Plant-based meat analogues: From niche to mainstream

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Abstract:

Meat analogues are gradually moving from niche to mainstream products. These products are gaining popularity due to surging consumer demand for plant-based products as “better for you” and “better for the planet” alternatives. In this frame, this review aimed to provide the current and forthcoming challenges for meat analogues industry by addressing their market growth drivers, formulation, the pros and cons of conventional and innovative processing, safety and healthiness as well as consumers perception and acceptance. Despite the significant improvements made in the flavor and texture of plant-based meat analogues, food industries still have difficulties in delivering the right sensory experience and there is increased request for sustainable, nutritious and clean label ingredients. For shaping the future of plant-based meat analogues, the main driver is sustainable nutrition through prompting further improvements in formulation [by enhancing proteins functionally (pre/post-processing) and healthiness (blending plant proteins with tailored nutritional makeup and reducing salt contents)] and processing [by finding solutions to their “processed” and “ultra-processed” nature]. In the future, meat analogue companies will keep pushing the boundaries to mimic meat experience (by improving taste and healthiness) as well as reduce product price and increase product convenience.

Keywords: plant proteins, health, nutrition, sustainability, consumer acceptance

1. Introduction

Meat is an important component of the daily diet providing essential elements for human body including protein, fats, vitamins, and minerals [1]. The global meat market is estimated to grow at a compound annual growth rate of 7.35% during the forecast period 2020-2025 (Research and Markets, 2020)**.** Nevertheless, meat consumption patterns are unpredictable due to constant changes in consumer behavior towards meat [3–5]. Several factors can influence consumer decision including price, appearance, convenience, quality, safety, social, individual, economic, and cultural aspects [3–6]. In the recent years, shift in preferences towards the consumption of plant-based products has been evident since health conscious consumers are seeking safe and healthy products [5]. Despite the health benefits of meat consumption, a diet rich in meat can be related to human issues due to the high content of cholesterol and saturated fatty acids [7, 8]. However, plant-based diets were reported to be cost-effective and with reduced risk towards cardiovascular disease, blood pressure, diabetes, and mortality [9–11]. Media also contributed in changing the dietary habits through promoting the healthiness and sustainability of plant-based products over those animal-based [6]. Population growth (expected to reach 9 billion by 2050) can be a factor pushing the rising interest in plant-based meat to respond to the increasing demand to proteins and to limit the sustainability issues associating animal proteins to increasing feed supplies and higher levels of greenhouse gases production [12]. Furthermore, ethical and religious issues are prevailing concerns surrounding animal-based proteins [13]. As an effective alternative, the development of plant-based meat analogues to replace animal products has created significant breaks for food industries against the above mentioned health, environmental and ethical concerns [12, 14, 15]. Recent studies of life cycle assessment indicated that plant-based meat analogues had a lower environmental impact than meat [16, 17]. These alternative products have a large potential for reducing greenhouse gas emissions (up to 583 MtCO2e per year) and improving nutritional outcomes (up to 52,700 premature deaths avoided per year), but the expected sustainability gains from meat alternatives differ widely based on the ingredients and the process [18, 19].The potential of meat analogues for climate change mitigation is strongly dependent on price reductions and consumers acceptability of the different type of meat analogues including cultured meat, mycoprotein and plant-based meat [20–22].

Plant-based meat analogues are particularly booming in the market, going from niche to more mainstream, with more than 6485 launches of new products worldwide since 2015 [23]. By definition, plant-based meat analogues (also called meat substitutes, mock meat, or faux meat) are plant-based products that mimic the appearance, flavor and the fibrous texture of animal meat [20, 21]. Various plant protein sources (*e.g.* cereals, vegetables, legumes, microalgae and fungi) are used to substitute animal proteins for the production of a wide spectrum of meat-free products such as burger patties, sausages, and nuggets [24–27]. In this frame, this article is focused on the main aspects of plant-based meat analogue industry based on critical compilation of scientific studies to: i) address their market position and the drivers of their growth compared to other meat analogues types, ii) elucidate their formulation with emphasis on the growing range of ingredients, ii) discuss innovative and conventional processing used of meat analogues texturization, iii) discuss the healthiness of the safety of the ingredients used and finally iv) underline the drivers and the obstacles toward consumer acceptance of these products.

