

Next-generation spreads: Emerging trends and innovation

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ABSTRACT

Spreadable foods are a diverse category that has gained attention in recent years. Changes in dietary habits and increasingly busy lifestyles have stimulated demand for convenient, ready-to-use products, while technological advances have enabled the creation of healthier formulations. While reviews on functional foods are available, a comprehensive synthesis of technological innovations and consumer perspectives in spread formulations has been lacking. This review brings together recent developments in both plant- and animal-based spreads, examining compositional innovations as well as processing strategies. This work combines product characteristics and consumer perspectives, shaping current directions for innovation. Ingredients are discussed according to their functional roles in improving oxidative stability, microbial safety, sensory properties, nutritional quality, and environmental sustainability. Studies show that sodium content can be reduced by up to 40 % without compromising sensory quality. Similarly, oleogel-based reformulations have lowered fat levels by 30–50 %, while consumer surveys report acceptance levels of 60–75 % for spreads containing novel or alternative ingredients. Emerging trends include the use of multifunctional and clean-label ingredients, valorization of sustainable raw materials, and the application of mild processing methods that help preserve quality while meeting consumer expectations. The review also identifies key areas where further research is needed, including balancing nutritional improvement with sensory acceptance, scaling up sustainable processing approaches, and addressing regulatory aspects of novel ingredients. By addressing both technological and consumer perspectives, this review is expected to guide future research and support innovation strategies in the food industry.

1. Introduction

Spreads are a diverse category of food products that serve both as staples in many diets and essential components in culinary innovation. They provide a practical way to support health, reduce disease risk, and promote sustainability through the use of innovative ingredients and processing technologies. As a result, they represent a promising niche in the growing market for nutritious, convenient, and sustainable products (Rezagholidade-shirvan et al., 2024).

In 2025, innovation in the food sector is accelerating, and this is clearly reflected in spread development. Formulations are based not only on consumer preferences and health awareness, but also on sustainability concerns, which influence both ingredient choices and processing approaches. Interest in plant-based diets, allergen-free options, and functional foods has promoted spreads from legumes (Grdeń and Jakubczyk, 2023; Olaimat et al., 2022), nuts (Malvano et al., 2024), seeds (Ghosh et al., 2021; Rohini et al., 2022), underutilized crops (Bilska, 2021; Bordim et al., 2023), fish (dos Santos Cruxen et al., 2021;

Ibrahim et al., 2024; Ignatova et al., 2020; Silva et al., 2020), algae (Bosnea et al., 2020; Jönsson et al., 2024; Muela et al., 2024; Siladji et al., 2024; Voloschenko et al., 2021), and insects (Bogusz et al., 2024; Wendin et al., 2021). In parallel, traditional spreads are being reformulated to reduce fat, trans fat, and salt while improving nutrition through alternative ingredients.

Spreads can be classified by raw material, processing method, functionality, or target consumers, with plant- and animal-based products as the main categories. Hybrid spreads combine both, creating distinctive flavours and textures (Tzompa-Sosa et al., 2021; Grasso and Goksen, 2023; Trindade et al., 2023). Such hybrid products are becoming increasingly popular, offering a strategy to reduce meat consumption as more consumers, particularly millennials, adopt omnivorous or flexitarian diets (Chin et al., 2024). They also show rising sustainability awareness (Bollani et al., 2019).

Plant-based spreads are made from a wide range of ingredients. These include vegetables such as eggplant (Mieles-Gómez et al., 2021), beetroot, pumpkin, broccoli, and carrot with soybean (Kostyra et al.,

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2024), legumes (Andersen et al., 2022; Olaimat et al., 2022), nuts (Malvano et al., 2024; Silva Zamora et al., 2023), and seeds like flax (Ghosal et al., 2022) and chia (Ghosh et al., 2021), as well as oil-based spreads (Hitlamani et al., 2023).

In practice, categories often overlap because formulations combine several plant sources to improve flavour, texture, and nutritional balance. By processing method, spreads can be categorized into thermally processed, fermented (Mosso et al., 2020; Palatzidi et al., 2025; Perri et al., 2024), and raw/minimally processed types (e.g., raw vegan spreads). Although peer-reviewed data are scarce, industry sources highlight a growing trend for raw-labelled products, driven by

clean-label demand and interest in preserving nutrients (<https://www.foodnavigator.com/Article/2016/04/25/raw-foods-on-the-rise-as-clean-label-consumers-crave-more/>). From a functionality perspective, plant-based spreads may be nutrient-enriched (e.g., omega-3 s, fibres) (Jönsson et al., 2024; Silva Zamora et al., 2023), or formulated as dietary options with reduced fat (Puşcaş et al., 2022; Tirgarian et al., 2023), sugar (Berk et al., 2024; Malvano et al., 2024), or salt (Nielsen et al., 2020).

Animal-based spreads can be categorized by source (dairy, meat, fish, and eggs), processing method, or functionality. Examples include cream cheese, meat/ fish pâtés, and mayonnaise. Processing method

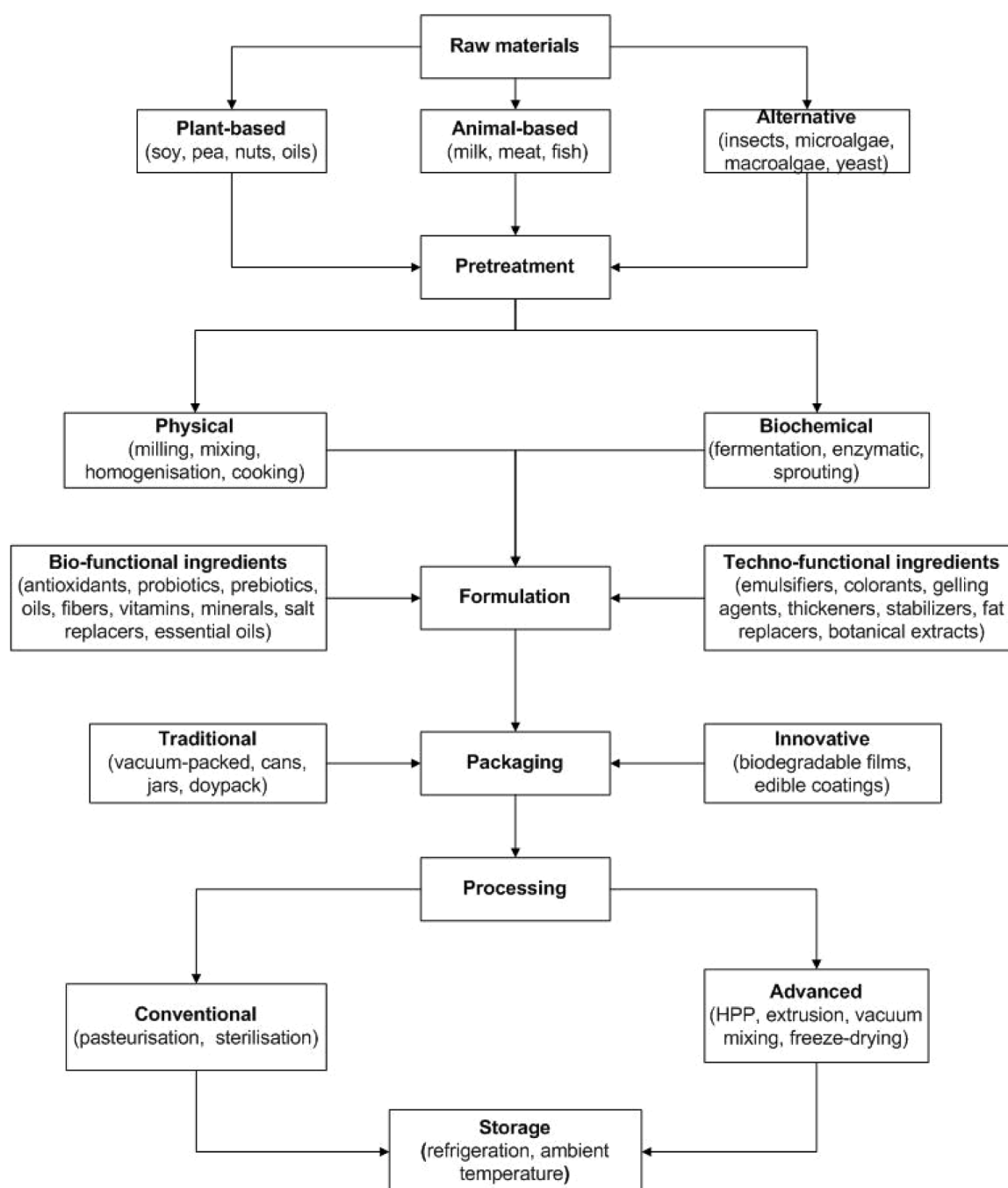


Fig. 1. Flow diagram of spread production stages.

range from fermented dairy to smoked or raw options. These spreads may be fortified with probiotics or omega-3 s, and can also be reformulated to reduce fat, salt, or cholesterol (Lima et al., 2022). Fig. 1 shows the main stages of spread production, from raw materials to storage.

Beyond their nutritional and functional aspects, spreads also represent a dynamic and steadily expanding market segment. The global market for food spreads was valued at USD 30.2 billion in 2023 and is projected to reach USD 41.1 billion by 2032, with a CAGR of 3.5 % (2024–2032) (Market Research Future, 2023). Growth is driven by shifting preferences, demand for healthier and natural options, ethnic cuisines, product innovation, snacking culture, and the popularity of vegan diets. It is also supported by e-commerce expansion, rising incomes, and wellness trends. The COVID-19 pandemic boosted demand for packaged and shelf-stable spreads, driven by increased home consumption (Timpanaro and Cascone, 2022; Žurek and Rudy, 2024; Global Market Insights, 2024).

This review provides a comprehensive overview of recent advancements in the development, reformulation, and functionalization of spreadable food products, focusing on both plant- and animal-based varieties. These products typically composed of fats, oils, and proteins are examined with the exclusion of fruit-based spreads such as jams and preserves. Special attention is given to emerging trends in ingredient innovation, processing technologies, and functional improvements. Unlike previous reviews that have mainly focused on isolated aspects such as specific formulation strategies or individual ingredient innovations, this review combines ingredient and technological innovation with consumer and market perspectives (Fig. 2).

This approach addresses an important gap in the literature and offers a timely synthesis of current trends in the field. In 2025, rapid progress in protein extraction proteins from novel sources, the growing use of oleogel-based reformulations, and the raising importance of participatory approaches are evident. In this context, such a synthesis is particularly timely and offers added value compared to earlier reviews.

2. Literature search and data collection

Relevant literature on spread development was retrieved from Scopus, Web of Science, ScienceDirect, and Google Scholar. The search covered studies published between 1 January 2019 and 1 June 2025,

with the final database query conducted on 1 June 2025. Keyword combinations included “functional spread,” “spread,” “pâté,” “new product development,” “innovative spread,” “plant-based spread,” and “innovative ingredients,” adapted for each database. Because the keyword spread often retrieved unrelated results (e.g., on disease or bacterial spread), only records clearly referring to food spreads were retained. Records from different databases were consolidated, and duplicates were removed. Non-peer-reviewed literature, conference abstracts, patents, and studies not specifically addressing spreadable food products (e.g., fruit-based spreads such as jams and preserves) were excluded. For each included article, data were extracted on type of spread, key and innovative ingredients, processing methods, functional and nutritional properties, and consumer-related aspects.

This review follows a structured narrative approach, combining systematic searching and predefined inclusion/exclusion criteria with a narrative synthesis of findings. This approach was chosen because the heterogeneity of study designs and outcomes did not allow for quantitative synthesis, but it enabled comprehensive mapping and interpretation of the available evidence.

