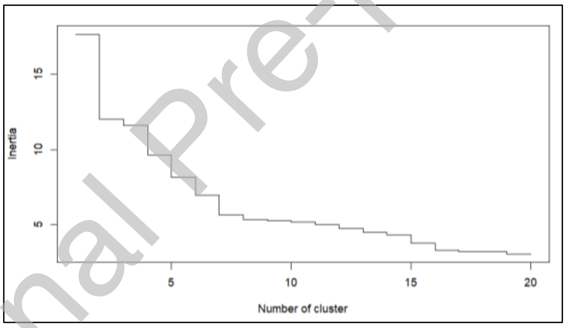

Fig. 3 . Loss of inertia of the hierarchical ascending classification based on PCA coordinates according to number of clusters.

The nutritional declaration revealed substantial heterogeneity across the products, indicating that the nutritional profile of the “burger” in the studied market is far from uniform as it could be expected considering the place occupied in a meal and on the shelves (Table 3). Group 1 is characterized by a water content below 50% and carbohydrate content close to 20%, a pattern similar to that observe in Group 4, although both groups also show comparatively lower protein levels than Group 3 and 5. Group 5 stands clearly apart, consisting of exclusively 100% beef burger made from lean meat and composed primarily of water and protein. Group 3 contains primarily fatty meat products and is distinguished of by high fat and protein levels. Group 2, composed mainly from plant-based burger, occupies an intermediate position between Groups 1-4 and Groups 3-5, particularly in terms of protein and carbohydrate contents. From a nutritional standpoint, this makes Group 2 the most comparable to traditional meat burgers. Conversely, products in Groups 1 and 4 exhibit nutritional compositions that differ markedly from what is typically expected for PBMA. According to the European food safety agency (EFSA), healthy adults require 0.83 g of protein per kilogram of body weight per day. A burger from Group 4 used as a primary source of proteins in a meal, will likely not meet this recommendation. Additionally, assessing nutritional adequacy in plant-based products requires considerations of nutrient which may differ substantially from those of meat products (De Marchi et al., 2021).

Table 2. Nutritional declaration of the five burger groups arbitrarily made.

Group	n	Energy (Kcal/100g)	Fats (%w/w)	Proteins (%w/w)	Carbohydrates (%w/w)	Fibers (%w/w)	Salt (%w/w)	Water (%w/w)
1	11	268.64 ± 26.98^{a}	15.64 ± 3.54^{a}	10.41 ± 3.01^{bc}	19.22 ± 6.99^{a}	5.01 ± 2.31^{a}	1.15 ± 0,19^{a}	48.57 ± 5.33^{d}
2	32	177.63 ± 35.46^{c}	8.5 ± 3.93^{c}	13.28 ± 3.86^{c}	9.78 ± 4.75^{b}	4.37 ± 1.47^{a}	1.15 ± 0.23^{a}	62.96 ± 5.53^{b}
3	16	214.31 ± 30.13^{b}	13.92 ± 4^{ab}	18.65 ± 4.2^{a}	3.27 ± 3.17^{c}	0.53 ± 0.67^{bc}	1.31 ± 0.54^{a}	62.32 ± 4.86^{b}
4	23	220.61 ± 23.54^{b}	11.11 ± 2.44^{bc}	7.5 ± 4.09^{b}	22.36 ± 5.68^{a}	1.23 ± 1.37^{b}	1.07 ± 0.24^{a}	56.72 ± 4.51^{c}
5	5	118.2 ± 10.47^{d}	3.3 ± 1.69^{d}	21.44 ± 0.93^{a}	0.54 ± 0.36^{d}	0.2 ± 0.27^{c}	0.34 ± 0.28^{b}	74.18 ± 0.94^{a}

Values are expressed as mean ± standard deviation. Different letters in a same column indicate a significant difference according to Tukey's HSD or Games-Howell post-hoc test on the Anova (p-value < 0.05).

Table 3. Randomly sampled burgers in each of the five groups arbitrarily made and theoretical corresponding nutritional declaration.

