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Functional butter for reduction of consumption risk and improvement of nutrition

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ABSTRACT

Butter has become renowned among consumers because of its exceptional flavor and taste. Nevertheless, conventional butter is deemed "unhealthy" due to its high concentration of saturated fats and cholesterol, which are linked to the development of cardiovascular ailments. Improving the health benefits of butter has become an essential topic of research in the butter industry. This review focuses on researches that have made improvements to functionality of butter, including the changes in fatty acid composition, cholesterol reduction, incorporation with bioactive substances, development of new sources. The reduction of saturated fatty acids and cholesterol in butter can help reduce the risk of disease from eating butter. In addition, incorporating probiotics or natural plant extracts can achieve nutritional functions such as balancing intestinal flora, enhancing nutrient absorption, and increasing the body's antioxidant capacity. Butter substitute products can be based on new vegetable oils, insect fats or microbial fats, which cater to the consumer demands for low-calorie butter while reducing the environmental impact that results from butter production. This review summarizes the effects and characteristics of various improvement methods and proposes some possible directions for future development of functional butter.

1. Introduction

Butter has been consumed by humans since the Neolithic period, as it offers a unique flavor and taste that is widely used in food production and enjoyed by consumers [1]. Butter-based products in the market can be delineated into two categories: natural butter, a dairy product made with pure milk, and margarine, an oil-based product produced using animal and vegetable oils. Hydrogenated margarine was once considered a viable alternative to natural butter, its popularity has grown, particularly in Europe and the United States, due to its similar appearance and taste. However, while hydrogenation does increase the saturation of double bonds, this process results in the loss of significant nutrition from the raw oil. Additionally, the unsaturated double bonds within the oil may be transformed into trans fatty acids that are absorbed by the body and cause arterial hardening, as well as other heart-related diseases [2]. In 2015, the Food and Drug Administration (FDA) announced that partially hydrogenated oils are no longer considered safe to eat [3]. The development of new functional butter and margarine is still ongoing.

From March 2023, the WOS core database was searched using "Butter" or "Margarine" as the subject. Fig.1A shows the top ten countries with the highest publication number of articles, and the annual publication and citation numbers of papers linked to butter or margarine, which illustrate the increasing trend in research in this field. Using VOS Viewer, a keyword co-occurrence analysis was conducted (Fig.1B), and the high-frequency keywords were classified into four categories. The yellow areas focus on cardiovascular disease, blue regions represent novel types of butter, green areas relate to margarine's physical and chemical properties, and red regions describe the quality of butter products.

The classification of a product as butter is based on strict criteria concerning its composition. The Codex Alimentarius Commission defines butter as a dairy product comprising only milk fat. The butter must contain not less than 80% fat, no larger than 16% water, and 2% milk solids [4]. The fat content of butter products has led to several classifications in various countries such as unsalted butter, salted butter, 100%,

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75%, and 50% butterfat spreads, according to European Union regulations. In the United States, products that contain larger than 80% milk fat are classified as butter, while those that contain larger than 40% are known as light butter. Japanese regulations for butter production allow the use of milk from other animals in addition to cow's milk. The Chinese national standard GB 19646–2010 provides clear definitions for butter and anhydrous butter. Butter is a dairy product derived from milk and/or cream (fermented or unfermented), which may or may not include other ingredients, food additives, and nutritional fortifiers. The butter product must contain a minimum fat content of 80.0%, and the anhydrous butter must have a minimum fat content of 99.8%. Fig.2 illustrates the various standards of butter products among different nations.

Butter is derived from milk and contains high-quality nutrients, including carbohydrates, proteins, fats, and micronutrients, in easily absorbed forms. In some experiments, butter is often used as a source of fat in the diet. For example, it is compared with n-6 polyunsaturated fatty acids to examine its effects on liver fat, inflammation, and metabolism in obese individuals [5]. Butyrate, which is abundant in butter, has been convincingly demonstrated to play a crucial role as a mediator in the gut-brain axis with significant impact on neurological disorders. Currently, butyrate is being explored as an experimental pharmacological intervention targeted at neurological disorders encompassing depression, neurodegenerative disorders, and cognitive impairments [6]. However, the intake of butter should be controlled within a reasonable range. Developing functional butter with health advantages has become a significant focus in butter research to minimize the potential health risks associated with consuming butter.