3. Novel ingredients

Ingredients, as the main constituents of food products, possess two complementary functions: bio-functional and techno-functional. Bio-functional refers to their nutritional and physiological properties. On the other hand, techno-functional encompasses their physicochemical characteristics that influence the appearance, texture, and stability of food products (Pojić et al., 2018). Additionally, a distinct group of ingredients plays a key role in promoting environmental sustainability, offering a range of bio-functional and techno-functional properties. Although bio-functional and/or techno-functional ingredients are primarily selected for their contribution to one of these functions, they often provide additional benefits as well. For example, ingredients that help prevent fat oxidation also contribute to enhancing the overall antioxidant potential of the product, while emulsifiers may not only improve texture and stability but also aid in the bioavailability of fat-soluble nutrients.

In the context of **innovation in spread formulations**, ingredients can be categorized into (Fig. 3):

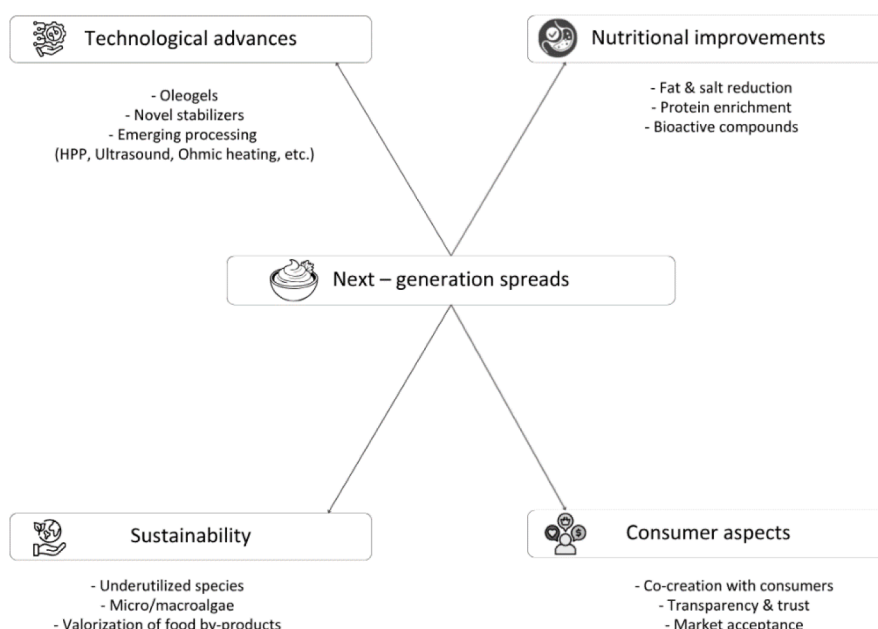


Fig. 2. Conceptual framework for next-generation spreads.

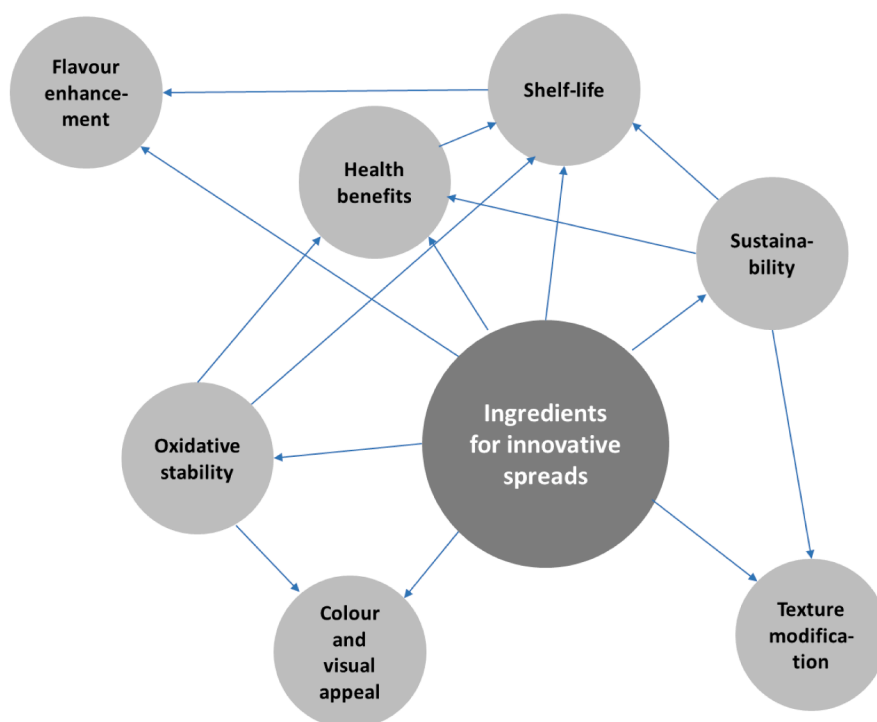


Fig. 3. Hierarchical diagram of ingredients for innovative spread formulation.

- Ingredients for improving oxidative stability of lipids
- Ingredients for improving colour and visual appeal
- Ingredients with health-promoting benefits
- Ingredients for enhancing flavour
- Ingredients for extending shelf-life through microbial inhibition
- Ingredients for texture and composition modification
- Ingredients for promoting environmental sustainability

3.1. Ingredients for improving oxidative stability of lipids

Polyphenolic compounds derived from green tea, grapes, pomegranate, berries and other plants serve as potent antioxidants, aiding in the reduction of oxidative stress and preventing lipid oxidation. When pork liver pâté was enriched with persimmon flour rich in polyphenols, especially gallic acid and flavanone glucosides, it resulted in a stable fatty acid profile and an increased PUFA content of pâté. However, differences in lipase activity during digestion, influenced by the use of pancreatins with varying enzymatic properties, contributed to increased lipid oxidation (Lucas-González et al., 2021). However, sometimes the enrichment of spreads with polyphenolics can negatively affect textural properties, namely spreadability and firmness, as well as the sensory acceptability of spreads due to the bitterness of phenolic compounds. Acan et al. (2021) demonstrated this in chocolate spreads enriched with grape pomace. Enriching chicken pâté with grape pomace demonstrated the highest antioxidant potential and was most effective in inhibiting lipid oxidation (Bordim et al., 2023). The study of Bilška (2021) evaluated the use of mulberry leaf extract in different concentrations (0.2 %, 0.6 %, and 1.0 %), as an additive in liver pâtés to reduce fat oxidation. By replacing 20 % of animal fat with rapeseed oil and adding the extract (in the concentration of 0.6 % and 1.0 %) the fat oxidation was effectively delayed, and the resulting pâtés had improved antioxidant properties with unaffected sensory and stable microbiological quality. Bilška et al. (2019) demonstrated the potential of rosemary extract as an ingredient in liver pâté. Its antioxidative activity was confirmed by the rancimat and oxidograph tests, and it slowed down the formation of secondary lipid oxidation metabolites. During the storage period of 15 days at

refrigeration temperature (1–5 °C), the extract helped in maintaining lipid stability by preventing oxidation in liver pâté.

3.2. Ingredients for improving colour and visual appeal

The food industry has been searching for natural additives that provide colouring and antioxidant properties to prevent oxidation in products and enhance their visual appeal. Colour of the spreads is one of the most important characteristics that influence consumers' choices for specific products. In the case meat spread – pâté, its colour is dependent on the concentration and/or chemical state of the myoglobin, physical characteristics, and the presence of ingredients that are not meat-based (Bordim et al., 2021). Bordim et al. (2023) showed the applicability of antioxidants extracted from *Moringa oleifera* leaves, propolis and grape pomace for use as natural colourant in chicken pâté. Upadhyay et al. (2024) developed an innovative table spread enriched with carotenoids extracted from carrot pomace with flaxseed oil. This product, characterized by a stable medium internal phase emulsion, demonstrated excellent thermal stability and antioxidant properties. The carotenoid extract served not only as a functional natural colorant but also as a rich source of carotenoids, while flaxseed oil contributed alpha-linolenic acid (ALA) to the formulation. Nutritionally, calculations indicate that one tablespoon of this spread could fulfil approximately 50 % of the daily ALA requirement for children and 42 % for adults. This made it a valuable functional food aimed at enhancing essential fatty acid intake (Upadhyay et al., 2024).

3.3. Ingredients with health-promoting benefits

Various ingredients that support immune function and contribute to overall health have been extensively studied, emphasizing their potential to enhance the functional properties of spreads.

3.3.1. Ingredients contributing to the prevention of non-communicable diseases

Omega-3 fatty acids, sourced from ingredients such as flaxseed, chia seeds, or fish oil, exhibit anti-inflammatory properties that support

cardiovascular and cognitive health (Ziaei et al., 2024). A meat spread enriched with omega-3 fatty acids is being developed for consumption by elderly individuals. In this case, flaxseed oil was used as a source of omega-3 fatty acids, and both macro- and nano-sized flaxseed oil emulsions (FOE) were prepared for the production of meat spreads. It was shown that higher incorporation levels of FOE led to a significant enrichment in omega-3 fatty acids (α -linolenic acid), underlining its potential as an efficient vehicle for functional fortification of meat spreads (Kim et al., 2023).

Plant sterols and stanols are additionally used to reduce cholesterol absorption, making them suitable for heart-health-focused products. In studies conducted so far, the enrichment of food products with plant sterols was predominantly done using spreads (38.12 %) compared to other food products. Additionally, the reduction in LDL cholesterol was greater when plant sterols were added to spreads than to other types of products (Fontané et al., 2023). However, despite these findings, recent studies specifically addressing the enrichment of spreads with plant sterols are scarce, with most available research dating back several years. On the other hand, Cedeño-Pinos et al. (2022) demonstrated that salmon pâté formulated with sunflower and/or linseed oil contains β -sitosterol, the predominant phytosterol in these oils. However, its content tends to decrease during cold storage, likely due to lipid oxidation.

Papagianni et al. (2021) indicated that the consumption of spread cheese enriched with mountain tea and orange peel extracts significantly increased total antioxidant capacity, enhanced plasma resistance to oxidation. It also reduced the postprandial rise in glucose and triglyceride levels in healthy volunteers (Papagianni et al., 2021). Grdeń and Jakubczyk (2023) reported that incorporating 10 % spelt grain into bean spreads resulted in a novel product with high nutraceutical potential. The formulation exhibited the highest concentration of bioactive peptides with strong antioxidant properties under simulated gastrointestinal conditions. Additionally, it demonstrated inhibitory activity against key enzymes associated with metabolic syndrome, including α -amylase, α -glucosidase, and angiotensin-converting enzyme, suggesting potential health benefits. Fonseca et al. (2024) incorporated probiotic culture *Akkermansia muciniphila* into a cheese spread consisting of Portuguese whey cheese and Greek-style yogurt in a 3.5:1 ratio and obtained a significant antidiabetic and antihypertensive activity in the resulting product. Likewise, the resulting probiotic cheese spread exhibited high microbiological quality, low phenolic content, and maintain high *A. muciniphila* viability during 21 days of refrigerated storage. The texture, colour, water activity, and pH of the probiotic cheese were comparable to the control, suggesting it may have good consumer acceptance. Rosemary extract applied in liver pâté effectively inhibited cholinesterase activity (both acetylcholinesterase - AChE and butyrylcholinesterase - BChE). Inhibition was stronger for AChE, indicating the extract's potential neuroprotective effects (Bilska et al., 2019).