2. Market landscape: growth, segmentation and drivers

Meat analogue products are witnessing a great expansion, where the global market is estimated to account for USD 1.6 billion in 2019 and is projected to reach USD 3.5 billion by 2026, recording a compound annual growth rate of 12.0% during the forecast period (Markets and Markets, 2020). Europe (51.5%) holds the largest share of the global market followed by North America (26.8%), Asia Pacific (11.8%), Latin America (6.3%) and Middle East & Africa (3.6%). The top 10 players are Beyond Meat followed by Boulder Brands, Hain Celestia, Nestlé, Garden Protein International, Vivera, Lightlife Foods, Woolworths, Naturli' Foods and Sainsbury's [23]. The main plant-based proteins used in meat analogues formulations are soy proteins (63.3% of total products; isolates 20.3%, concentrates 33.4% and textured 9.6%) followed by wheat (46.8% of total products; ´wheat protein 14.7% and gluten 32.1%), pea (40.2% of total products; isolates 12.2% and concentrates 28.4%), rice protein (7.2%) and vegetable proteins (4.7%) [23].

The main drivers of market growth are attributed to plant meat substitutes association with "better for you" and "better for the planet" tends. Plant-based meat substitutes have been promoted as healthier sources of proteins compared to meat offering health benefits that may play a role in reducing meat consumption [6, 24]. Meat analogs are plant-based protein products that contain highly beneficial essential amino acids, low saturated fat, and are cholesterol-free [29], whereas numerous studies reported the potential links between high consumption of meat products and health issues [30]. The ethical-conscious consumer switched towards plant-based products due to the environmental burden of animal protein production on global warming and resource consumption [14, 31]. Environmental research and life cycle assessments underlined the positive impact of plants (*e.g.* legumes) on preserving soil fertility, conservation agriculture and biodiversity [32–34]. Ethically, animal welfare rights have also contributed in switching consumer preferences [35–37]. Thus, rising niches of ethical and health-conscious consumers mainly vegans, vegetarian and flexitarians greatly contributed in shaping the market of meat analogue, where most of marketed meat analogues have health and nutrition claims mainly vegan (78.1%), vegetarian (32%), high/added protein (37.1%) and gluten-free (31.3%) [23]. Flexitarians following semi-vegetarian diet are a key segment driving the plant-based meat analogue boom as their gateway for a more sustainable and healthier meat substitute [38].

In the future, plant-based meat might have to compete with cultured meat, which is not currently commercialized since it has to fulfill food safety standards [39]. Considering the scenario that cultured meat is proven safe, consumer acceptance toward plant-based meat will be strongly endorsed by: i) familiarity since plant based meat are described “familiar” contrary to cultured meat described as an “unfamiliar” food; ii) ethical concerns over the use of animal cells isolated from slaughtered animals and the use serum bovin foetal as the cells growth media; iii) high level of cell multiplication that might induce some dysregulation similarly to cancer cells; and iv) relatively high production costs and controversial foot printings impact of cultured meat [39–42]. Likewise, ethical cultured meat is still a challenge, where animals’ cells are isolated from egg to resolve the ethical issue [43]. Therefore, plant-based meat analogues present numerous advantages compared to conventional meat and cultured meat thereby contributing in reinforcing their position in the market.

3. Formulation

The major components of fibrous meat analogues are plant proteins (20-50%), vegetal lipids (0-5%), polysaccharides (2-30%) and other ingredients to enable a meat-like experience as summarized in Table 1 [44].