Burger name (brand)	Category	Energy (Kcal/100g)	Fats (%w/w)	Proteins (%w/w)	Carbohydrates (%w/w)	Fibers (%w/w)	Salt (%w/w)	Water (%w/w)	Group number	Pan conditions (min)	Oven conditions at 180 °C (min)
Burger aux Légumes (abinda bio & veggie)	plant-based	245	16.1	10.6	13.1	5.1	1.1	54	1	6	12
Burger Vegan Galettes haricots noirs-noix de cajou (Alnatura)	plant-based	251	13	6.8	23	7.4	1.2	48.6	1	5	12
Burgers Chicken Style Green Cuisine (iglo)	plant-based	305	17	12	23	6.2	1	40.8	1	12	20
Epinards-fromage de chèvre (abinda)	plant-based	278	17.2	10.4	19.2	3.3	1.4	48.5	1	8	11
Burger Natural (Veggi deli)	plant-based	207	8,5	17.6	11.9	6.5	1.2	54.3	2	4	10
Crispy Chick'n Burger (Damhert)	plant-based	171	5,7	9.6	15	6	1.1	62.6	2	6	20
Le burger aux oignons (Boucher Jean Rozé)	Meat	195	13	14	4.1	2.9	0.94	65.06	2	8	25

Sensational Burger (Garden Gourmet)	plant-based	197	13.5	14	1.9	5.9	0.9	63.8	2	8	13
Vegan Burger (Garden Gourmet)	plant-based	156	5,6	16.9	6,8	5.8	1.3	63.6	2	6	9
Veggie burger (Boni)	plant-based	209	10	18	10	3.5	1.1	57.4	2	8	11
Burger porc-fromage (BH)	Meat	225	15	21	1.8	0.5	1.1	60.6	3	10	10
Classics Hamburgers (Mora)	Meat	202	14	14	3.6	2.7	1.8	63.9	3	5	10
Superhero burger Végé'Hachés (Wheaty)	plant-based	235	9	28	9	0	1.9	52.1	3	5	10
Burger porc boeuf bio (Delhaize)	Meat	277	22	20	0.5	0.5	1.1	55.9	3	10	16
Burger de cabillaud (Lidl)	Fish	218	11	13	17	0	1.1	57.9	4	9	15
Burger de légumes (The Bio Veggie)	plant-based	246	14.5	3.8	24	0	0.9	56.8	4	5	9
Burgers de saumon (Boni)	Fish	236	13	16	13	1.3	0,99	55.71	4	5	10
Plant-Based Fish Burger (Vegan Fisherman)	plant-based	210	6.8	5.6	30.7	2.8	1.3	52.8	4	13	20
Burger de bœuf (Colruyt)	Meat	104	1.3	22	0.7	0.5	0.14	75.36	5	7	15
Steak Haché (Lidl)	Meat	121	3.4	22.2	0.5	0	0.1	73.8	5	7	16
Burger de boeuf (Spar)	Meat	111	1.9	22	1	0	0.6	74.5	5	10	15

3.2. Characterisation of sampled raw burgers

3.2.1 To be a burger or not to be? Physical characteristics of burgers

Across the 21 sampled products, the burger patties consistently logically exhibited a round or oval shape with relatively limited variations in their dimensions. As mentioned earlier, there is no official or legal definition of the food product burger in Belgium and more globally in EU. The mean thickness and diameter were approximately 1.8 cm and 9.31 cm, respectively, and the average weight was close to 100g. The predominant surface colour was light brown ($L*$ = 51.23, $a*$ = 11.88 and $b*$ = 26.56), meaning a colour quite similar to cooked beef. These findings align closely with those reported in a study of 49 burgers from the Spanish market, where median values for physical attributes were highly comparable (Rizzolo-Brime et al., 2023). Similarly, the colour coordinates ($L*$ and $a*$) of both plant-based and beef burgers in a U.S. study were consistent with the values observed in the present dataset (Zhou et al., 2022). The slightly higher $b*$ values recorded in some products can be attributed to the presence breadcrumb coatings, which confer a more yellow hue than the un-breaded samples described by Zhou et al., (2022).

Overall, the physical aspect namely lightness, weight, shape, diameter and thickness showed limited variability relative to other measured parameters particularly the nutritional composition. These traits can therefore be considered structural markers of the "burger" model, reflecting a relatively standardized physical identity across products despite substantial nutritional heterogeneity.

Table 4. Average physical characteristics of burgers sold in Belgian supermarkets in 2024-2025. Values are expressed as mean ± standard deviation.