3.3.2. Ingredients contributing to the immune support

Enriching spreads with vitamins and minerals strengthens immune support and provides functional properties. Enriching traditional Polish bread spread based on melted cheese, formulated with micronized eggshell, lysine, vitamin D3, and vitamin K improved all tested physicochemical properties except water activity. Eggshell supplementation increased calcium levels >2.5 times compared to the control, while lysine improved spread elasticity and structural stability. Moreover, calcium bioavailability was higher in samples containing lysine and vitamin K than in those with eggshell alone (Kobus-Cisowska et al., 2020). Mosso et al. (2020) reported the fortification of vegan spreads with folates through fermentation using a folate-producing *Lactobacillus sakei* strain. The spreads were made from Andean potato and amaranth, with and without chia. Folate levels reached 1900 ng/g and remained stable during storage, with no adverse effects on texture or stability; however, sensory analysis showed higher acceptability for the

formulation without chia. Tolve et al. (2021) fortified chocolate spread formulated with vitamin D and magnesium-calcium carbonate nanoparticles which yielded in 15 times more vitamin D and 9 times more calcium in the final product. However, the addition of Mg-CaCO₃ nanoparticles resulted in a significant viscosity increase due to particle-particle interaction and particle rearrangement. On the other hand, the addition of hydrophobic vitamin D to the formulation likely reduced particle interactions, as the increased presence of fat-like material facilitated the coating of all particles. Yessimbekov et al. (2021) reformulated traditional liver pâté by incorporating meat-bone paste obtained by micro-milling to enhance its calcium content. The optimal mineral balance in the final product was achieved with a 15 % addition, while other key quality attributes remained unaffected. Black carrot extract as added to the white and compound chocolate spread had no significant impact on its physico-chemical, textural, flow, or melting properties, while it increased bioactive compounds and bioaccessibility, especially anthocyanins contributing to the development of functional products (Baycar et al., 2021).

3.3.3. Ingredients contributing to the gut health

The inclusion of probiotics, such as *Lactobacillus* and *Bifidobacterium* species, in food formulations aims to promote gut health and strengthen the immune system. These bacteria can be stabilized in spreads to retain viability and efficacy upon consumption. Cruxen et al. (2021) demonstrated this in a fish pâté spread containing prebiotic fructooligosaccharides, where *Lactobacillus acidophilus* LAFTI L10 remained above 6 log CFU g⁻¹ up to the 34th day of refrigerated storage. Agrawal et al. (2024) developed a probiotic chicken meat spread fermented with *L. acidophilus* and malted sorghum flour. The resulting spread(s) exhibited a decrease in pH values during storage, likely due to chemical changes induced by fermentation, leading to lactic acid formation. Additionally, increases were observed in free fatty acid, thiobarbituric acid values, and titratable acidity. All of these parameters remained within the prescribed limits after 16 days of storage. The spread(s) also demonstrated improved emulsion stability and an enhanced capacity to retain water and fat, preventing separation of phases. Thiel et al. (2024) demonstrated the strong market potential of fish pâtés formulated with two underutilized species, *Oligosarcus robustus* and *Loricariichthys anus*, enriched with prebiotic fructooligosaccharides and probiotic *L. acidophilus* LAFTI L10. These pâtés exhibited high consumer acceptance, improved oxidative stability, and enhanced microbiological and sensory quality. Olive pomace debittered using a mixture of *Lactiplantibacillus pentosus* starter strains was used to obtain an olive pâté. The resulting product exhibited prebiotic, eubiotic, and bifidogenic effects in the colon, highlighting its potential as a suitable carrier for probiotic delivery (Nissen et al., 2024). Toczek et al. (2022) developed emulsion spreads similar to commercial margarines, optimised to contain inulin and milk fat (20 % each). When whey protein concentrate was used as the emulsifier, the spreads were enriched with live *L. acidophilus* La-5, *Streptococcus thermophilus*, and *Bifidobacterium animalis* BB-12 at levels above 10⁷ cfu g⁻¹, sufficient to achieve therapeutic effects. It was shown that whey protein concentrate used as an emulsifier was crucial for the survival of LAB.

3.4. Ingredients for texture and composition modification

Texture-modifying ingredients, including fat replacers, emulsifiers, gelling agents, thickeners, and stabilizers collectively enhance the consistency, texture, spreadability, and stability of spreads. They also optimize sensory attributes and modulate composition, caloric value, and overall product performance.

3.4.1. Ingredients for fat replacing

To reduce fat content in food products, various fat replacers and ingredient combinations have already been used in commercial products, while more innovative solutions have been explored for scientific

purposes. A wide range of fat replacers is available, and they can be classified into four categories according to their composition: protein-based, carbohydrate-based, lipid-based, and complex fat replacers (Gao et al., 2024). Apart from improving spreadability and consistency, fat replacers also alter product composition by reducing fat content and caloric value.

Protein-based fat replacers, including both animal-derived proteins (e.g., whey, gelatin, egg protein, casein, collagen) and plant-based proteins (e.g., soy, wheat gluten, pea, potato), are widely used for their diverse structural and functional properties (Nourmohammadi et al., 2023). Sánchez-Obando et al. (2020) demonstrated the potential of microparticulated whey protein particles as fat mimetics in reduced-fat cheese spread. The incorporation of 5 % fat mimetics did not result in significant differences compared to the control samples. Textural properties such as hardness, springiness, cohesiveness, chewiness, gumminess, and firmness remained unchanged.

Carbohydrate-based fat replacers derived from plants, legumes, and cereals contain both digestible and non-digestible carbohydrates including starch, cellulose, inulin and hydrocolloids (Agyei-Amponsah et al., 2021; Gao et al., 2024). Prebiotic fibres, such as inulin, are used for their ability to promote beneficial gut microbiota and enhance digestive health. They are also used for their gel-forming properties, which contribute to improved mouthfeel, flavour, and spreadability. It was shown that solution of high-performance inulin with degree of polymerization of 23 forms a spreadable gel with fat-like properties. For this reason, inulin is commonly used as a fat substitute in mayonnaise and other types of spreads such as soft and spreadable cheeses to reduce the caloric density of spreads (Cofrades et al., 2024; Tumbarski et al., 2024). Kambarova et al. (2020) used extruded cereal and pseudo cereal flours from rice, oat, corn and buckwheat combined with skimmed milk powder, dried egg mélange and water to develop a plant-based protein supplement to be incorporated in turkey pâté. By incorporation of this supplement, the resulting pâté was of reduced lightness and redness, with increased yellowness. The protein plant-based supplement significantly increased the content of essential amino acids, especially lysine, valine, leucine, isoleucine and threonine. The increase of total content of monounsaturated fatty acids by 27.8 % and polyunsaturated fatty acids by 0.7 % in the final pâté was also observed. Florczuk et al. (2022) utilized two types of β -glucans - curdlan and scleroglucan as fat replacers in low-fat processed cheese spreads. Their addition did not negatively affect the taste or aroma of the product, but also enhanced the cheesy flavour of the product. However, the resulting product exhibited a coarser microstructure with numerous protein-polysaccharide-fat complexes, leading to higher hardness and reduced spreadability and meltability. Therefore, it was recommended that the level of β -glucan additives in low-fat PCS should not exceed 0.5 %. Silva Zamora et al. (2023) demonstrated the potential of spray drying to produce microparticles ($<10\ \mu\text{m}$) of dietary fibers from inulin, glucomannan, psyllium husk, and chia mucilage, which served as effective fat replacers in hazelnut spreads. By completely replacing palm oil, the reformulated product achieved a 41 % reduction in total unsaturated fats and a 77 % decrease in saturated fats. Additionally, it increased dietary fibre content by 4 % and reduced total calories by 80 % compared to the original formulation. Sensory evaluation showed that 73.13 % of panellists preferred the modified spread, particularly due to its enhanced brightness. Rezler et al. (2021) demonstrated the effects of partially replacing fat with chemically modified potato starches (E1412, E1420, E1422, and E1450) on the rheological, textural, and sensory properties of pâté. Resulting pâtés exhibited increased viscoplastic properties after pasteurization/sterilization and cooling, with lower firmness, spreadability, and adhesion compared to the control. The type of starch modification and heat treatment significantly influenced textural differences. Higher values of the storage modulus (G') were observed in pâtés where fat was substituted with starch preparation E1412, indicating a firmer structure. In contrast, the pâtés with starch preparation E1450 exhibited the lowest G' values, suggesting a softer and less structured texture. This difference

in fat crystallization significantly influenced the overall texture and stability of the pâté, whereby higher crystallization contributed to a more stable, solid texture, while lower crystallization lead to a softer, more spreadable product.

Lipid-based fat replacers, particularly structured lipids obtained through the esterification of fatty acids and vegetable oils such as olive, soy, sunflower, flax, rapeseed, or marine oils, have emerged as a promising strategy in food formulation. Their application contributes to enhancing the nutritional quality and overall health profile of food products. Rich in monounsaturated and polyunsaturated fats, these oils offer healthier alternatives to saturated fats (Gao et al., 2024). Martins et al. (2020) demonstrated the use of beeswax to develop an edible oleogel based on linseed oil, rich in linolenic acid, which replaced 30 % and 60 % of pork fat in meat-based pâté. They reported a decrease in hardness and adhesiveness in the pâtés with oleogel incorporation. Studies substituting pork backfat with microencapsulated oils of tiger-nut, chia, and flaxseed (at a substitution level of 50 %) in deer pâté showed improvements in the nutritional profile. However, these substitutions altered texture and increased susceptibility to oxidation (Vargas-Ramella et al., 2020). Vargas-Ramella et al. (2022) evaluated the effect of partially replacing pork backfat with microencapsulated fish oil (at levels of 25 % and 50 %) in pork liver pâté. This substitution reduced fat content, improved the fatty acid profile (increasing PUFA and adjusting the n-6/n-3 ratio), and increased moisture and cholesterol. The textural and rheological properties were altered, as indicated by a reduction in the viscous modulus (G'') and consistency index, leading to a less structured matrix while maintaining a predominantly elastic behaviour. The resulting softer texture was likely due to increased moisture and PUFA content. Despite these modifications, the sensory quality remained comparable to the control, with no significant differences in overall liking. When macro- and nano-sized flaxseed oil emulsions were utilized in meat spreads, the resulting product was softer and less chewy due to its lower melting point and rheological characteristics (Kim et al., 2023). Viriato et al. (2019) proposed the incorporation of low melting triacylglycerols derived from high oleic sunflower oil to butter to improve its physical characteristics and spreadability, especially at low temperatures. The study revealed that these modified spreads exhibited lower hardness and maintained a stable crystallization profile for 30 days under refrigeration. This approach not only enhanced the plasticity of the product, but also increased its unsaturated fatty acid content without employing chemical modifications. Malvano et al. (2024) reported an optimal formulation for a pistachio spread with no added sugars, low levels of saturated fat, and a high protein content. This was achieved by using an olive oil-based oleogel as a fat replacer and incorporating milk-derived powders (skimmed milk powder and whey protein concentrate) for structural modification. The final optimized spread consisted of 20 % oleogel, 13.16 % whey protein, and 26.84 % skimmed milk. This formulation achieved desirable quality scores, including good spreadability and high sensory ratings for meltability and mouthfeel. Puşcaş et al. (2022) developed a chocolate spread formulated with a walnut oil oleogel structured with 10 % candelilla wax and monoglyceride. This system was designed to replace milk fat and thereby reduce the content of saturated fatty acids. The resulting product was of higher firmness, low adhesiveness and spreadability similar to traditional milk fat spreads. Its microstructure closely resembled that of cream-based spreads and demonstrated strong gel characteristics ($G' > G''$). Fourier transform infrared (FTIR) analysis revealed unique intensity changes while retaining peaks similar to walnut oil, indicating its distinctive properties (Puşcaş et al., 2022). Tirgarian et al. (2023) demonstrated the potential of water-in-oleogel emulsions as an effective fat replacement strategy in chocolate spreads. The emulsions were designed with various water-to-oleogel ratios, and their impact on the physical, rheological, and sensory properties of chocolate spreads was examined. The spread formulated with a 45:55 water-to-oleogel ratio achieved a texture, viscosity, and microstructural integrity comparable to full-fat chocolate spreads.

Sensory scores for the reduced-fat spread were similar or superior to the control sample. The study of Botella-Martínez et al. (2024) evaluated the effect of partially replacing animal fat (10 % and 20 %) with a gelled emulsion based on hemp oil and buckwheat flour in traditional pâté. The replacement improved the nutritional profile by reducing cholesterol and enhancing the n-6/n-3 and PUFA/SFA ratios. While the reformulated pâtés were more susceptible to lipid oxidation and showed some changes in physicochemical properties, these did not negatively impact sensory acceptance.