**Table 1

Plant proteins play several roles in structure, color, texture and flavor of meat analogues owing to their tech-functional properties (solubility, emulsification, foaming, viscosity, gelling, flavor binding and film formation) [45–47]. Plant proteins differ in functionality, compositional and nutritional features depending on source, variety, pre-processing, and purity [48]. Plant proteins can be deriving from one source or a blend of sources to achieve a better functionality and nutritional value. Up until now, soy protein is the most used protein used in meat analogue products due to its high functional properties and balanced amino acid composition (protein digestibility-corrected amino acid scores (PDCAAS) of 1.00 comparable to meat) [21, 49]. Soy proteins ensure a double role as extenders and binders at low price. However, manufacturers are gradually moving toward 'clean label' and non-genetically modified protein ingredients [50]. Due to its rheological and viscoelastic properties, wheat protein has a long history of use in meat analogues enabling the formation of fibrous-like texture of the final meat products [46, 51]. Gluten particularly can play the role of binder and extender thereby reducing cooking losses during processing. It holds the fiber together in the matrix for meat analogues to stick the product together and remain stable thanks to its functional properties due to its functional properties such as solubility, viscosity, swelling, and water holding capacity [46]. Pea protein is a rising alternative to soy protein owing to its high adaptability, hypo-allergenicity and good functionality, and mostly used in combination with other sources (*e.g.* gluten) to improve the nutritional and textural attributes of meat analogues [47]. Other proteins from rice and potato are gaining traction specially for formulating gluten-free meat alternatives [52, 53]. Protein ingredients innovations keep moving towards more diverse portfolios through the use of fava bean protein and mung bean protein as well as novel proteins such as microalgae, seaweed and fungi [12, 26, 54] and sweet lupin (due to the absence of alkaloids) [55]. Insects and single cell proteins are gaining interest as alternative protein sources such as owing to their high nutritional value, high content in proteins, sustainability and affordability [56–58].

Lipids rich in saturated fatty acids *(e.g.* coconut oil and cocoa butter) or rich in unsaturated fatty acids (*e.g.* sunflower oil, canola oil, sesame oil and avocado oil) are used to intensify the flavor as well as to improve texture and mouthfeel [59–62]. The source and composition of fatty acids is extremely important to mimic meat flavor related to lipid oxidation and volatiles generated by Maillard reaction during thermal processing [63]. From a nutritional perspective, vegetable oils are cholesterol-free, and thereby considered healthier than animal fats; but more attention must be paid to the composition in unsaturated and saturated fatty acids to create meat-like sensory attributes [64]. Oleogels might be an interesting strategy to substitute saturated fats in plant-based meat alternatives [65]. The application of fiber rich ingredients such as oat-hull-based ingredient or oat's soluble fiber (β-glucan) as fat-free fat replacers thanks to the water binding ability of β-glucan improving the structural characteristics of reduced-fat products [66, 67].

Polysaccharides play important functional and structural roles in shaping meat analogues owing to their thickening/emulsifying properties generally required to improve the consistency and water binding [61, 68, 69]. Native starches and flours (*e.g.* potato, corn, wheat, cassava, pea and rice) are used mainly as fillers ingredients to improve the texture and consistency [49, 70]. Fibers from different sources (*e.g.* pea, potato, oat, soybean, Bamboo, citrus and apple) and polysaccharide gums (*e.g.* xanthan gum, gum Arabic, carrageenan and alginate) enable thickening and reducing cooking loss of the product due to their high water holding capacity through creating stable oil/water emulsions [71].

Flavoring ingredients such as savory yeast extract, paprika, sugar, spices and herbs, are added to mimic/compensate the aromatic profile of meat products and to mask off-flavors of legume proteins.

Coloring agents such as annatto extracts (E 160b), lycopene, beet juice extract or leghemoglobin, are used to mimic meat red color; while titanium dioxide is used to mimic chicken color [47, 53, 72–74]. To ensure heat stability of these pigments, other ingredients are added including ascorbic acid or juices rich in polyphenols and ascorbic acid (*e.g.* apple extract and citrus fruit extracts) [47, 75]. These juices also play the role of antimicrobial and preservative agents ensuring quality stability and shelf-life extension. More research is required to find "clean label" and heat stable colorants.

Fortification ingredients (minerals, amino acids and vitamins) are included to enhance the nutritional value of meat analogues. Health-beneficial ingredients naturally found in animal products such as tocopherols, zinc gluconate, thiamine hydrochloride, sodium ascorbate, niacin, pyridoxine hydrochloride, riboflavin, and cobalamin are added to replicate the composition of meat and to enable to meet the recommended daily allowance [76]. Vitamin B12 is one of the main supplement required by vegans to reach the recommended daily intake [77]. Beside their health benefits, these ingredients can play relevant roles in enhancing meat analogue quality, storage and lipid oxidation. Noteworthy, vitamins and minerals can be added as purified ingredients or within matrices such microalgae, mushrooms or pulses flours [26, 78].