Functional foods are part of a new market niche that seeks consumer recognition, satisfaction, and acceptance. They have been attracting interest from the food industry for both economic reasons and due to scientific evidence related to their health benefits [7]. Functional foods provide consumers with functional advantages that are related to specific nutrients, such as vitamins, minerals, fiber, prebiotics, or probiotics. These added ingredients provide benefits beyond basic nutrition [8]. Recently, consumers have become more conscious of the nutrition

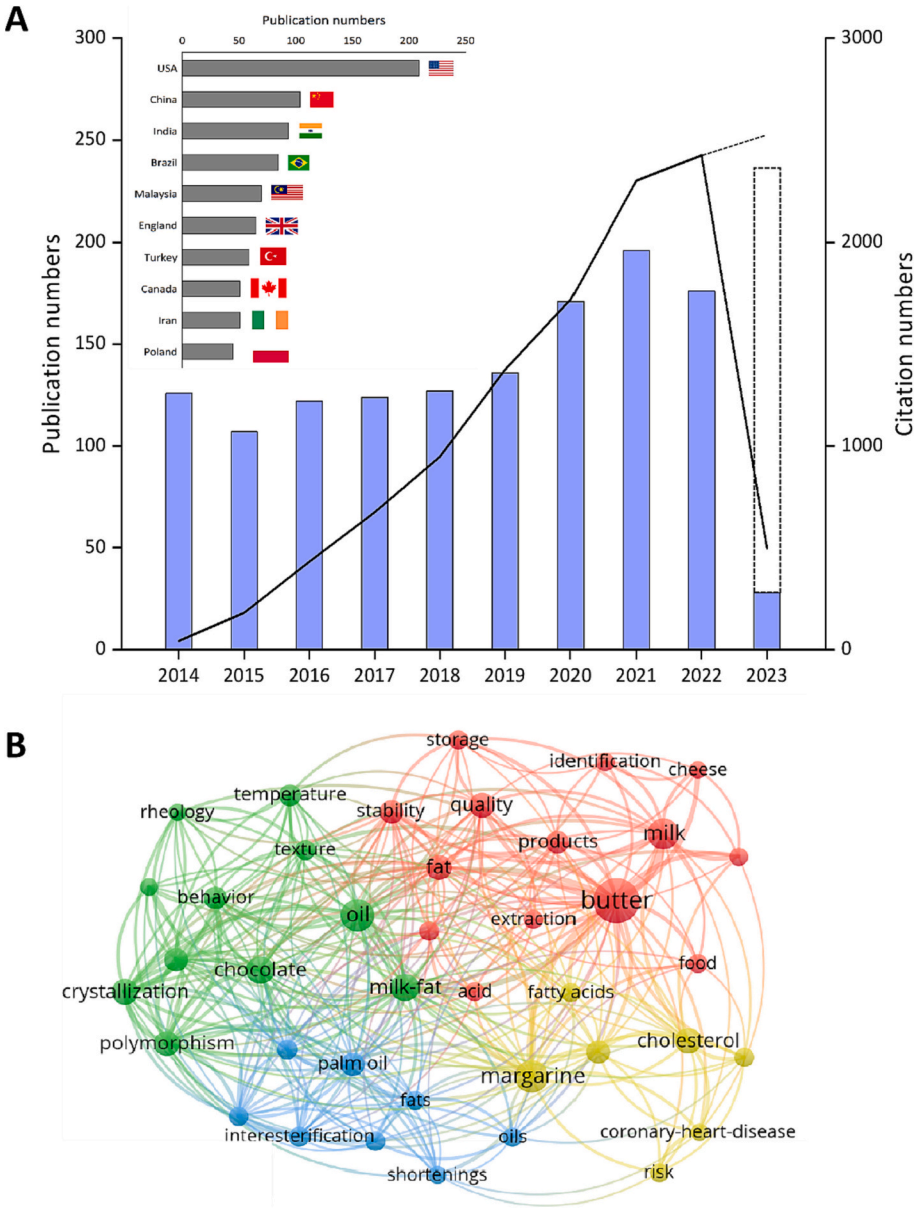


Fig. 1. Analysis of global literatures about butter and margarine in recent 10 years. (Fig.1 A shows the top ten countries with the highest publication number of articles, and the annual publication and citation numbers of papers linked to butter or margarine; Fig.1 B shows the keyword co-occurrence analysis.)