Composite fat replacers may contain proteins, carbohydrates and/or lipids. As demonstrated by Cofrades et al. (2024), the application of pork lard emulsions stabilized with soy protein concentrate (with or without methylcellulose and carboxymethylcellulose) and supplemented with silicon resulted in a significant reduction in total fat in pork liver pâtés. The physicochemical and sensory properties of the reformulated pâtés were similar to the control. In vitro digestion tests revealed lower lipid digestibility for emulsions with added silicon compared to those made with pork lard and soy protein. Additionally, the lipid bioaccessibility in the reformulated products was lower than in the control, successfully reducing fat content and absorption (Cofrades et al., 2024). Espert et al. (2020) reported the development of a reduced-fat emulsion from cellulose ethers (methylcellulose and hydroxypropyl methylcellulose) and anhydrous milk fat. This emulsion can be used either directly as a spread or as an ingredient in foods requiring the plastic properties of the fat phase. The resulting product was of similar characteristics to butter, but softer and spreadable at refrigeration (5 °C) and room temperature (20 °C).

3.4.2. Ingredients for salt reduction

A range of strategies has been suggested to reduce the sodium chloride content in processed food. These strategies include reducing the salt content in formulations, modifying flavour through the use of taste enhancers, herbs, spices, and monosodium glutamate, and applying salt replacers. They also encompass the physical modification of salt (Duntelman et al., 2021). Nielsen et al. (2020) demonstrated the effects of using a natural salt replacer, consisting of a sodium–potassium chloride blend, to partially substitute regular table salt in salmon pâté. The study found that this salt blend effectively reduced sodium content by 22 %. At the same time, it preserved microbiological safety as well as key sensory and physicochemical properties, thereby maintaining a quality level comparable to the original product. To the best of our knowledge, physical modification of salt has not yet been used in spread formulations, although this strategy has been demonstrated in burgers formulated with micronized salt (<60 mesh). In this case, salt content was reduced from 1.5 % to 1.0 % without affecting pH, colour parameters, perceived saltiness, taste, juiciness, fattiness, or spiciness (Rios-Mera et al., 2019). Wang et al. (2024) developed a promising curcumin/sodium chloride complex using γ -cyclodextrin as a carrier. This multifunctional ingredient can be applied in different food systems for salt reduction, flavour enhancement, and as an antimicrobial agent. The resulting product was characterized by distinct flavour characteristics, such as increased saltiness perception and reduced bitterness compared to sodium chloride alone.

3.5. Ingredients for enhancing flavour

Ingredients that enhance taste and aroma not only play a key role in improving the overall sensory experience of spreads but also contribute to product preservation and safety. Botanical extracts such as oregano, thyme, marjoram, sage, basil, fenugreek, fennel, coriander, pimento, ginger, turmeric, rosemary, and others provide antioxidative, anti-inflammatory, antidiabetic, antihypertensive, and antimicrobial properties, while simultaneously enriching the sensory profile of spreads (El-Sayed and Youssef, 2019; Sleem and Shaaban, 2023).

3.6. Ingredients for extending shelf-life through microbial inhibition

Enrichment of spreads with functional ingredients, such as garlic extract (GE) and citric acid (CA), can improve product safety. This was demonstrated by Olaimat et al. (2022) in hummus, where a reduction in *L. monocytogenes* and *S. enterica* counts was observed. In this case, both ingredients inhibited pathogen growth, with the effect being particularly pronounced at lower temperatures (4 °C and 10 °C). Concentrations of 1–1.5 % CA or 2.0–3.0 % GE were especially effective in reducing pathogen levels. Chromatographic analysis identified 2-vinyl-4,5-dimethylthiazole (2-VDT) as the main organosulfur compound in garlic responsible for its antimicrobial activity, with a concentration of 22.9 mg/g. These findings highlighted the critical role of refrigeration and the use of CA or GE to enhance food safety of hummus. Bolívar et al. (2021) demonstrated the bioprotective capacity of *Lactobacillus sakei* CTC494 against *Listeria monocytogenes* in tuna pâté. Strong inhibition of *L. monocytogenes* was observed at 2 °C (<0.5 log increase), while only limited growth occurred at 12 °C (<2 log increase). The use of the expanded Jameson-effect model in this study offered a understanding of the interactions between probiotics and pathogens, which can guide the optimization of food formulations (Bolívar et al., 2021). Rodrigues et al. (2025) investigated the impact of incorporating black pepper essential oil into chicken pâté formulation. A significant reduction in mesophilic bacteria counts was observed for at least two weeks when 1 % black pepper essential oil was used. However, this concentration negatively affected the taste and overall acceptance of the final product. The study of Glišić et al. (2024) incorporated the ethanolic extracts from post-harvest sunflower and maize stalk residues in pork liver pâtés. The both extracts improved microbiological quality, but negatively affected the sensory characteristics, exhibited pro-oxidant effect and accelerated lipid oxidation in pâtés during storage. The addition of rosemary extract contributed to the microbiological stability of liver pâté by preventing microbial growth during 15 days of refrigerated storage (1–5 °C). Under these conditions, the content of aerobic microorganisms did not exceed 3.66 log₁₀ cfu/g, *Pseudomonas* counts ranged from 10² to 10³ cfu/g, and no *Enterobacteriaceae* were detected (Bilska et al., 2019). The study of Gorzin et al. (2024) highlighted the role of nanoencapsulated essential oils as natural preservatives. Encapsulated *Oliveria decumbens* and basil oils demonstrated strong antibacterial effects (MIC 0.25–1.25 mg/mL; MBC 1.00–3.00 mg/mL) and significantly reduced microbial counts in minced meat during storage. In addition, encapsulation helped mask undesirable flavours and improved sensory acceptance. While these results are promising, they were obtained in minced meat models rather than spread formulations, which raises questions about their direct applicability. This reflects a broader trend in the literature, where functional benefits demonstrated in simplified systems often remain unverified in more complex, commercially relevant products such as spreads.

Essential oils can be incorporated into spread formulations not only as direct antimicrobial ingredients, but also as active components of packaging materials (Pateiro et al., 2021). As demonstrated by Doğan et al. (2025), sage essential oil was successfully integrated into gelatin/polyamide 6 nanofibrous mats, enhancing the preservation of ultra-filtrated spreadable cheese. The incorporation of sage essential oil into G-PA6 nanofibrous mats resulted in improved cheese preservation by reducing bacterial growth and lipid oxidation. These results highlighted the potential of such mats for application in active food packaging.

In addition, study of Sulieman et al. (2023) highlighted the increasing consumer reluctance to purchase food containing synthetic preservatives due to potential health risks. This concern has motivated research into natural alternatives, such as spices, which possess antimicrobial properties and serve as natural, safer and more sustainable food preservatives for extending shelf life.

3.7. Ingredients for promoting environmental sustainability

Ingredients that promote environmental sustainability are increasingly sourced from by-product streams, as well as other underutilized or renewable resources such as micro- and macroalgae or insects. Their use not only reduces environmental impact but also supports circular economy principles and fosters the development of more sustainable food systems.

3.7.1. Underutilized species

Several authors have reported the use of low-value, underutilized fish species in the development of fish pâtés, highlighting it as an effective strategy for promoting sustainability, reducing environmental impact, and offering innovative, nutritious products (Duarte et al., 2022; Racioppo et al., 2021; Silva et al., 2020). This approach provides an alternative to fish pâtés made from commercial species, whose over-exploitation can contribute to biodiversity loss. The development of innovative, sensory-rich products from underutilized fish is challenging due to consumer expectations. New formulations are often compared with commercially available pâtés produced from more commonly used fish species. To overcome potential sensory challenges, Silva et al. (2020) emphasized that fish harvested in winter are particularly suitable for pâté production. Seasonal characteristics such as chewiness, cohesion, firmness, and a distinctive oceanic aroma and flavour significantly enhance the overall sensory appeal. The smoked blue jack mackerel pâté was prepared by smoking the fish fillets with bay leaves, removing the skin, mincing the fillets, and combining them with chili, cream cheese, pickles, onion, and mustard. Kazhibayeva et al. (2019) developed fish pâté from underutilized fish species bream. The resulting fish pâté had excellent sensory properties and a high nutritional value characterized by high protein content and significant amount of essential amino acids such as valine, isoleucine, threonine and tryptophan. To prepare pâté from white cachama (*Piaractus brachipomus*), Mancera-Rodriguez et al. (2022) included both animal-based fats (pork back fat) and plant-based oils (canola, olive, or sacha inchi oil) as lipid sources. An optimal mixture was found with 50 % white cachama paste, 21 % canola oil, and 23 % water. The final product had a shelf life of 42 days and an 82 % acceptability rating.

3.7.2. Processing by-products

Apart from utilization of underutilized fish, fish pâté can be formulated on the basis of low-value fish processing by-products (Furey et al., 2022). Roe, milt, and liver from marine fish caught in Irish fisheries were blended in various ratios with plant-based ingredients to create a seafood pâté targeted at teenage consumers. These consumers showed a generally positive attitude towards seafood and a favourable sensory acceptance of the new pâté. The pâté containing only roe being the most preferred, while the pâté with 25 % milt/liver was the least accepted. Acan et al. (2021) incorporated dried grape pomace (Cabernet Sauvignon), a by-product of wine production, into chocolate spread formulation as a partial replacement for sugar and milk powder. This substitution increased the total phenolic compound content in the final product but negatively affected sensory attributes—particularly bitterness—as well as textural properties such as spreadability and firmness. Additionally, digestibility values showed a decreasing trend. To achieve a sensory-acceptable spread, grape pomace should be used at levels of up to 10 %. Similarly, Bükler et al. (2021) demonstrated the potential of dried apple pomace as a partial replacement for sucrose in chocolate spread formulation, yielding similar outcomes—an increase in polyphenol content and a deterioration of textural properties such as hardness, firmness, and spreadability. Additionally, colour parameters and overall acceptance of the product decreased. To achieve better results when incorporating by-product pomace, it was observed that pre-grinding of the raw material is essential to improve the physico-chemical properties of the formulations. The study of Achilladelis et al. (2023) demonstrated the impact of fortifying tahini with red grape and

chickpea by-products - 4 % lyophilized microwave-ultrasound-assisted red grape pomace extract and 6 % freeze-dried aquafaba. The fortified tahini exhibited a 76 % and 78 % increase in total phenolics and total flavonoids, respectively, as well as enhanced antioxidant activity. Thus, another by-product valorisation route was demonstrated to enhance tahini's functional properties while supporting waste reduction and circular economy principles.

3.7.3. Alternative ingredients with lower environmental impact

Wendin et al. (2021) investigated the incorporation of insect-based ingredients, specifically mealworm protein and mealworm flour, into plant-based pâté. This approach, however, resulted in lower consumer acceptance despite the recognized importance of sustainability in purchasing decisions. The lower acceptance was due to the reduced vegetable odour and flavour, but increased the taste of cinnamon and pepper, along with the greasy texture. Jönsson et al. (2024) developed a plant-based yellow pea spread enriched with four European seaweed species—*Saccharina latissima*, *Alaria esculenta*, *Palmaria palmata*, and *Ulva* sp. The inclusion of 3.0 % seaweed increased the spread's total fiber content by 20 %. Among the tested seaweeds, *S. latissima* and *A. esculenta* were the most preferred, while *P. palmata* received the lowest scores. The preference for *S. latissima* and *A. esculenta* may be due to their neutral taste and finer texture, whereas *P. palmata*'s lower scores likely resulted from its strong marine flavours and coarser consistency. Tzompa-Sosa et al. (2021) demonstrated the use of insect ingredients as more sustainable alternatives in spread formulations, specifically examining the impact of yellow mealworm (YMW) oil on hummus properties. It was found that deodorized YMW oil could replace vegetable oil without affecting the overall sensory experience, liking, or appearance. At the same time, its use resulted in a less firm, more spreadable, and less sticky hummus. While crude YMW oil had a negative impact on flavour and overall liking, deodorized YMW oil served as an effective substitute for vegetable oil in hummus, maintaining favourable sensory properties. Amiri et al. (2024) demonstrated that proteins extracted from *Scenedesmus obliquus* possess functional properties relevant for spread formulation, including a 124 % fat absorption capacity and favorable emulsifying ability. A subsequent study (Amiri et al., 2025) confirmed that pepsin hydrolysis further improved these functionalities. In particular, low-molecular-weight peptides (<5 kDa) exhibited superior fat-binding and emulsifying properties. However, the use of *Scenedesmus obliquus* in food applications remains constrained by its classification as a Novel Food in the European Union. Similar regulatory and market-entry barriers reported for other alternative ingredients illustrate how promising functional findings are often difficult to translate into commercial products.