Diameter (cm)	9.31 ± 0.85
Thickness (cm)	1.80 ± 0.27
Weight (g)	99.37 ± 23.74
Volume (cm³)	110.59 ± 18.53
*L**	51.23 ± 8.86
*a**	11.88 ± 5.21
*b**	29.56 ± 12.48

3.2.2 Classification and clustering according to appearance

Classification based on appearance (colour coordinates and dimensional parameters), as it could be expected, showed no clear correspondence between nutritional grouping and visual characteristics (**Error! Reference source not found.**). Indeed, four distinct clusters could be identified using appearance-related variables namely colour and all dimensional attributes. Except for burgers belonging to nutritional Group 5 (100% beef burger, lean meat), products from the previously defined nutritional groups, especially Group 1 and 3, were distributed relatively irregularly across the appearance-based clusters. Burgers from group 2 and 4 displayed for their part a respective tendency to remain together. Appearance remains a key quality attribute as it can contributes directly to consumer expectations and product palatability (Zhou et al., 2022).

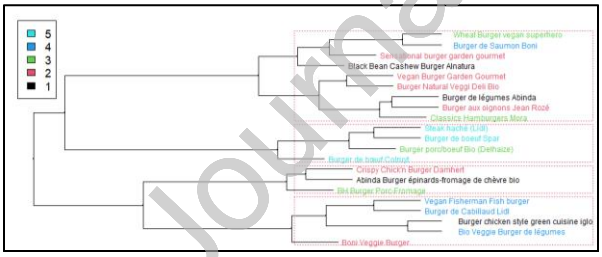

Fig. 4. Dendrogram of the AHC applied on colour coordinates and dimensional parameters of the 21 samples burgers. Colour codes of previously assigned nutritional group maintained.

3.2.3 Classification and clustering according to appearance and nutrition

The burger products available in the Walloon market exhibit far greater variability in their nutritional profile than in their physical appearance (Fig. 5). Notably, the initial five-groups classification based solely on nutritional data (seven variables considered) remained largely consistent when appearance-related parameters, colour and physical dimensions (seven variables considered), were incorporated into the clustering procedure. Four clusters emerged. Burgers belonging to nutritional Group 5 (100% lean beef) consistently formed a distinct cluster, whereas Group 1 and 4 tended to merge.

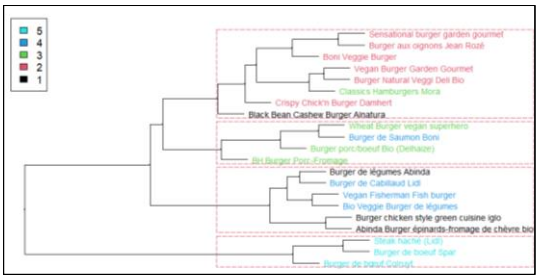

Fig. 5. Dendrogram of the AHC applied on colour, dimensions and nutritional declaration of the 21 samples burgers. Colour codes of initially assigned nutritional group maintained.

These findings highlight that the "burger" as a food model is more strongly and clearly defined by its visual and structural attributes than by its nutritional composition, which can vary widely in the considered market. The colour tends to be light brown, the weight is close to 100g, the diameter is near 9.31 cm and the thickness is close to 1.8 cm. As expected, the shape is always circular or oval. From a nutritional perspective, two broad categories of plant-based products appear to co-exist, (i) formulations that more closely approximate meat's nutritional profile and could therefore be considered as true meat analogues and (ii) products that resemble meat burgers primarily in shape and size but diverge substantially in nutrient composition.

3.3. Cooking properties

Beyond sensory properties and visual appearance, the handling and cooking characteristics of food products also influence consumer dietary choices (Niimi et al., 2022). During cooking several physicochemical and molecular transformations occur, including water evaporation, protein aggregation and denaturation and fat crystal melting. These phenomena can lead to fluid expulsion and structural shrinkage, ultimately reducing the volume and mass of cooked burger (Zhou et al., 2022). In the present study, cooking losses were generally higher for oven-baked burgers compared with those cooked in a pan or sous-vide in a thermostatic bath (**Error! Reference source not found.**b). These losses probably consisted mainly of water (Fig. 6a). Unexpectedly, no significant differences were observed between pan cooking and sous-vide cooking, likely because water and especially liquefied fat or oil were able to escape from the patties and accumulate within the sous-vide pouch. Regarding moisture loss (Fig. 6a), primarily driven by evaporation, a significant difference was observed between oven-baking and pan-cooking. As expected, sous-vide cooking resulted in lower moisture losses than both dry-heat methods; however, moisture retention was not complete. Burgers tended to shrink within the sealed pouch during sous-vide cooking, creating an internal headspace that allowed some water to evaporate and liquefied fat or oil to be expelled, despite the lower temperature conditions.