4. Texturizing techniques

The development of the flavor and fibrous structure of meat analogue is strongly related to the ingredients and processing [29]. Beside proteins, non-protein ingredients play an important role in the solidification and the flavoring of meat analogues [12]. Texturizing multiphase blends (*e.g.* protein and polysaccharides) results in anisotropic material whilst pure proteins result in an isotropic material [79, 80]. Texturization is a crucial step since consumers expect a product with similar texture, mouth-feeling, taste, and nutritional value to those of meat products [12]. To mimic the fibrousness of meat muscle, plant-based proteins must go through a series of transformations from their native form (globular shape) to obtain textured protein (linear shape) by applying different processing (*e.g.* extrusion, wet or electro-spinning, high temperature conical simple shearing, freeze structuring, blends proteins- hydrocolloids and 3D printing) (Table 2).

Extrusion is the most traditional patented process for protein texturization and still one of the most used process due to its high productivity, low cost, versatility, and energy efficiency [81, 82]. In addition, extrusion denatures heat-labile anti-nutritional factors (*e.g.* trypsin inhibitors and hemagglutinins) and inactivate hydrolytic enzymes (*e.g.* lipoxygenases, peroxidases and lipoxidases) and increase protein digestibility [83, 84]. Noteworthy mentioning that most of extrusion processes and patents were established for soy protein, but recently more studies have been carried out focusing on wider range of plant proteins (*e.g.* pea, microalgae and *Cannabis sativa*) [26, 29, 47, 85]. Extrusion enable changes in protein conformation (denaturation, unfolding, crosslinking and alignment) due to shearing, heating, compression and cooling to create a meat-like structure (structured aggregates or fibrils) [86]. At low moisture extrusion technology (<35% moisture), meat analogues result with a sponge-like texture requiring a further hydration to create the meat-like texture [87]. However, high moisture extrusion (40–80%) imparted a fibrous meat-like structure due to a better control of product expansion thereby facilitate fat emulsification, protein gelation, particle restructuring, and shaping [60, 88]. The use of high temperatures (140–180 °C) during extrusion ensure protein melting and polymerization but also can lead to changes in color due to Maillard reaction, caramelization, hydrolysis, and degradation of pigments [29, 85].

High-temperature induced shearing was proved efficient in plant proteins texturization in a simple, mild, and cost-effective way [89]. Two devises with different geometries, cone-on-cone and cylinder-in-cylinder, are used to ensure shear-induced structuring of proteins [70, 90, 91]. The cone-in-cone device is designed so the product is placed in the cavity between both cones (the bottom cone is rotating while the top cone is stationary) enabling its heating via an oil bath from both sides at high sheer stress and high temperatures (95–140 °C) [47, 91]. In the cylinder-in-cylinder device, the product is placed between two cylinders (stationary outer cylinder and rotating inner cylinder) creating similar shear flow to that of cone-in-cone device [70, 92]. Compared to extrusion, shear induced structuring results in a defined fibrous structures due to the combination of simple shear and heat [92]. The heating temperature is a key parameter, since shearing at high temperature (140°C) yielded a solid anisotropic food texture contrarily to low temperatures resulting in a layered structure [79].

Wet-spinning has a long history for making fibrous protein products [93–96]. In the wet-spinning process, aged, alkaline protein solution was forced through a spinnerette and then immersed into an acid coagulating bath for precipitation and solidification [94]. The resulting filaments (≈ 20 μm thickness) may be bundled together and stretched to orient the molecular structure of the fibers [93]. This process, however, requires pure proteins, low pH, high salt concentrations and chemical additives [70, 97]. Moreover, this process yields large amounts of wastes (wastewater streams from coagulation and washing steps) [79].

Electrospinning has recently gained interest as a cost-effective and scalable technology for the production of very thin fibrils [98]. During electrospinning, a polymer solution is subjected to a strong electric field through a hollow needle or spinneret. When the electrical forces overcome the surface tension of the solution, the generated electrically charged polymer solution travels toward an electrically grounded collector [99]. On their way, the solvent rapidly evaporate and the jets stretch and bend in ultrathin dry fibrils (≈100 nm) [100] [101]. In electrospinning process, the most important parameters are associated with polymer properties (type, molecular weight, structure and concentration), solvent properties (viscosity, surface tension and electrical conductivity) and ambient parameters (temperature and relative humidity) [99]. Polymers need to be highly soluble and at high concentration to ensure enough overlapping between the molecules and thus creating, an entangled network and the solution must have the right conductivity, viscosity and surface tension. Proteins are generally difficult to electrospin, expect few proteins such as zein due to its amphiphilic polymeric nature [45, 102]. Mixing plant proteins (*e.g.* pea proteins and soy protein) with spinnable polymers (*e.g.* cellulose and maltodextrin) can be a good strategy to ensure the efficiency of this technique [103].