4. Spread reformulations – innovative approaches from the literature

Numerous research studies have focused on optimizing the nutritional profile and functional properties of various types of spreads, with increasing emphasis on the use of natural extracts, food industry by-products, and healthier fats. The Table 1 shows examples of reformulated plant- and animal-based spreads, highlighting the applied innovations, specific ingredients, and the significance of the interventions. From the examples presented in the table, several clear trends can be observed in the reformulation of spreads, including the one towards the "clean label" approach characterized by the reduction of additives and substitution of synthetic ingredients with natural alternatives. In addition, there is a clear emphasis on health benefits, natural ingredients, product functionality, and economic considerations in the development of new spreads. Innovations that combine functionality, sensory quality, and raw material sustainability show great potential for further development of this product category. However, it remains questionable how meaningful these innovations are, considering that the majority of these formulations have not been developed in close collaboration with

Table 1
Examples of innovative plant- and animal-based spreads: Ingredients and key features.

Spread type	List of ingredients and quantity of ingredients	Special ingredients	Significance/Innovation	Reference
Chicken paté	39–41 % chicken meat	0.50 % naturally coloured antioxidants from <i>Moringa oleifera</i> leaves, propolis and grape pomace	Natural colorants, oxidative protection, extract-specific performance	(Bordim et al., 2023)
Chicken meat spread	86 % chicken meat, 6 % soyabean oil, 3 % condiments, 3 % spice mix, 2 % salt	2 %, 4 % and 6 % malted sorghum flour, 1 million cfu/g <i>L. acidophilus</i>	Improved yield and emulsion stability, enhanced flavor through fermentation, high-moisture low-fat formulation	(Agrawal et al., 2024)
Chicken paté	52.1 % meat, 1 % salt, 11.5 % milk, 10.4 % water, 20.8 % olive oil, 4.2 % starch	1 % black garlic powder, 0.3 %, 0.7 %, 1 % black pepper essential oil	Antimicrobial and antioxidant benefits; potential for cleaner-label meat products with careful sensory optimization	(Rodrigues et al., 2025)
Functional liver paté	43 % class II pork meat, 42 % fine fat, 15 % liver, 30 % brot, 1.5 % salt, 0.15 % pepper, 0.05 % marjoram, 0.4 % onions	0.2 %, 0.6 %, 1 % mulberry water leaf extract	Natural antioxidant effect, ACE and cholinesterase inhibition, clean-label potential	(Bilska et al., 2021)
Liver paté	43 % class II pork, 42 % finely minced fat, 15 % liver, 30 % broth, 30 %, 1.5 % salt, 0.15 % pepper, 0.05 % marjoram, 0.4 % onion	20 % rapeseed oil, 0.2 % rosemary extract	Lower SFA, higher omega-3, improved shelf life with rosemary extract	(Bilska et al., 2019)
Paté	-	Moringa, propolis, and red grape pomace extracts	Positive effect of awareness, minimal impact of color, flavor-dependent acceptability	(Bordim et al., 2019)
Pork liver paté	65 % dewlap, 25 % liver, 10 % backfat, 15 % water, 2 % salt, 300 (mg kg ⁻¹) polyphosphates, 125 (mg kg ⁻¹) nitrite, 500 (mg kg ⁻¹) ascorbate, 1 % caseinate. 0.05 % white pepper, 0.03 % nutmeg, 0.03 % thyme	Persimmon flour: 3 % and 6 %	Reduced nitrites, lower lipid oxidation, improved sensory acceptance	(Lucas-González et al., 2019)
Liver paté	55 % beef liver, 10 % beef brain, 30 % pork back-fat, 3.1 % sauteed onion, 1.3 % salt, 0.4 % white sugar, 0.2 % spices	5 %, 10 %, 15 %, 20 % and 25 % meat-bone paste	Mineral enrichment, by-product utilization, cost-effective formulation, maintained nutritional quality	(Yessimbekov et al., 2021)
Paté	19.6 % meat, 33.3 % pork liver, 14.58 % pork backfat, 27.95 % water, 5.82 additives	31.95 % biopolymeric emulsions with added silicon	Fat reduction and lower fat absorption in paté; good sensory quality retained.	(Cofrades, Saiz and Álvarez, 2024)
Turkey paté	8 % turkey liver, 52 % turkey meat, 13 % broth, 6 % onion, 0.9 % garlic, 2 % sodium chloride, 0.1 % black pepper	18 % protein-herbal supplement (oat, rice, corn, and buckwheat flours)	Fat reduction and improved nutritional and sensory quality	(Kamborova et al., 2020)
Pork liver paté	39 % pork meat, 24.3 % pork fat, 14.6 % pork liver, 19.5 % pork broth, 0.2 % pepper, 0.2 % marjoram, 0.8 % onion, 1.4 % salt	1 % modified starch	Fat reduction, improves health profile, maintains good texture and sensory appeal	(Rezler et al., 2021)
Meat-based paté	40 % pork subcutaneous fat, 2 % sodium caseinate, 23 % cold water, 15 % lean meat, 18 % liver, 2 % sodium chloride	12 %, 24 % linseed oleogel	Fat reduction, enhances omega-3 content and health profile with minimal texture compromise.	(Martins et al., 2020)
Pork liver paté	20 % lean pork meat, 30 % pork backfat, 33 % pork liver, 11.5 % water, 2 % sodium chloride, 2 % milk powder, 1 % sodium caseinate, 0.5 % sodium phosphate, 0.015 % sodium nitrite, 0.025 % sodium ascorbate	7.5, 15 % microencapsulated fish oil	Improved fat profile, good acceptability retained	(Vargas-Ramella et al., 2022)
Pork liver paté	33 % liver, 30.0 % subcutaneous fat, 20.7 % lean meat, 12.5 % water, 1.5 % soy protein isolate, 1.5 % curing salt, 0.5 % sodium tripolyphosphate, 0.3 % mix of spices	1.5 % sunflower stalk residues extract, 1.5 % maize stalk residues extract	Antimicrobial activity but had a pro-oxidant effect and reduced sensory acceptability; further optimization needed for use as natural preservatives	(Glisić et al., 2024)
Paté	65 % dewlap, 25 % liver, 10 % backfat, 15 % water, 2 % salt, 1 % caseinate, 300 mg/kg polyphosphates, 125 mg/kg nitrite, 0.05 % white pepper, 0.03 % nutmeg, 0.03 % thyme	10 %, 20 % gelled emulsion of hemp oil	Healthier lipid profile with increased PUFA and omega-3, reduced cholesterol, maintained sensory acceptability, and preserved traditional taste.	(Botella-Martínez et al., 2024)
Meat spread	40 % pork ham, 30 % pork backfat, 30 % ice, 1.5 % nitrite-picking salt, 0.05 % ascorbic acid, 0.5 % lecithi, 0.3 % tripolyphosphate	12.5 %, 25 %, 50 % macro-flaxseed oil emulsion and nano-flaxseed oil emulsion	Increased n-3 fatty acids, reduced saturated fats, improved texture and emulsion stability	(Kim et al., 2023)
Fish paté	55.25 % fish (Viola or Tambica), 20 % water, 1.5 % sodium chloride, 0.15 % curing salts, 0.1 % white pepper, 0.1 % garlic, 0.2 % onion, 0.1 % paprika, 0.35 % antioxidant and color fixative, 0.25 % polyphosphate, 12 % sunflower oil, 10 % fructooligosaccharides	0.25 % <i>L. acidophilus</i> Lafti L10	Functional enhancement, probiotic viability, high consumer acceptance	(Cruxen et al., 2021)
Salmon paté	Eggs, minced salmon, cream, sour cream, dill, 1 % salt, white pepper, water	Saltwell® (mixture of sodium chloride and potassium chloride and contains approximately 35 % less sodium per gram than common salt)	22 % sodium reduction with Saltwell®, maintaining microbiological safety, sensory quality	(Nielsen et al., 2020)
Tuna paté	35 % tuna, sunflower oil, cow milk, potato flakes, water, salt, carrageenan, monosodium glutamate, disodium ribonucleotides, citric acid, acacia gum, aroma	10 ² CFU/g <i>Latilactobacillus sakei</i> CTC494	First quantitative modeling of LAB–L. monocytogenes interactions in fish matrices; food-dependent inhibition patterns revealed using expanded Jameson-effect model	(Bolívar et al., 2021)
Smoked blue jack mackerel paté	-	Blue jack mackerel (<i>Trachurus picturatus</i>)	Valorization of low commercial value fish species, development of marine-based food products with added value	(Silva et al., 2020)
White cachama paté	50 % minced fish paste, 21 % water, 22 % canola oil, 0.8 % salt, 1.5 % isolated soy protein, 1.3 % starch, 2.1 % stabilizer, 0.45 %	White cachama (<i>Piaractus brachipomus</i>), 22 % pork back fat, 22	Nutritious alternative to traditional paté and promoting underused aquaculture species	(Mancera-Rodriguez et al., 2022)

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Table 1 (continued)