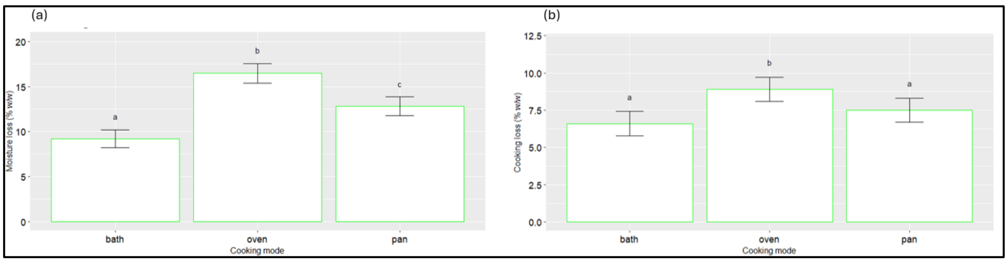

Fig. 6. Moisture loss (a) and cooking loss (b) according to applied cooking mode. Values are expressed as estimated marginal means ± standard error. Different letters indicate a significant difference according to contrasts of the estimated marginal means from the linear mixed model (p-value < 0.05).

Cooking and moisture losses were highest in burgers from Group 5, which consisted exclusively of 100% lean beef meat (Fig. 7a and b). Those burgers initially contain a high-water content (74% w/w) and require a longer cooking time to ensure microbiological safety compared with most plant-based products, which are often pre-cooked. During the heating, contraction of the proteins network generates internal pressure that drives water out of the product, contributing to substantial moisture loss (Hernández-Alhambra et al., 2024). Among the plant-based products, only burgers from Group 2, those with nutritional profiles most closely resembling meat, showed water-loss levels more comparable to those observed in Group 5 across all three cooking methods. This similarity suggests that if lean meat burgers are considered as the reference standard, water loss could be interpreted as a physical marker for meat analogue formulations.

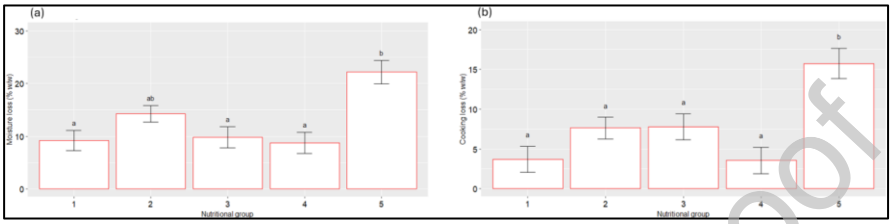

Fig. 7. Moisture loss (a) and cooking loss (b) according to assigned nutritional group. Values are expressed as estimated marginal means ± standard error. Different letters indicate a significant difference according to contrasts of the estimated marginal means from the linear mixed model (p-value < 0.05).

Pan cooking, which transfers heat primarily through conduction, induces greatest surface colour change among the three cooking methods evaluated (Fig. 8b). Direct contact with a hot solid surface promotes Maillard reactions and the formation of a browned crust, both of which intensify surface pigmentation (Yoganarasimhaswamy et al., 2025). Higher temperatures are known to enhance browning reactions and improve the visual appeal of meat analogue products (Souppez et al., 2025). Colour remains a critical quality attribute, as it strongly affects sensory perception and consumer food choices (De Marchi et al., 2021); thus colour changes induced by cooking are likely to be perceived as desirable by consumers. Sous vide cooking in a thermostatic bath and oven baking had comparable effect on burger colour, producing more moderate changes relative to pan cooking. Importantly, the previously assigned nutritional group, did not significatively influence the magnitude of colour change (Fig. 8a), indicating that compositional differences among products did not translate into visually detectable differences in cooking induced browning.