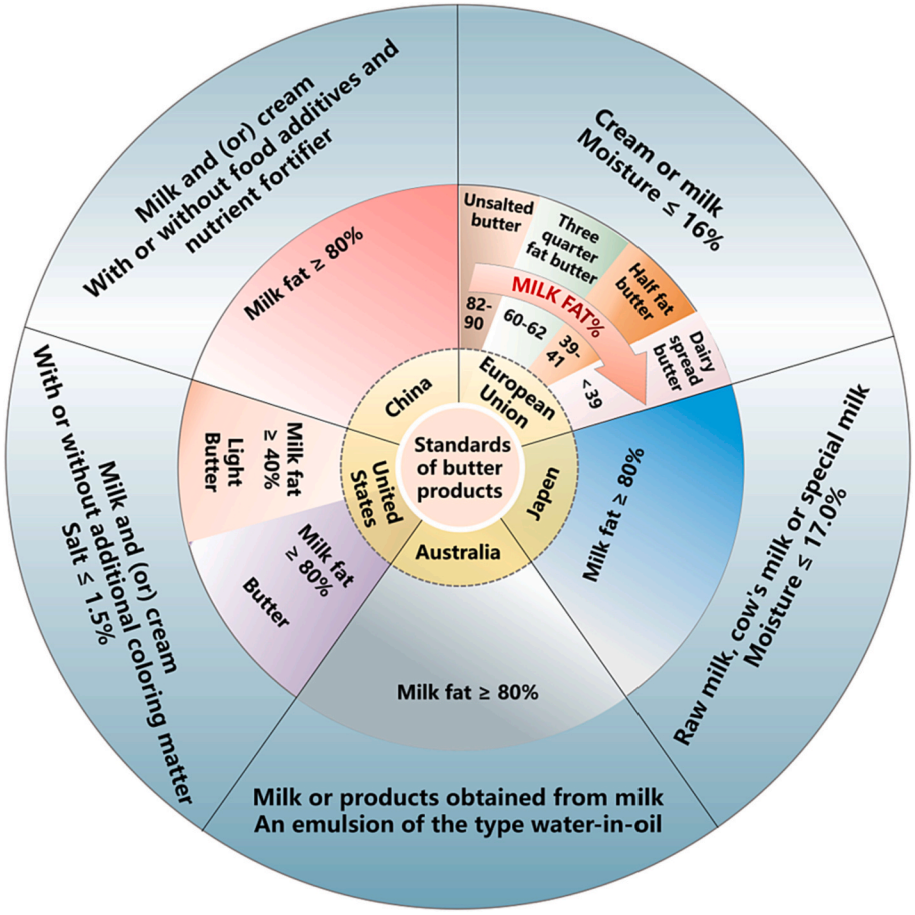


Fig. 2. Definitions and classifications of butter products in different countries.

and quality of their food, resulting in an increased demand for "healthy" foods. The food industry has responded to this demand by increasing the supply of potentially functional foods in the marketplace, particularly those foods traditionally considered unhealthy. Traditional butter's nutritional function can be improved by enhancing fatty acid profiles, reducing cholesterol, adding bioactive components, and developing new raw materials (Fig. 3). Furthermore, the development of butter substitute product has also become a topic of focus in recent years. This paper examines the application of innovative technologies and raw materials in producing functional butter or butter substitute, as well as the various characteristics of functional butter.

2. Functional butter for reducing health risk

2.1. Butter fortified with unsaturated fatty acids

Butter contains abundant medium and short-chain fatty acids, which have special physiological functions such as easy absorption, fast metabolism, growth promotion, broad-spectrum antimicrobial properties, and maintenance of intestinal health. However, butter has high proportion of saturated fatty acids (SFAs) and low content of n-3 fatty acids. SFAs can lead to obesity, a problem that is widely recognized [9]. Obesity is a well-known risk factor for multiple comorbidities, such as type 2 diabetes, cardiovascular disease, steatohepatitis, certain types of cancer, and mental health illnesses, including dementia and cognitive impairment [10,11]. Moreover, the potential relationship between long-chain SFAs and hypothalamic dysfunction in obese patients has been demonstrated. A diet that is high in SFAs also increases low-density lipoproteins (LDL) in the body. This increase in LDL can easily cause an inflammatory reaction in the vascular endothelium, thereby increasing the risk of cardiovascular and cerebrovascular diseases, such as atherosclerosis [12]. Adjusting the fatty acid profile of butter can help reduce the health risks associated with SFAs. One method of changing the fatty acid composition in milk fat is directly adding fatty acid supplements, which is a convenient and effective way of controlling the content of specific fatty acids. However, certain supplements may have a distinctive odor that could affect the butter taste. To avoid this, indirect addition of fatty acid supplementation, such as special feeding of cows, has been studied extensively.