Spread type	List of ingredients and quantity of ingredients	Special ingredients	Significance/Innovation	Reference
Fish <i>pâté</i> for therapeutic and prophylactic purposes	seasonings, 0.33 % curing salts, 0.48 % sodium polyphosphate, 0.04 % sodium erythorbate	% canola oil, 22 % olive oil, 22 % sachai inchi oil	Fish <i>pâté</i> enriched with vegetables offers high protein and mineral content, expanding functional food options in the modern meat and fish industry.	(Kazhibayeva et al., 2019)
Seafood <i>pâté</i>	63 % pike, 23 % carrot, 6 % butter, 4 % fish broth, 4 % dillweed, table salt, black pepper, muscat	20 % comprising pumpkin, 7 % vegetable oil	Value-added use of fish by-products, promising sensory acceptance	(Furey et al., 2022)
Table spread	75.40 % fish ingredients, 10.56 % grated parsnip, 6.03 % finely chopped onion, 4.52 % tomato paste, 2.04 % oat flour, 1.13 % fine salt, 0.15 % white pepper, powdered 0.11 % nutmeg powdered, 0.06 % dried dill	100 % plaice roe, 75 % roe/25 % milt, 75 % roe/25 % liver, 75 % roe/12.5 % liver/12.5 % milt	Natural colour, improved nutrition, functional ingredients from carrot waste	(Upadhyay et al., 2024)
Butter, margarine, spreads	Butter, 15 % flaxseed oil, 1 % common salt, 0.3 % trisodium citrate, whey protein concentrate, emulsifier, stabilizer, spice mix, water	15 % carotenoid extract derived from carrot pomace	LDL-C reduction influenced by dose and food format	(Fontané et al., 2023)
Cheese spread	-	plant sterols and plant stanols	Enhanced postprandial antioxidant potential	(Papagianni et al., 2021)
Cheese spread	-	6 % mountain tea and orange peel extract	Antihypertensive and antidiabetic potential	(Fonseca et al., 2024)
Reduced-fat spread	54.9 % cheese base, 45.1 % fat base	3.5:1 probiotic <i>Akkermansia muciniphila</i>	Fat reduction, good sensory and textural properties	(Sánchez-Obando et al., 2020)
Cheese spreads	Milk, 0.6 % mesophilic aromatic culture Flora Danica (<i>Lactococcus lactis</i> subsp. <i>cremoris</i> , <i>Lactococcus lactis</i> subsp. <i>lactis biovar. diacetylactis</i> , <i>Lactococcus lactis</i> subsp. <i>lactis</i> and <i>Leuconostoc</i>)	3.5 % and 14.1 % microparticulated whey protein	Enhanced probiotic growth and sensory quality in fresh cheese spread; stable physicochemical properties	(Tumbariski et al., 2024)
Low-fat cheese spread	22.80 % mix of Dutch-type cheese (70 % w/w) and quark (30 % w/w), 12.90 % butter, 38.99 % milk, 1.98 % trisodium citrate, 18.06 % non-fat dry milk, 1.49 % whey protein, 0.79 % sodium chloride, 0.99 % soy lecithin, 1.98 % MILLI-Q® water	1 % , 2 % agave inulin, 0.2 % thyme, 0.4 % hawthorn fruit	Fat reduction, functional formulation without phosphates, good sensory potential	(Florczuk et al., 2022)
Polish bread spread	62 % lean curd, 18.7 % butter, 19.1 % water	0.6 %, 1.09 % scleroglucan, curdlan	Efficient calcium and vitamin delivery with preserved sensory and physicochemical properties	(Kobus-Cisowska et al., 2020)
Milk fat emulsion spreads	20 % inulin, 20 % and 25 % anhydrous milk fat, emulsifier (2 % and 4 % whey protein concentrate or 2 % lecithin)	265 mg micronized eggshell, 250 mg lysine, 1 µg vitamin D3, and 15 µg vitamin K	AMF-inulin spreads with whey protein support probiotic viability and stable texture; optimal formulation identified, storage effects pending	(Toczek et al., 2022)
Milk fat spread	Milk cream	0.015 % <i>L. acidophilus</i> La-5, <i>Streptococcus thermophilus</i> and <i>Bifidobacterium animalis</i> BB-12	Softer texture and improved lipid profile	(Viriato et al., 2019)
Reduced-fat spreads	Anhydrous milk fat	70:30, 60:40, and 50:50 (% w/w) anhydrous milk fat and high oleic sunflower oil	Development of softer, spreadable reduced-fat spreads with cellulose ethers and AMF; improved fat crystal structure and melting behaviour without chemical modification	(Espert et al., 2020)
White spread	26 % anhydrous vegetable fat, 45 % sugar, 3 % hazelnut puree, 0.02 % vanillin, 13.58 % whey powder, 0.25 % soy lecithin, 12 % skimmed milk powder, 0.15 % hazelnut flavour	0.25 %, 0.50 %, 0.75 % and 1 % black carrot extract powder	Enhances bioactivity and bioaccessibility; good consumer acceptance	(Baycar et al., 2021)
Reduced-fat mayonnaise	70.3 % sunflower oil, 12.1 % spray dried egg yolk, 15.1 % vinegar, 1 % salt, 1 % sugar, 0.5 % powdered mustard, 0.03 % potassium sorbate, 0.03 % sodium benzoate	35.2 %, 56.2 % and 68.9 % starch-based fat replacer	Fat reduction with preserved sensory characteristics (creaminess, thickness, mouthfeel)	(Agyei-Amponsah et al., 2021)
Low-fat spread	-	22.8 % plant sterols esters	LDL reduction without impairing vascular function	(Ras et al., 2015)
Bean spread	-	10, 20, 30 % spelt grain	Antioxidant and antimetabolic activity	(Grdeń and Jakubczyk, 2023).
Vegan spread	33.3 % Collareja Andean potato, 5.5 % amaranth flour, 5 % sunflower oil, 1 % NaCl, 1.5 % cheese flavor, 53.5 % tap water, 0.2 % inoculum	Probiotic folate-producing <i>Lactobacillus sakei</i> strain, 3.3 % chia flour	Natural folate enrichment, stable texture, high acceptability in vegetarians	(Mosso et al., 2020)
Olive <i>pâté</i>	Olive pulp	Mixture of <i>Lactiplantibacillus pentosus</i>	Probiotic-fortified olive <i>pâté</i> modulates microbiota, enhances SCFA production, reduces harmful VOCs; early lipid fermentation risks noted	(Nissen et al., 2024)
Hummus	Chickpeas, tahini, cooled drinking water	0.5, 1.0 or 1.5 % citric acid and 1, 2, or 3 % garlic extract	Effective control of <i>S. enterica</i> and <i>L. monocytogenes</i> in hummus using CA or GE; enhanced antimicrobial action at 4–10 °C linked to high 2-VDT content.	(Olaimat et al., 2022)
Hazelnut spread	34.1 % sugar, 31.6 % hazelnut, 12.4 % fat-free milk. 5.6 % cocoa, 1.2 % soy lecithin, 1.1 % vanilla, 14 % palm oil	14 %, 7 %, 4.5 % microparticulates of different dietary fibers	Fat reduction, mimics fat sensory properties, supports fiber intake	(Zamora et al., 2023)

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Table 1 (continued)

Spread type	List of ingredients and quantity of ingredients	Special ingredients	Significance/Innovation	Reference
Pistachio-based spread	40 % pistachio paste, 20 % oleogel, 26.84 % skimmed milk, 13.16 % whey proteins, 0.7 % soy lecithin, 0.3 % vanillin, stevia (0.08/100 _{gspread})	Oleogel: 5.3 % GMS in olive oil, dissolved at 75 °C under stirring	No added sugars, low in saturated fat, high protein content	(Malvano et al., 2024)
High protein, no added sugar pistachio spread	40 % pistachio paste, 34 % sucrose, 15 % palm oil, 9 % skimmed milk, 1 % whey protein concentrate, 0.7 % soy lecithin, 0.3 % vanillin	20 % oleogel (glycerol monostearate, olive oil)	Pistachio spread without added sugars, low in saturated fat; optimized spreadability and positive sensory attributes	(Malvano et al., 2024)
Chocolate spread	Sugar, skimmed milk powder, whey powder, 4 % alkalized and neutralized cocoa powder, 6.55 % hazelnut paste, 16.1 % sunflower, 10.8 % cottonseed oil, 0.4 % lecithin, 0.1 % polyglycerol polyricinoleate, 0.02 % ethyl vanillin, 0.03 % salt	35–50 % sugar, milk originated powder 0.066–8 % and 0.23–15 % dried grape (<i>Cabernet sauvignon</i>) pomace	Valorization of dried grape pomace, a winery by-product; as a partial substitute for sugar and milk powders in chocolate spread	(Acan et al., 2021)
Chocolate spread	50 % sugar, 8 % milk originated powders as total skimmed milk powder and whey powder in equal amounts	0.23–15 % dried grape pomace	Improved phenolic content, sugar reduction, lower cost potential	(Acan et al., 2021)
Chocolate spread	maltitol, sunflower oil, 13 % hazelnuts, skimmed milk powder, whey powder, inulin, low-fat cocoa powder, cocoa butter, emulsifier lecithin (sunflower), vanilla extract	166 µg/kg vitamin D, 11.6 g/kg magnesium-calcium carbonate nanoparticles, inulin, maltitol	Vitamin D and calcium fortification, consumer acceptability, nanoparticle-based enhancement	(Tolve et al., 2021)
Chocolate butter	-	Oleogel (10 % candelilla wax, 10 % monoglycerides, walnut oil)	Spreadable, firm texture, clean label and similar to commercial product	(Puşças et al., 2022)
Reduced-fat chocolate spreads	26 % skimmed milk, 25.4 % icing sugar, 4 % cocoa powder, 0.5 % soy lecithin, and 0.1 % vanilla powder	44 % water-in-oleogel emulsions	Reduced fat, cocoa butter-like mouthfeel, potential for hydrocolloid-based aw control	(Tirgarian et al., 2023)

consumers. This is particularly important as the use of alternative ingredients can significantly affect sensory properties, which in turn may influence consumer acceptance and ultimately limit the market success of the products.

5. Innovative processing technologies in spread development

Recent research on spreads and pâtés increasingly explores innovative processing methods. These can be broadly grouped according to their primary objectives and applications:

- Technologies for preservation and shelf life extension
- Technologies for food structure and property modification.

However, their application in spreads remains largely experimental, with most studies limited to the laboratory or pilot scale. Moreover, challenges such as high capital costs, process optimization for complex matrices, and consumer perception of novel technologies continue to limit their wider industrial adoption (Melios et al., 2025).

5.1. Technologies for preservation and shelf life extension

The potential of high-pressure processing (HPP), which is used for food preservation without the need for high temperatures was evaluated for spread product in the study of Osaili et al. (2025). They assessed the impact of HPP at 350 MPa for 1–5 min on the microbial safety, physical/chemical properties, and sensory characteristics of hummus. The treatment significantly reduced the microbial load, with a 1.8 log cfu/g decrease in total microbial counts after 5 min. The shelf life of hummus was extended to 28 days at 4 °C and one week at 10 °C following HPP, compared to 14 days and 7 days in the control samples. In another study Ahmed et al. (2020) evaluated the effect of high-pressure treatment (300–600 MPa for 15 min) on the microbial safety of hummus. The results showed that the pressure treatment at 400 MPa completely inactivated *Listeria monocytogenes*, ensuring the safety of the product. This demonstrates that high-pressure treatment can be effective in eliminating harmful microorganisms, thereby improving the microbiological safety of hummus. Another innovative technology applicable for preservation and shelf life extension is microwave (MW) processing as demonstrated by Son et al. (2022). This study evaluated the application

of MW for decontamination of hummus, especially addressing *Salmonella* and *Listeria* outbreaks. A computational model was developed to predict temperature changes during the process, which was validated by experimental data from hummus samples processed in a lab-scale MW system (60 g, 8.5 cm diameter, 1.2 cm height, in polystyrene petri dishes). The MW treatment at 70 W for 5 min achieved an average temperature of 95.3 °C. Under these conditions, a > 4 log reduction of *Salmonella* inoculated at $\approx 7\text{--}8 \log_{10}$ CFU/g was observed. This process had minimal effects on colour and rheological properties, and only minor mass losses were observed. The efficacy of high-pressure processing (HPP) for inactivating Hepatitis E virus (HEV-3) was evaluated using both a cell culture system and artificially contaminated pork pâté. While HPP reduced the HEV-3 load in media by 2 log units under various pressure and time conditions, only a 0.5 log reduction was achieved in pork pâté. This indicates that the effectiveness of HPP is matrix-dependent and may not fully mitigate the risk of HEV-3 in food products (Nasheri et al., 2020). In the study of Martínez-Zamora et al. (2023) the red bell pepper-based hummus enriched with mustard sprouts was treated with ultrasound (US) at 50 °C, 35 kHz for 12 min, and microwaves (MW) at 9 kW for 35 s. Although both treatments (US and MW) reduced microbial spoilage by 1–4 log CFU/g, their effects on nutritional compounds differed. US maintained higher levels of vitamin C and sulforaphane, whereas MW caused significant reductions, indicating that US is more effective in preserving both microbial safety and nutritional quality. Aydin et al. (2020) compared the effects of ohmic heating (OH) with conventional heating (CH) in hot-smoked fish pâté. OH was evaluated as an alternative, energy-efficient preservation technology with potential benefits for nutritional characteristics. The results revealed that OH-treated pâté showed higher total volatile base nitrogen (TVB-N), but lower thiobarbituric (TBA) and pH value compared to CH-treated samples. Ohmic heating significantly reduced the heating time of fish pâté to 8.28 min, compared to 19.54 min with conventional heating. It also demonstrated much lower cooking energy consumption (195.57 kJ/kg) and specific cooking energy (3.69 kJ/kg °C). In contrast, conventional heating required 1895.00 kJ/kg and 35.75 kJ/kg °C, respectively. Moreover, ohmic heating achieved a remarkably higher energy efficiency of 89.89 %, whereas conventional heating reached only 9.25 % (Aydin et al., 2020).