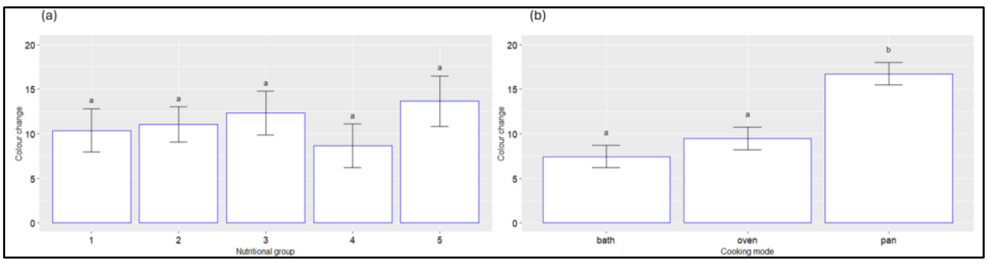

Fig. 8. Colour change according to assigned nutritional group (a) and cooking mode (b). Values are expressed as estimated marginal means ± standard error. Different letters indicate a significant difference according to contrasts of the estimated marginal means from the linear mixed model (p-value < 0.05).

Across all products, burgers thickness, initially relatively consistent among samples, slightly decreased after cooking, although the reduction was less pronounced in the pan-cooked burgers, compared with those cooked sous-vide in a thermostatic bath (Fig. 9a). Surface area was also affected by cooking method: pan-cooked burgers exhibited slightly greater surface reduction than oven-baked burgers (Fig. 9b).

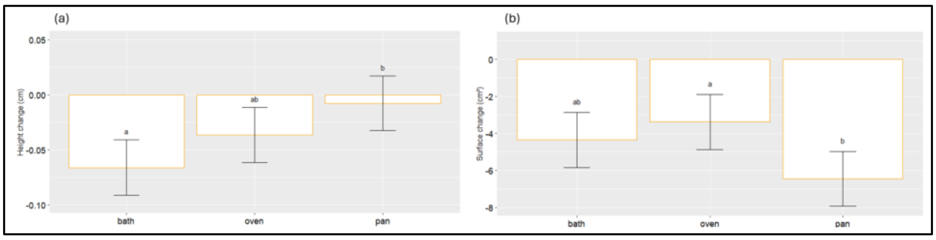

Fig. 9. Thickness change (a) and surface change (b) according to cooking mode applied. Values are expressed as estimated marginal means ± standard error. Different letters indicate a significant difference according to contrasts of the estimated marginal means from the linear mixed model (p-value < 0.05).

When dimensional were examined, based on manual measurements, within the previously defined nutritional groups, thickness and surface reductions tended to follow similar patterns among all groups as no differences are observed (Fig. 10a and b). This indicates that shrinkage during cooking, knowing the limits of the measurement method, could be a characteristic of the burger model itself. In other words, dimensional change could be inherent to the structural behaviour of burgers during heating, regardless of their macronutrient profiles.

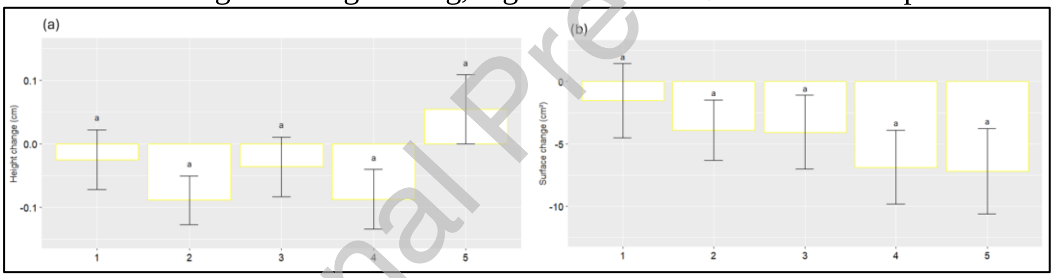

Fig. 10. Thickness change (a) and surface change (b) according to assigned nutritional group. Values are expressed as estimated marginal means ± standard error. Different letters indicate a significant difference according to contrasts of the estimated marginal means from the linear mixed model (p-value < 0.05).

3.4.Cooked burgers characterisation

3.4.1 Classification

Once cooked, that is, in the form in which consumers ultimately encounter them, burgers become more difficult to classify than when only the nutritional declaration is considered. Indeed, for each cooking mode, only two distinct clusters could be identified (**Error! Reference source not found.**). Products made from fatty or lean meat, namely Group 3 and 5, exhibited more similar physical attributes (colour and dimensions) and textural characteristics (6 parameters) than plant-based burgers, which were mainly distributed between Groups 1,2 and 4. Burgers in Group 1, characterized by high carbohydrates content and low proteins levels, remained relatively homogeneous in both appearance and texture across all cooking methods.