2.1.1. Butter fortified with n-3 fatty acids

2.1.1.1. Fish oil. Fish oil is a rich source of long-chain polyunsaturated n-3 fatty acids, such as α-linolenic acid (ALA), docosahexaenoic acid (DHA), and eicosapentaenoic acid (EPA) [13]. The high levels of n-3 fatty acids in fish oil are associated with beneficial effects on heart, brain, and nervous system function. The health benefits of consuming fish oil have been supported by numerous studies, including the prevention of cardiovascular disease, cancers, and Alzheimer's disease [14]. Additionally, the fatty acids found in fish have been proven to have positive therapeutic effects on obesity, type 2 diabetes, depression, non-alcoholic fatty liver disease, and other related conditions [15]. The n-3 fatty acids not only decrease the risk of cardiovascular disease but also improve heart rate and decrease the risk of heart attack, high blood pressure, lipid levels, and atherosclerosis. Despite the demonstrated and emphasized significance of n-3 polyunsaturated fatty acid (n-3 PUFA) for human health, their intake in the daily diet remains low, adding fish oil to food is an effective way to increase n-3 fatty acid intake among the population [16].

Adding fish oil to butter can increase the proportion of PUFA in its

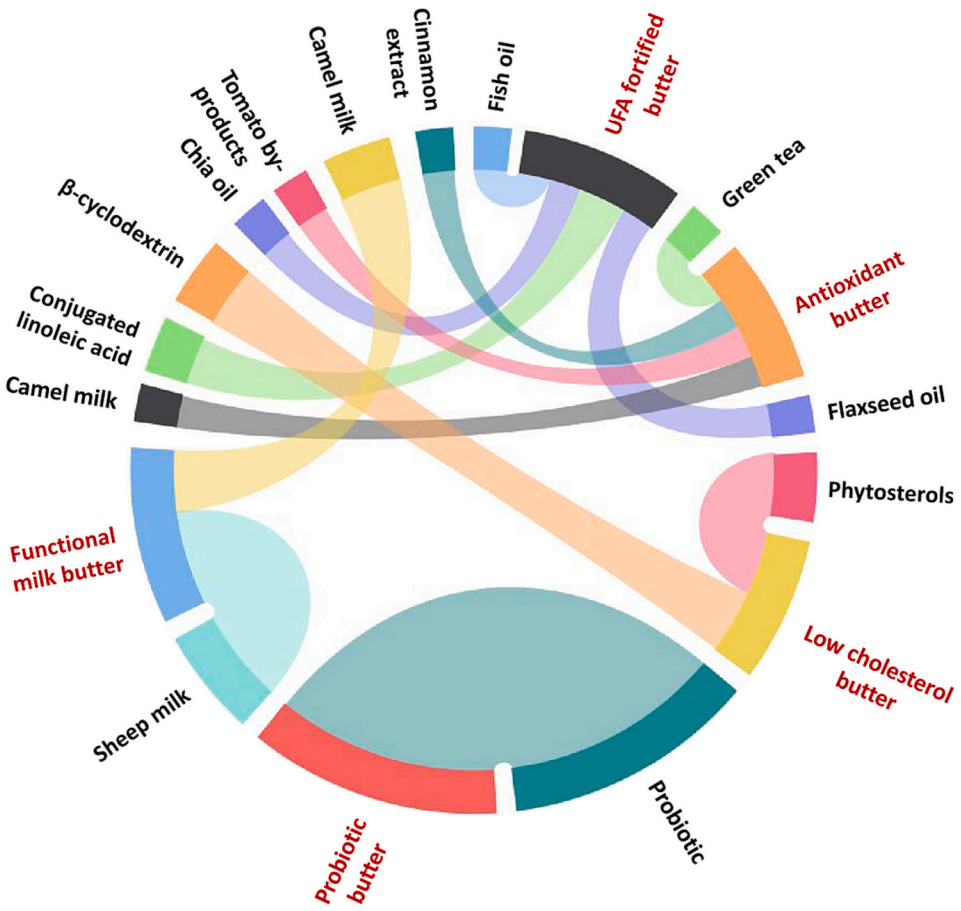


Fig. 3. Ingredients added to functional butter in previous studies. (The width of the chord is proportional to the study frequency of functional ingredients).

fatty acid composition, which helps reduce the risk of cardiovascular disease associated with butter consumption. Additionally, the hydrophilic components of butter improve the oxidative stability of fish oil, ensuring better nutritional value [17]. Studies have shown that fish oil butter positively affects the level of n-3 PUFA in plasma, red blood cells and liver cells of hamsters compared to commercial butter [18].

The incorporation of fish oil into traditional butter altered its texture by increasing adhesion and reducing hardness and the melting point. Fish oil butter offers exceptional spreadability; However, its sensory properties are inferior to that of regular butter due to the distinct aroma of fish oil. Subroto et al. [19] believed that when preparing fish oil butter, the optimal mixing ratio of fish oil to cream was 5:95 *w/w*, and this formula could make the EPA content in the final product reach 2.05%.