Freeze structuring can also enable the formation of a fibrous structure but it is strongly related to the plant protein source and properties (water holding capacity, solubility and gelation) and freezing/drying conditions (temperature and duration). During this process, proteins are blended with other components until obtaining a uniform emulsion. The resulting blend was molded, frozen (to form ice crystal layers) and dried (steaming, baking or frying) [49]. Drying at high temperature ensure setting the protein fibrous texture (irreversible substantially insoluble form) without melting the ice crystals [104]. Textural properties of proteins can be tailored by modulating freezing conditions (the rate of freezing, pH, the solids content of the material, surface effects, heat exchange effects, degree of confinement, and pressure effects) [104].

Mixing plant proteins and hydrocolloids is also a patented technique for creating meat-like products [105]. A mixture of water, a vegetable fat or oil with a protein (*e.g.* lupine protein, pea protein, potato protein or rape protein), hydrocolloid(s) (*e.g.* sodium alginate and methylcellulose) was sheared to form a stable emulsion and a colloidal solution of divalent metal cations. To initiate fiber formation, casein, with the ability to coagulate with cations, was added to the emulsion cations ensuring the entrapment of the anisotropic structures. The formed fibrous can be modulated through the concentration of the hydrocolloids and the divalent metal cations required for the precipitation and the micellar casein.

Bioprinting (3D printing technology) was recently applied to print meat analogues formulated using plant proteins [106]. The concept of this technique is based on the extrusion of a paste made with plant proteins and other components (*e.g.* water, fat, polysaccharides) through a fine nozzle to build multilayer blocks [107]. The viscosity of the paste is a critical parameter to obtain the required structure, and usually some rheological modifiers are used to achieve the desired rheological properties. The constructed meat analogue go later through a maturation phase in a bioreactor under specific conditions to ensure the stability of structure [107, 108]. This technique enable the design of products with texture similar to muscle fibers and tailored nutritional content. Nevertheless, its major drawbacks are associated with production cost, the complexity of spatial structure and long maturation process [109].

5. Healthiness and safety

Health-conscious consumers pay lot of attention to the nutritional profile of meat analogues, where label readers further focus on the healthiness of the ingredients. In a survey (n=137 products) conducted in Sydney supermarket, plant-based analogues had lower energy, total and saturated fat, but higher carbohydrate, sugars, salt and dietary fiber compared with meat [24]. In these cases, high amounts of fat, sugar and salt were generally used to mask the vegetal notes related to some source (*e.g.* legumes) or to enhance the texture of the product [24]. Only 4% of products were low in sodium (58–1200 mg/100 g) and 24% of products were fortified with vitamin B12, 20% with iron, and 18% with zinc [24].

Formulation is important to improve the nutritional attributes of meat analogues through using natural and clean label ingredients. However, in the pursuit of mimicking meat texture appearance and taste, brands rely on the use of several ingredients, where most of them are heavily processed or/and genetically-modified (GMO)[110]. In recent year, a drastic shift was recorded from GMO to free-GMO, where 39% of launched products are declared GMO-free [23]. Naturalness of the ingredients is gaining traction as consumers are increasingly associating healthy food to natural, recognizable and chemical-free foods. As such, 62% of products launched since 2015 are claimed natural [23]. In this frame, applying clean label ingredients will further reinforce the position of meat analogue in the market, not only for vegan and vegetarians, but also for consumers looking for healthier food options. In recent years, several natural ingredients have been used to substitute those artificial including red colorants, where most brands are more focusing on clean-label and natural red pigments [72]. In addition, breeding for protein with better nutrition and functionality can reduce antinutrients and off-flavor and increase functionality thereby reducing the level of processing and the need to masking agents. More research are required to find solutions (ingredients or/ and processing) to obtain a fibrous structure through the use of health-beneficial ingredients. On the other hand, meat analogues are generally classified as ultra-processed products hampering their healthy image [111]. Concerns are being raised over the association between level of processing and the risk towards health issues such as to cancer and obesity [112, 113]. Meat analogues developers', therefore, need to find solutions enabling the use of clean label ingredients and less processed products to meet consumer expectations [111].