Among the plant-based burgers, Group 2 continued to resemble meat burgers most closely, consistent with the observations from the analysis of raw nutritional profiles.

Oven baking yielded the clearest separation between 100% meat burgers and plant-based products (**Error! Reference source not found.**a). Only one plant-based burger clustered together with meat products after cooking. Within the plant-based category, Group 2 burgers consistently remained close to one another and did not intermingle with Group 1 and 4 which are characterized by higher carbohydrates and lower protein contents.

When burgers were sealed sous-vide and cooked in a thermostatic bath at 60 or 70°C for 1 hour or when they were pan-cooked, two distinct clusters consistently emerged (**Error! Reference source not found.**b and c). Notably, the clustering results oven-baking and sous-vide cooking were remarkably similar, despite the substantial differences in heating mechanism and cooking conditions. In both cases, one cluster comprised all meat and fish burgers, along with most Group 2 plant-based products, whereas the second cluster consisted largely of products from Group 1 and 4, typified by higher carbohydrate and lower protein contents.

Across all analyses, the parameters exerting the greatest influence on the clustering of cooked products were those related to the texture (data not shown) indicating that textural behavior during cooking is a key determinant of product similarity.

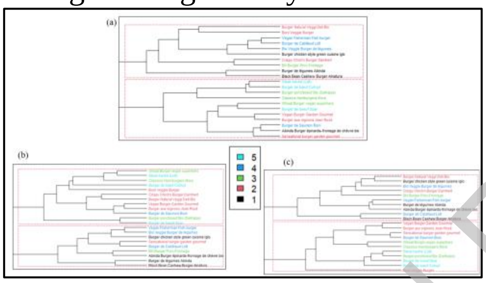

Fig. 11. Dendrograms of the AHC applied on colour, dimensions and textural attributes of cooked burgers. Oven baking (a), thermostatic bath cooking (b) cooking and pan cooking (c). Colour codes of initially assigned nutritional group are shown for a better understanding.

3.4.2 Textural properties comparison

Burgers containing high levels of carbohydrates (Group 1 and 4) exhibited textural profiles that differed markedly from burgers from those of meat-based products (Group 3 and 5) (Fig. 12). In contrast, burgers from Group 2, characterized by lower carbohydrate contents, higher protein levels and, in most of the cases the inclusion of extruded proteins, displayed textural properties more closely aligned with meat-containing burgers. This makes Group 2 the most promising plant-based candidate for mimicking meat in terms of nutritional composition, post-cooking appearance and textural behaviour. Notably, this group represents 50% of the plant-based burgers included in the dataset. Previous studies have similarly identified texture, alongside cooking loss, as a key discriminating factor between plant-based and beef burgers (Zhou et al., 2022). Additional work has highlighted chewiness, hardness, resilience and cohesiveness as critical parameters differentiating plant-based and beef burgers in the United Kingdom (Souppez et al., 2025), which is consistent with the present findings. No clear textural distinction was observed between high-fat and low-fat beef burgers (Group 3 vs Group 5), suggesting that fat content alone does not substantially modify textural outcomes within meat products.

In this study, “Dimensions 1” summarizes six highly correlated TPA-derived textural parameters, hardness (bite 1 and 2), cohesiveness, springiness, resilience and chewiness, into a single, dimensionless axis (Fig. 12). This composite variable provides an integrated measure of overall textural performance and facilitates comparison across product categories.

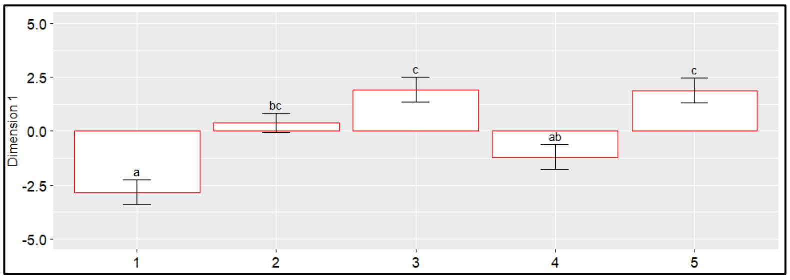

Fig. 12. Texture (one dimension from 6 parameters from PCA = Dimension 1) according to assigned nutritional group. Values are expressed as estimated marginal means ± standard error. Different letters indicate a significant difference according to contrasts of the estimated marginal means from the linear mixed model (p-value < 0.05).