5.2. Technologies for food structure and property modification

D'Alessio et al. (2024) investigated the impact of high-pressure homogenization (HPH) on the gelling properties of a commercial pea protein concentrate. The study aimed to formulate emulsion-filled gels as a model spreadable plant-based product. Pea protein dispersions (10 %–15 %–20 %) were treated at 60 and 150 MPa for 5 cycles. HPH treatments reduced residue size and induced smaller agglomerates, affecting gel formation. The 150 MPa treatment produced stiffer, compact, and elastic gels, confirmed by rheological, TPA, and CLSM analyses, with a more structured and compact gel matrix. Sánchez-Obando et al. (2020) demonstrated the production of micro-particulated whey proteins (MWP) as fat replacers by applying different treatments, including temperature (85–95 °C) and homogenization pressure (100–180 bar), after ultrafiltration of whey proteins (7 %–11 % protein, 16 %–19 % soluble solids). The study optimized the process through a central composite design (90 °C–140 bar) and evaluated the application of MWP in reduced-fat spread and petit-suisse cheeses. Outcomes showed that viscosity and rheological parameters depended on MWP concentration, while sensory testing confirmed good acceptability, particularly in 5 % low-fat spread and 10 %–40 % low-fat petit-suisse cheeses.

Recent advances in microbial biomanufacturing have also opened possibilities for producing bioactive compounds, biopolymers, and natural colorants with potential applications in food processing and preservation (İncili et al., 2025). Although not yet implemented in spread formulations, it highlights one of the technological approaches towards sustainability.

6. Socio-economic aspects of spread consumption

Consumer acceptance plays a critical role in the success of novel food products. However, in both academic research and industry practice, the development of innovative spreads often follows a product-centric approach. Typically, new formulations are created and finalized before being presented to consumers for sensory evaluation. This sequential process can be particularly problematic when products incorporate unconventional ingredients, as it may lead to market failure due to misalignment with consumer preferences and expectations (Castanho et al., 2024). With changing consumption trends and the growing need for innovation across industries, it has become increasingly important to involve consumers from the very beginning of the development process, not just at the evaluation stage. This has encouraged a shift from product-centric to user-centric approaches in food product development, including the development of spreads. Although the user-centric approach is widely recognized for its potential to align food products with consumer expectations, its practical application is often limited. In many cases, consumer involvement is confined to later validation stages, rather than being integrated throughout the development process. This limited engagement may reduce the effectiveness of the approach and result in products that fail to meet actual consumer needs or market demands (Castanho et al., 2024; Sijtsema and Snoek, 2023) (Sijtsema and Snoek, 2023; Castanho et al., 2024). As consumer preferences increasingly shape the development of spreadable products, an overview of key spread categories in relation to demand, formulation challenges, market trends, and acceptance is presented in Table 2.

6.1. Product-centric approach to spread development

Andersen et al. (2022) demonstrated that informing consumers about the environmental impact and history of pulses in hummus formulations increased their willingness to try and pay for the product. Similarly, sensory analysis of plant-based and functional spreads highlights the importance of texture, flavour, and spreadability in determining consumer preferences. Achieving the right balance between these sensory attributes is essential for the success of new spread

products in the market. Tolve et al. (2021) reported that consumers showed high acceptance of no added sugar chocolate spreads enriched with multiple micronutrients. Over 80 % were willing to purchase these products, while 66 % stated they would pay 10–15 % more. Foguel et al. (2021) involved 102 participants using the Check-All-That-Apply (CATA) method to assess sensory attributes of five cream cheese samples, including traditional and low-fat formulations. The results showed that consumers preferred samples with a "white," "matte," and "milky" appearance, with higher fat content offering softer texture and better spreadability. Low-fat options, while firmer, were less preferred due to reduced spreadability. Jönsson et al. (2024) explored the consumer liking of spreads formulated with the addition of four different species of northern European seaweeds, whereby spreads formulated with *S. latissima* and *A. esculenta* appeared to be the most favoured by Swedish consumers, likely due to their milder taste and finer texture. In contrast, *P. palmata* was rated lowest, which may be attributed to its stronger marine flavour and coarser texture. As part of a study to develop fish-based products for preschool children, a sensory evaluation with children aged 1–7 years was conducted. The results showed that fish pates received the highest ratings (66.7 %) compared to fish balls (60.0 %), fish ham (53.3 %), and fish sausages (46.7 %), suggesting good acceptance of this product type and its potential in early childhood diets (Jia et al., 2025). Several cocoa-free spreads with functional ingredients have been developed using various cocoa powder alternatives. Formulations were tested with chickpea, carob, doum, black rice, date seeds, and beetroot. Products containing chickpea, carob, doum, and black rice were rated higher in overall acceptability and sensory properties than those with date seeds and beetroot (Smuda et al., 2024). Consumer acceptance of egg-free mayonnaise based on canned bean aquafaba as an egg white substitute depended on achieving a creamy texture, stability, and balanced flavour. Aquafaba provided a mouthfeel and spreadability comparable to traditional formulations (Sachko et al., 2023).

6.2. User-centric approach to spread development

Consumer perspectives emphasize that spreads with functional attributes are not only evaluated for their nutritional composition, but also for how they align with broader lifestyle choices. As highlighted by Abedinia (2025), functional foods should not be seen as a quick substitute for unhealthy habits, but rather as part of an integrated approach to well-being. This view reflects a consumer-centric orientation, where spreads are expected to contribute to a healthier dietary pattern rather than serve as isolated solutions.

Using a co-creation process involving children, Velázquez et al. (2022) developed healthy dairy products that were well accepted. The approach included several steps: exploration, prototyping, refinement, and validation. It showed that children's preferences were shaped by familiarity, taste, and perceived health benefits, and that they also contributed to product promotion through packaging design and marketing ideas. They engaged children in selecting ingredients and evaluating prototypes, showing that they accepted vegetables like carrot and pumpkin when masked in dairy, increasing acceptance of reduced-sugar formulations. Similarly, Pinesso Ribeiro et al. (2025) worked with adolescents to co-create healthy dairy products, prioritizing taste and health impact. Adolescents participated in a structured co-creation process involving the design, tasting, improvement, and promotion of healthy dairy products, using a variety of ingredients such as fruits, vegetables, grains, and nuts. Despite sugar reduction and the use of less familiar healthy ingredients, the final products were well accepted both by adolescents who were involved in the co-creation and those who were not. The study showed that involving adolescents in product development can lead to healthier products that align with their preferences and support public health goals related to sugar reduction and improved dietary habits. The study of Javier-Pisco et al. (2024) explored consumer-driven ideas for new products made from sea bream and prawns, using focus groups as a tool for co-creation. Participants

Table 2

Consumer expectations, innovation challenges, and trends across major spread categories.

SPREAD GROUP	CONSUMER DEMAND	MAIN CHALLENGES	MARKET TRENDS	CONSUMER ACCEPTANCE
EGG-LIKE SPREADS	<ul style="list-style-type: none"> Growing interest in plant-based and functional mayonnaise alternatives Increasing availability of allergen-free and egg-free products Focus on sustainability through the use of by-products and alternative stabilizers <p>Allergen free (egg free) and plant-based mayonnaise alternatives (Mirzanajafi-Zanjani et al., 2019)</p>	<ul style="list-style-type: none"> Technological challenges related to egg yolk removal and texture (Chetana et al., 2019) Alternative stabilizers or emulsifiers to achieve the desired sensory and rheological properties (de Menezes et al., 2022) 	<ul style="list-style-type: none"> Low-fat and probiotic-enhanced mayonnaise (Mirzanajafi-Zanjani et al., 2019) Utilization of food by-products (Vieira et al., 2023) Legume-based emulsifiers (vegetable proteins: lupin, faba bean, pea, soy) often combined with hydrocolloids (Vieira et al., 2023) Fruit flour: nectarine, pear and apple (Vieira et al., 2023) Hydrocolloids and gums (xanthan gum, pectin, and guar gum) (Rudra et al., 2020) Aquafaba (Sachko et al., 2023) Rice bran and sesame oils (Chetana et al., 2019) Fish myofibrillar protein (shrimp oil) (Rajasekaran et al., 2024) 	<ul style="list-style-type: none"> Consumer acceptance depends on creamy texture, stability, and a balanced flavor profile. Vegetable proteins can negatively impact mouthfeel, if not optimized to prevent undesirable graininess (de Menezes et al., 2022) Hydrocolloids and fruit flours improve viscosity and emulsion stability (Vieira et al., 2023) Aquafaba based mayonnaise has good mouthfeel and spreadability, minimal visual difference, except for the color (Sachko et al., 2023)
DAIRY SPREADS	<ul style="list-style-type: none"> Demand for low-calorie and low-sodium dairy spreads Growing market for plant-based cream cheese alternatives Use of oleogels and plant proteins to preserve texture <p>- Reduced fat content (Bemer et al., 2016)</p> <p>- Reduced salt content (Lučan et al., 2020)</p> <p>- Plant-based alternatives (Short et al., 2021)</p>	<ul style="list-style-type: none"> Reduced fat content can alter texture, flavor and appearance (Bemer et al., 2016) Salt modification impacted texture and taste (acid, unsalted and bitter) (Lučan et al., 2020) Consumer liking is the biggest challenge for any plant-based substitute (Mintel Group Report, 2020) 	<ul style="list-style-type: none"> Oleogels as fat substitute to maintain desirable spreadability while reducing saturated fat content (Rao and Devaraja, 2021) Reducing and replacing sodium chloride in cream cheese with potassium chloride (Lučan et al., 2020) Processing and fermentation of soybeans and blending of non-dairy milks are potential ways to improve consumer liking of these products (Boukid et al., 2021; Short et al., 2021) Incorporation of pea protein, inulin, and olive oil emulsions to mimic traditional dairy textures (Mefleh et al., 2022) Lentil protein and different oils (Boukid et al., 2021) Herbs and spices to improve the nutritional and medicinal value (El-Sayed and Youssef, 2019) 	<ul style="list-style-type: none"> Texture, flavor, and appearance strongly influence consumer acceptance of cream cheese. Consumers prefer a firm, white, matte product with a mild, milky taste. Low-fat versions increased firmness but reduced spreadability, lowering preference (Foguel et al., 2021) Consumers preferred full-fat butter with a yellowish appearance and rich taste. Lower-fat variants spread better but were less accepted. Taste was the key factor in choice (Chudy et al., 2022)
FISH SPREADS	<ul style="list-style-type: none"> Development of functional fish spreads with probiotics and plant-based ingredients Combination of fish and plant proteins is gaining popularity Underutilized fish are used as raw materials Focus on pleasant texture and mild flavor for broader consumer acceptance <p>- Functional food applications, integrating ingredients that promote health benefits and sustainability (Chehade et al., 2025; Cruxen et al., 2021)</p>	<ul style="list-style-type: none"> Sensory attributes as important factor in the overall acceptability and liking of a food product and purchase intentions (Ranilović et al., 2020) 	<ul style="list-style-type: none"> Novel fish (<i>Oligosarcus robustus</i> and <i>Loricariichthys anus</i>) pâtés containing prebiotics and probiotics (dos Santos Cruxen et al., 2021) Combination of fish and plant-based ingredients, including legumes, algae, and vegetable proteins (Chehade et al., 2025) The use of vegetables, cereals, and herbs (Dvoryaninova et al., 2022) Fish pate for therapeutic and prophylactic purposes (using freshwater fish (pike, bream), pumpkin, seaweed, and vegetable oil (Kazhibayeva et al., 2019) 	<ul style="list-style-type: none"> Texture, flavor, spreadability, and aftertaste are influencing consumer liking for fish pâtés (Ranilović et al., 2020) Consumers prefer fish pâtés that are homogeneous, without signs of graininess, smearing consistency (Dvoryaninova et al., 2022), firm, with dense texture and easy to spread (Ranilović et al., 2020) Consumers prefer fish pâtés with balanced flavor, seasoning, and saltiness. Mild-flavored species and moderate intensity enhance appeal. (Dvoryaninova et al., 2022) Lighter colors, such as pink and yellow, are preferred for visual appeal (Jia et al., 2025)
MEAT SPREADS	<ul style="list-style-type: none"> Introduction of plant-based and insect proteins as partial meat substitutes Market demand for healthier versions with reduced saturated fat Growing interest in sustainable and functional meat spreads 			