Different plant protein sources are used to tailor the nutritional profile of meat analogues. Such a variability can give a wide array of choice to consumers and thereby indirectly resolve the issue of allergenicity associated with some proteins (*e.g.* soy, gluten, fungi and pulses).Beside macronutrients, edible fungi particularly increase lysine, which is one of the limiting amino acids in cereal-derived proteins [114]. Noteworthy, the safety of edible filamentous fungi species is still a work on progress as it is closely related to authenticity, purity and medium composition [115]. Microalgae also ensured the production of meat analogues with high protein content and balanced amino acid composition [26]. Beyond proteins, the addition of Spirulina increased phenols and flavonoids concentrations as well as antioxidant capacity and vitamins (B and E) [12, 26]. Thus, consumers can select the meat analogue products fitting their needs. From a regulatory point of view, novel proteins deriving from seaweed, algae and some fungi species must go through a regulation procedure to prove their safety for human consumption. Legislation are still unclear and warrant further studies on the regulation aspects [116]. Another issue might be the presence of antinutrients that can be naturally found in legumes. Considering that ingredients go through a series of processing (physical, thermal or/and biological) during meat analogue production, these components (thermolabile or thermostable) can be denatured thereby offering a final product with better nutritional value.

Noteworthy, the absence of regulations defining meat analogues denomination, safety standards and criteria creates an ethical dilemma, where consumers will find difficulties to understand the healthiness or not of these products [24]. This give room to speculation and social media pressure to create a “fake” image of plant-based meat for promotion or defamation.

6. Consumers acceptance : motivators and demotivators

The future of plant-meat analogues development rely on understanding consumer perception. Identifying consumer’s motivators and demotivators are deemed necessary for designing meat analogues of the future (Figure 1).

6.1. Motivators

Motivations behind consumer’s purchasing/consuming plant based meat analogues can be related to conventional drivers (taste, cost, and convenience) or/and emerging drivers (health and wellness, safety, environment, animal welfare and familiarity) [6, 24, 117–119]. Apostolidis and McLeay (2016) showed that consumers’ (n=247 U.K. participants) motivation toward purchasing conventional meat (e.g., pork, beef) or plant-based meat (e.g., soy protein) depended on several factors (meat type, fat content, environmental impact, brand, and price) suggesting the complexity of meat-consumption choices. This confirms that providing additional information about product properties (*e.g.* product nutritional labelling, brand, foot printing) can influence purchasing decisions [6, 24, 120, 121]. The strongest motivator was "price" (45%) followed by environmental impact (17%), taste (15%), health (11%), organic (10%), and vegetarian (6%) [6]. Interest in buying plant-based meat also depended on age, income, gender, education and geography [122]. In term of age, millennials preference toward plant-based meat was driven by convenience and environmental impact, while older generations (45–59) were driven by taste and familiarity [122, 123]. Meat reduction was mostly common among low-income population, while high-income countries consume meat in high quantities [122]. It was also found that meat reduction is more frequent among women than men [124]. Consistently, environmental-conscious consumers were profiled as young (age 18 and 34) female with high educational levels, while health-conscious consumers were female over 55 [123, 125]. A cross-countries (US, China and India) surveys revealed that the attitudinal predictors of purchasing meat analogue in the US were appeal, excitement, and low disgust; whereas healthiness, appeal, tastiness, and sustainability were the primary predictors in China; and sustainability, excitement, necessity, and goodness were predictors of plant-based meat purchase intent in India [123].

Hence, these quantitative surveys revealed the association between consumer's dietary behavior and their motivation to consume/purchase plant-based meat analogue. In this frame, three main categories were identified: meat eaters (i.e. conventional consumers), meat reducers (i.e. flexitarians), and meat avoiders (i.e. vegans and vegetarians) [6, 126]. Emotional attachment assessment confirmed this classification, where 49% of respondents demonstrated a highly emotional "attachment" to meat, while 37% demonstrated a less emotional "avoidance" of meat and 14% demonstrated a highly emotional "disgust" [127]. Conventional eaters' attachment to meat is closely related to emotional connection and taste [128], while vegetarians or vegans are mainly motivated to avoid meat for ethical concerns (animal and human welfare). Flexitarians are an intermediary group motivated by health, environmental and ethical concerns resulting in meat consumption reduction [122, 127]. Beside health and environmental concerns, meat reduction can be reinforced by producing plant-based products similar to meat (aspect and taste) [129, 130].