Pan cooking produced slightly different textural outcomes compared with sous-vide cooking in a thermostatic bath and oven-baking (

Fig. 13). However, the magnitude of this effect was smaller than the influence of the nutritional composition of the burgers (Fig. 12). These findings are consistent with previous research showing that cooking method, whether pan frying, air frying or oven-baking has only a limited impact on the final properties of both plant-based and beef burgers (Vu et al., 2022; Zhou et al., 2022). Pan-cooking nevertheless generated distinct effects on colour and texture relative to the other methods, likely due to direct contact with a hot surface that promotes crust formation and enhances browning.

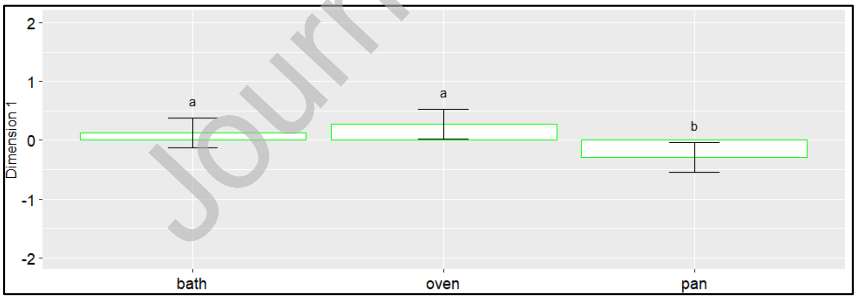

Fig. 13. Texture (one dimension from PCA = Dimension 1) according to applied cooking mode. Values are expressed as estimated marginal means ± standard error. Different letters indicate a significant difference according to contrasts of the estimated marginal means from the linear mixed model (p-value < 0.05).

3.5. Implications for next-generation product development and food regulatory policies

The burger category in Belgium is highly versatile in terms of composition, texture and nutritional profile making it a strategic food model for the incorporation of novel or unconventional ingredients. Belgian supermarket burgers widely include ingredients beyond meat and fish, such as nuts, seeds, vegetables, pulses and even algae demonstrating the

category’s adaptability. Moreover, in the near future, microbial proteins could be incorporated into meat analogue formulations such as burgers, contributing to the development of more resilient and sustainable food systems (Muazzam et al., 2025). Examples of microbial protein sources currently under investigation include spirulina, purple bacteria, and chlorella (De Rijdt et al., 2025; Spanoghe et al., 2021; Wang et al., 2024).
Importantly, the physical attributes of burgers, particularly weight, dimensions, and, to a lesser extent the colour, are remarkedly consistent across both plant-based and meat products. These attributes can therefore be considered as defining “codes” of the burger format and need to be consider by industrials.
From a product development perspective, several opportunities emerge: (1) a non-meat-analogue plant-based burger, with textural and a nutritional characteristics similar to those in Group 1 and 4, could be developed to align with products already well represented on supermarket shelves; (2) A more meat-like plant-based burger, similar to those in Group 2, typically containing extruded proteins and exhibiting nutritional and textural properties close to meat, represents another viable direction; (3) A hybrid burger, combining meat with plant proteins or even with other alternative proteins offers a third potential perspective (Zhao et al., 2026). Hybrid products may achieve uncompromised sensory quality (Niimi et al., 2022) although they currently remain marginal; only one such product was identified among 87 burgers included in this study. Moreover, an empirical study in Belgium showed that health perception of those hybrid products is the most prominent criteria regarding the food choice (Profeta et al., 2021).

Notably, the cooking method does not appear to be a major determinant of product differentiation, as it introduced fewer variations than the nutrient composition itself. Instead, the primary challenge for developing new products in this category lies in consumer acceptance. In Europe, consumers can be broadly categorized into three groups : meat lovers, plant purists and omnivores (Watson et al., 2025). Among them, omnivores may be the most receptive target audience for novel protein sources. However, successfully introducing a new protein, whether plant-based, microbial, or hybrid, requires a holistic strategy encompassing technological feasibility, packaging, marketing, product naming, and regulatory considerations. Past examples, such as insect and fungal proteins in Western Europe, illustrate the significant hurdles associated with consumer adoption (Chezan et al., 2022; Onwezen et al., 2021).