(continued on next page)

Table 2 (continued)

SPREAD GROUP	CONSUMER DEMAND	MAIN CHALLENGES	MARKET TRENDS	CONSUMER ACCEPTANCE
	<ul style="list-style-type: none"> - Functional ingredients with lower saturated fat (Frunză et al., 2022) - Alternative protein sources (Smarzyński et al., 2019) - Partial meat substitute (Trindade et al., 2023) - Sustainable ingredients (Smarzyński et al., 2019) 	<ul style="list-style-type: none"> - Colour affecting consumer preferences (Smarzyński et al., 2019) 	<ul style="list-style-type: none"> - Pork pâté enriched with cricket powder (Smarzyński et al., 2019) - Pâtés formulated with pea protein isolate as a partial meat substitute exhibited improved spreadability and softer texture, but unpleasant colour (Trindade et al., 2023) - Use of oleogels to replace saturated fats and improve the overall fatty acid profile (Manzoor et al., 2022; Martins et al., 2020) - Omega-3 enriched spreads (Kim et al., 2023) - Replacing pork fat with fish oils or vegetable-based alternatives (Borsolyuk and Verbytskyi, 2023) - Sprouted wheat as a functional ingredient in poultry pâtés (Frunză et al., 2022) 	<ul style="list-style-type: none"> - Taste, texture, aroma are the main determinants of consumer liking for pâté (Borsolyuk and Verbytskyi, 2023) - Key attributes for chicken liver pâté include taste, smell, and color, with smooth texture, absence of synthetic additives, and price also influencing consumer preference (Frunză et al., 2022) - Pork pâté with 2 % cricket powder maintained high consumer acceptance, though the darker, bluish color affected perception (Smarzyński et al., 2019) - Pea protein enhanced spreadability and resulted in a softer texture (Trindade et al., 2023)
PLANT-BASED SPREADS	<ul style="list-style-type: none"> • Increase in interest for vegan and functional spreads • Focus on sensory attributes (texture, flavor, appearance) • Consumers seek familiar ingredients and clean label products - Health benefits and nutritional value (Baltuonytė et al., 2022) - Sustainability and ethical considerations (Estell et al., 2021; Šmiglak-Krajewska and Wojciechowska-Solis, 2021) - Utilization of zero-waste ingredients (Mikasauskaitė-Tisoet al., 2023) - Utilization of functional ingredients (Gärtner et al., 2024; Kumari and Sharma, 2022) - Convenience of consumption (Possidónio et al., 2021) - Cultural and regional influences (Šmiglak-Krajewska and Wojciechowska-Solis, 2021) - Labeling and transparency (Henn et al., 2023) 	<ul style="list-style-type: none"> - Sensory acceptance (Amyoony et al., 2023; Kostyra et al., 2024) - Unfamiliarity and consumer resistance to new ingredients (Possidónio et al., 2021) - Storage stability and microbial safety (Zelenakova et al., 2024) - Storage and shelf-life (Bhos et al., 2019) - Consumer knowledge and engagement (Šmiglak-Krajewska and Wojciechowska-Solis, 2021) - Competition with traditional spreads (Bidinger, 2024) 	<ul style="list-style-type: none"> - Plant-based and sustainable options: legumes, nuts and amaranth (Kumari and Sharma, 2022); eggplant (Mieles-Gómez et al., 2021); sweet potato, beetroot, guava, and peanut (Bhos et al., 2019); vegetable oil spreads enriched with lingonberry pomace (Baltuonytė et al., 2022); pumpkin seed (Devi et al., 2019); beech achene kernel and sessile oak acorn kernel (Socaciu et al., 2023); tortula yeast (Gärtner et al., 2024); algae (Cappelli, 2022); zero-waste and sustainable sourcing e.g. whole root vegetables (beetroot, carrot, parsnip) and vegetable peel (Mikasauskaitė-Tisoet al., 2023); probiotic and fermented spreads <i>Lactobacillus sakei</i> (Mosso et al., 2020) 	<ul style="list-style-type: none"> - Taste and flavor balance (Kostyra et al., 2024; Amyoony et al., 2023) (e.g., mild, pleasant, non-lingering flavors) - Texture and spreadability (Mieles-Gómez et al., 2021; Trindade et al., 2023) (e.g., smooth, creamy, easy to spread) - Color and appearance (Jia et al., 2025; Bhos et al., 2019) (e.g., light, natural colors, appealing visual presentation) - Aftertaste (Amyoony et al., 2023) (e.g., mild, quick aftertaste, no bitterness) - Familiarity and ingredient recognition (Possidónio et al., 2021; Onwezen et al., 2021) (e.g., legumes, tofu, familiar plant-based ingredients) - Sensory enhancement through natural ingredients (Kostyra et al., 2024; Bhos et al., 2019) (e.g., beetroot, sweet potato, peanut) - Reduction of undesirable flavors (Kostyra et al., 2024; McClements & Grossmann, 2021) (e.g., flavor masking, reduction of bitterness) - Textural improvements through fermentation (McClements & Grossmann, 2021; Mosso et al., 2020) (e.g., umami flavors, improved texture) - Consumer preference for mild flavors (Amyoony et al., 2023; Andersen et al., 2022) (e.g., mild, roasted, nutty flavors)

suggested a variety of product concepts, categorized as fresh, dehydrated, fermented, marinated, or canned. This co-creation approach proved useful for generating relevant ideas and showed potential for guiding the development of innovative aquaculture products. Although examples of co-creation specifically involving spreads or pâtés are limited, several recent studies have explored the participatory development of other food products, such as healthy dairy products, snacks, and beverages with different consumer groups (Ketkaew et al., 2024; Romeo-Arroyo et al., 2025; Vrgović et al., 2022). These studies, which applied multi-stage frameworks and sensory-based feedback,

demonstrate that involving consumers in the product development process can lead to well-accepted, nutritionally improved food innovations. Their findings offer a transferable approach that may be valuable for the design of nutrient-enriched food products tailored to target consumers. Moreover, co-creation studies have also emphasized the relevance of taking gender and age differences into account when designing products for specific groups. Such insights offer practical direction for developing products that more closely match the expectations and requirements of the intended consumers (Javier-Pisco et al., 2024).

7. Challenges in next-generation spread development

In recent years, many innovative trials have been made to reformulate spreads with novel ingredients and processing technologies. These efforts indicate the progress and opportunities in new product development, but also a number of open questions and challenges that limit broader industrial uptake.

One important limitation is scalability and technology readiness levels (TRLs). Most spread formulations described in the literature remain at the laboratory scale (TRL 4), with only a few pilot-scale examples reported (Botella-Martínez et al., 2024; Wendin et al., 2021; Vargas-Ramella et al., 2022). The lack of systematic progression towards higher TRLs limits the commercialization pathway of research results. Beyond academia, start-ups and food companies also play an important role in introducing innovative spreads. Start-ups, with their strong focus on commercialization, can move new ideas to the market more quickly (Klerkx and Villalobos, 2024), while established companies, by using their internal R&D and know-how, are refining formulations and introducing new products to the market. However, these contributions are rarely documented in the scientific literature, which makes them difficult to assess from a research point of view.

Regulatory approval is another major barrier. In the EU, novel ingredients such as microalgae or insect proteins, as well as some emerging processing technologies, fall under the Novel Food Regulation (EU 2015/2283) and require EFSA evaluation before market entry (European Parliament and Council, 2015; Commission Implementing Regulation (EU) 2017/2470; EFSA 2024). While essential for consumer safety, these procedures can slow down or limit the introduction of new formulations (Cruz and Vasconcelos, 2023). Regulatory aspects are also a key issue for oleogels. Despite their clear potential as fat replacers, uncertainties about health effects, variable sensory performance, lipid oxidation, high production costs, and unresolved approvals still restrict their wider use (Günel-Köroğlu et al., 2024; Liu et al., 2024; Abe et al., 2025).

The use of novel ingredients also brings specific challenges. For microalgae, these include preserving functional compounds and ensuring safety, particularly the presence of toxic compounds and elevated nucleic acid levels in certain strains. In addition, undesirable colour, flavour, and textural properties further restrict consumer acceptance when microalgae are incorporated into spreads (Martínez-Ruiz et al., 2025). In the case of macroalgae used as novel ingredients in spreads, a key challenge is ensuring safety due to the potential accumulation of heavy metals, excessive iodine, and other contaminants, especially when biomass is sourced from variable aquatic environments (Guo et al., 2023). In the context of underutilized ingredients for spread development, their wider application remains limited due to challenges such as inconsistent supply, variability in composition and functional properties, potential safety concerns, regulatory barriers, and limited consumer familiarity, all of which need to be addressed to unlock their full potential.

In the context of consumer aspects, most studies examine either product reformulation or consumer acceptance, but rarely consider both together, which limits understanding of how ingredient innovations can meet consumer expectations and market needs.

8. Future research directions in the development of next-generation spreads

Future research should be conducted to optimize texture and flavour, particularly through the use of oleogels, plant proteins, and alternative stabilizers that meet clean-label requirements. In addition, the exploration of innovative ingredients such as bioactive oleogels, microalgae, and underutilized crops offers significant potential for improving nutritional value and sustainability. These novel components, however, require further investigation regarding safety, sensory performance, and consumer acceptance before broader application in spreads.

Another promising research direction is the development of multi-functional and hybrid spreads that combine nutritional enhancement with desirable sensory qualities, aligning with flexitarian and sustainable diets. At the same time, future work should better integrate consumer perspectives with technological innovation, ensuring transparency and trust. Addressing challenges related to scale-up, cost-effectiveness, and regulatory approval will be essential for translating research advances into market-ready products. Finally, participatory approaches such as co-creation with consumers and other stakeholders could accelerate adoption and improve the long-term success of next-generation spreads.

9. Conclusion

This review shows that spreadable foods are increasingly shaped by demands for healthier and plant-based options, and sustainability. Innovation has been driven by advances in ingredients such as plant proteins, oleogels, and underutilized resources, as well as by the application of emerging processing technologies. At the same time, most reported studies remain at laboratory scale, while challenges related to scalability, cost, regulatory approval, and consumer acceptance continue to limit broader uptake. This work combines technological advances with consumer perspectives to give a clearer picture of progress and remaining challenges. Continued collaboration between academia, industry, and consumers will be essential to translate innovative concepts into market-ready products that meet expectations for nutrition, sensory quality, and sustainability.

Ethical statement

This study is a review article and does not involve any new experiments on human participants or animals. All data and information included have been obtained from previously published studies, which adhered to appropriate ethical standards. Therefore, no ethical approval was required for this work.

CRediT authorship contribution statement

Miloš Županjac: Writing – original draft, Methodology, Investigation, Data curation. **Dragana Ubiparip:** Writing – original draft, Visualization, Investigation. **Predrag Ikonjić:** Writing – review & editing, Supervision. **Milica Pojić:** Conceptualization, Supervision, Writing – review & editing, Funding acquisition.

Declaration of competing interest

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

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Data availability

Data will be made available on request.

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