6.2. Demotivators

The debate on meat and health can be also in favor of meat consumption since many consumers consider meat products as a crucial part of their diet [131]. Indeed, a cross-country (Belgium, Denmark, Germany, Greece and Poland) survey showed that all participants considered meat as an important source of protein and iron [131]. From a consumer perspective, healthiness of meat is related to animals feeding and growth, meat processing, and formulation (clean label ingredients or additives). In addition, participants were concerned about the amount and frequency of meat that one should eat. Consistently, a survey conducted in Swedish schools (fifty-nine students and five teachers from five different schools) showed that meat was perceived as central to nutritional health [132].

Environmental consciousness of meat is still an understood topic [133]. Indeed, a survey conducted on twelve focus groups revealed that most meat eaters showed lack of awareness of the association between meat consumption and climate change [134]. Therefore, these consumers showed less willingness to change their eating patterns [134]. These results highlighted the importance of actions to rise consumers' understanding of environmental issues related to meat production [133]. For conscious meat-eaters, the consumption of meat rely on rationalization, where they deny that animals suffer during slaughtering and that animals worth moral concern [135–137]. They build their justification through considering meat as a natural, normal, and necessary food [135]. Taste and nutritional quality were the most important motivators for eating meat [121]. Furthermore, they associate eating meat with pleasure and enjoyment [134]. Likewise, several studies underlined a cultural fact associating meat consumption to men over women [138, 139]**.** Familiarity can be a boosting factor for meat consumption as consumers are more familiar to conventional meat, resulting in a less attraction and acceptance to alternatives meat, considered unfamiliar [140, 141]. In this case, innovative foods are rejected and consumers prefer maintaining their usual dietary habits for emotional attachment or/and food neophobia (fear of eating new/unfamiliar foods) [135, 142].

7. Conclusions and future outlooks

Plant-based meat analogues are a growing food segment to be more than an alternative for vegetarian and vegan customers mainly due to increasing awareness towards meat consumption drawbacks on health and on the environment. Nevertheless, to keep boosting this market growth, further investigations are required to enhance taste and texture. Developing ingredients delivering desirable meat-like texture and flavor as well as selecting/ optimizing processing might be suitable strategies. Based on consumer’s segmentation, food manufactures have a plenty of opportunity to persuade consumers willing to reduce meat consumption. In the last years, established food companies as well as startups are launching new products into the market to meet consumer demand. Future interventions and policies are deemed necessary to clarify the regulatory uncertainties surrounding plant-based analogues. Nutritional labelling, and health and nutrition claims are, indeed, an opportunity for brands to promote their new products through creating a solid ground of trust and transparency with consumers.

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Table 1: Main ingredients of plant-based meat analogues

Ingredient	Sources	Main role	References
Plant proteins	-soy, wheat, legumes, pea, lupin, rice and potato -microalgae and seaweed	Nutrition, structure, color, texture and flavor tech-functional properties	[56–58]
Lipids	-rich in saturated fatty acids *(e.g.* coconut oil and cocoa butter) -rich in unsaturated fatty acids (*e.g.* sunflower oil, canola oil, sesame oil and avocado oil) -fat replacers: Oleogels and fibers	Flavor, texture and mouthfeel	[59–62]
Polysaccharides	-native starches -flours -fibers	Consistency and water binding	[61, 68, 69]
Flavoring ingredients	savory yeast extract, paprika, sugar, spices and herbs	Flavor	[78]
Coloring agents	lycopene, beet juice extract or leghemoglobin	Meat color	[47, 53, 72–74]
Fortification ingredients	tocopherols, zinc gluconate, thiamine hydrochloride, sodium ascorbate,	Nutritional value	[26, 78]