Across Europe, countries exhibit heterogeneous attitudes toward the adoption of alternative proteins (Zaleskiewicz et al., 2024). In particular, consumers in Eastern Europe appear less inclined to adopt such dietary shifts compared to their Northern European counterparts, highlighting the importance of cultural and regional factors in shaping food transitions.
Within this context, the designation “burger” remains a contentious issue in the European Union. Although the European Parliament initially voted at the end of 2025 to ban the use of this term for plant-based products, this position was subsequently reconsidered. In March 2026, following several weeks of debate, EU policymakers decided to retain the term for plant-based products. However, this decision remains provisional, reflecting the ongoing uncertainty surrounding product classification and labeling.
The findings of the present study provide timely and relevant insights into this debate. By demonstrating the existence of two nutritionally distinct categories within the so-called “burger” segment, this work highlights a critical inconsistency: products with markedly different nutritional profiles are currently marketed under a single designation. Such ambiguity may contribute to consumer misunderstanding and weaken trust in product labeling.

Therefore, these results strongly support the need for a more structured and evidence-based regulatory framework. Establishing clearer definitions based on objective nutritional and physical characteristics would improve labeling consistency and enhance transparency. Ultimately, this would empower consumers to make more informed dietary choices and facilitate a more effective and credible protein transition.

4. Conclusion

Burgers in Belgium represent a strategic and flexible food category capable of accommodating diverse ingredient sources. Products labelled as “burger” in supermarkets share consistent physical characteristics, most notably a round or oval shape, a diameter of roughly 9 cm, and a thickness close to 1.8 cm, suggesting that the format’s primary commonality is its intended use or culinary role, rather than a standardized nutritional or textural profile. Lean beef burgers (100% meat), considered as a reference point of comparison, remain distinct from other products in both physical and nutritional attributes. Among plant-based products, two main categories can be identified: (1) exhibiting textural properties that diverge substantially from those of meat (fatty and lean meat), and (2) often incorporating extruded proteins and more closely mimicking meat in texture and nutrition; these products can thus be considered as real meat analogues. Across cooking methods, textural and main cooking properties were not markedly altered, reinforcing that nutrient composition rather than cooking mode is the primary source of variation.

Two major issues emerge from this study. First, given their versatility and strong market presence, burgers represent a valuable model for the incorporation of novel protein sources. From an industrial perspective, this format offers significant advantages, as development efforts can primarily focus on formulation rather than product design, thereby facilitating innovation. However, this flexibility may also lead to consumer confusion, as these products do not necessarily provide nutritional equivalence to meat.

Second, the term “burger” remains highly controversial within the European Union and has recently been the subject of significant political debate. In this context, the present study contributes to the discussion by providing a scientific basis for the development of a regulatory framework. In particular, it supports the need to establish clearer guidelines regarding the nutritional composition of products marketed under the term “burger,” with a specific focus on protein and carbohydrate content.

Future research involving consumer testing would provide essential insights into the sensory attributes that should be prioritized in the development of next-generation burgers, especially those incorporating unconventional ingredients such as microbial proteins. Furthermore, similar classification and technological approaches could be extended to other contested product categories, such as “nuggets” or “sausages,” to support broader efforts toward harmonized and evidence-based food labeling.

Declaration of Competing Interest

There is no conflict of interest between the authors and organisations.

Data availability

Data are available on request.

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Ethical statement

No animal or human studies were performed in this study.

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CRediT authorship contribution statement

De Rijdt Mathieu: Writing – original draft, Investigation, Software, Methodology, Conceptualization. **Brostaux Yves:** Software, Methodology **Goffin Dorothée:** Funding acquisition, Project administration, Validation, Conceptualization **Haubruge Eric**: Funding acquisition, Project administration, Validation, Conceptualization.

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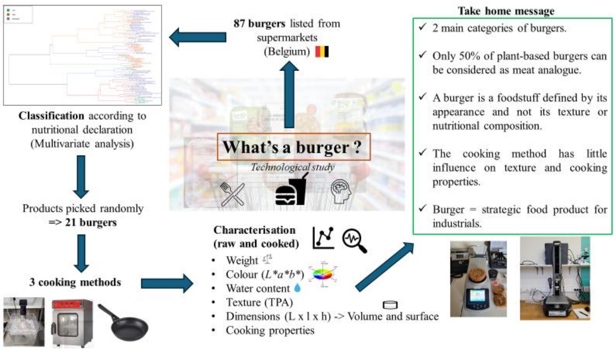
Ethical statement

No animal or human studies were performed in this study.

Graphical abstract



Declaration of Interest Statement

☒ 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.

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