Table 2: **Pros and cons of texturizing technologies of meat analogues**

Technology	Advantages	Disadvantages	References
Extrusion	-high productivity -low cost -versatility -energy efficiency -anti-nutritional factors denaturation -increase protein digestibility	changes in color due to Maillard reaction, caramelization, hydrolysis, and degradation of pigments	[29, 81, 82, 85]
High-temperature induced shearing	-cost-effective -produce defined fibrous structure	-require more investigations for scaling	[47, 89, 91]
Wet-spinning	-produce defined fibrous protein products	-requires pure proteins -low pH -high salt concentrations and chemical additives -large amounts of wastes	[70, 79, 97]
Electrospinning	-cost-effective -scalable -production of very thin fibrils	-several parameters to control -difficulties to electrospin plant proteins	[45, 98, 99, 102]
Freeze structuring	-modulation of textural properties of plant proteins	-several freezing conditions to optimize and monitor	[49, 104]
Mixing plant proteins and hydrocolloids	-form fibrous structure that can modulated	-require hydrocolloids and the divalent metal cations for the precipitation	[105]
Bioprinting (3D printing technology)	-enable the design of products with texture similar to muscle fibers -tailor the nutritional content of the product	-require maturation under specific conditions -high production cost -the complexity of spatial structure	[106–108]

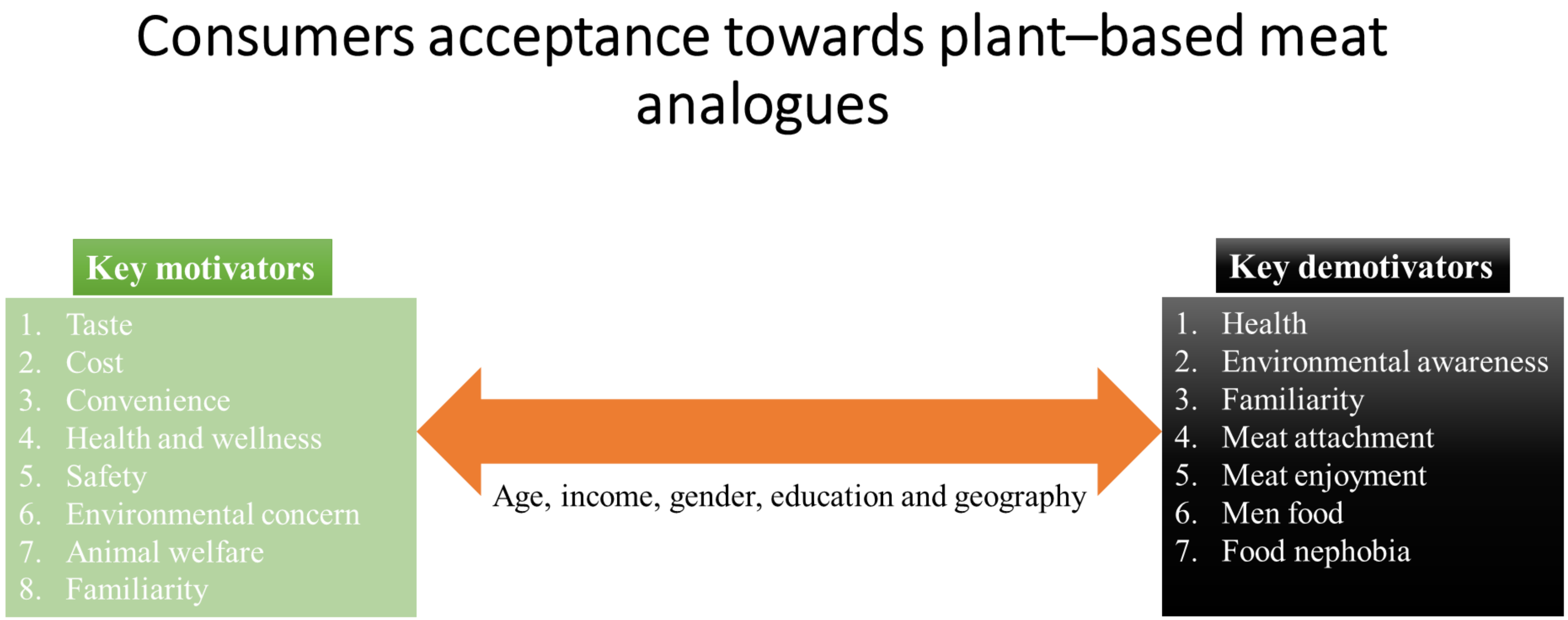

Figure 1: Key factors behind consumers' acceptance to consume/purchase plant-based meat analogues.