To minimize the interference of fish oil odor, several indirect addition methods have been developed. Previous studies have explored the effect of adding fish oil to cow feed on milk's nutritional quality. After feeding cows with tuna oil for ten days, the levels of EPA and DHA in milk increased by 6.9 and 10.1 g/kg milk fat, respectively, resulting in an increase in total n-3 PUFA concentration in milk fat by 3 to 4 times [20]. Ramaswamy et al. [21] obtained n-3 PUFA rich-butter by feeding cow's special feed, and the hardness of fish oil butter was not significantly different from that of ordinary butter. Additionally, compared to the controls, the fish oil butter had a higher concentration of trans-vaccenic acid as well as unsaturated fatty acids. In contrast, Baer et al. [22] noted that butter in the fish oil group was significantly softer than that of the control group at both 4 °C and 20 °C. The addition of fish oil to the cow's diet did not have a negative impact on the production performance of the dairy cows or the consumer acceptability of milk and cheese. Additionally, the fish oil butter exhibited similar taste to that of control butter while having better oxidation stability.

2.1.1.2. Chia oil. Chia seeds are composed of 15%–25% protein, 30%–33% fat, 41% carbohydrate, and 18%–30% dietary fiber. Additionally, they are rich in polyphenols and are commonly utilized for extracting bioactive compounds and creating functional foods [23]. Chia oil, in comparison to fish oil, has a lighter taste and is more abundant in PUFA. There have been some studies on adding chia oil to butter. This method can increase the amount of ALA in margarine by directly adding chia oil [24]. However, the UFA of chia oil caused the oxidation stability of butter to be inferior to that of commercial butter.

Microencapsulated chia oil is a viable option in enhancing the oxidation stability of n-3 fatty acids, making it an ideal ingredient in butter. Incorporating 8% microencapsulated chia oil to butter resulted in a noteworthy increase in the amount of n-3 fatty acids in the butter fatty acid profile while also exhibiting no substantial difference before and after 90 days of storage [25]. This finding confirms the possibility of producing ALA-rich butter by adding chia oil. The health benefits of ALA-rich butter have been proven [26]. Mice fed with butter rich in ALA had greater thermogenesis after exposure to extreme cold. ALA supplementation promoted mitochondrial biosynthesis, which contributed to the brown adipose tissue (BAT) remodeling.

2.1.1.3. Flaxseed oil. Flaxseed has a typical fatty acid profile, with PUFA accounting for 73% of total fatty acids and SFAs accounting for only 9%. It contains the highest percentage of ALA, reaching up to 57%, compared to all other known plant seeds [27]. Adding flaxseed oil to food increases PUFA levels effectively [28]. However, flaxseed oil is prone to oxidation due to its high PUFA content. Toxic peroxides produced during oxidation will affect the quality and safety of the product,

so flaxseed oil is more suitable to be added as an emulsifier. Butter supplemented with a concentrate of 6.8% flaxseed-whey protein had an ALA content 3.7 times higher than the control group, providing almost 25% of the recommended daily intake. And the sensory quality of the fortified butter remained unaffected by the inclusion of flaxseed oil [29].

In addition to chia oil and flaxseed oil, traditional plant oils such as olive oil, rapeseed oil, and sesame oil are also rich in n-3 UFA. In recent years, their health benefits have been extensively researched. Some novel oils, such as sage oil, have been found to be abundant in n-3 UFA and can replace up to 10% of plant fats in food and beverages. In 2014, according to European Union Commission Regulation (EC) No 258/97, sage oil was classified as a novel food ingredient and approved for use as a food supplement. The combination of these oils, rich in n-3 UFA, with butter holds significant importance in the development of new unsaturated fatty acid butter varieties.

2.1.2. Butter fortified with conjugated linoleic acids

Linoleic acid is classified as an essential fatty acid. The risk of atherosclerosis and cardiovascular diseases may be reduced by adequate intake of linoleic acid [30]. Conjugated linoleic acid (CLA) is a group of isomers having two conjugated double bonds located in different positions of fatty acids. A moderate intake of CLA can lower cholesterol levels, reduce body fat, and potentially lower the risk of cancer. Including oleic and linoleic acid-rich fat in the diet of dairy cows increases the content of CLA in dairy products. In the study carried out by Avramis et al. [31] and Jones et al. [32], there was no significant sensory difference between CLA-fortified milk and ordinary milk, while sensory studies of Campbell et al. [33] believed that CLA-fortified milk was less acceptable than ordinary milk due to its vegetable oil flavor. There is no obvious sensory difference between commercial butter and CLA butter [34]. CLA butter, in comparison to commercial butter, shares a basic sensory profile but with enhanced attributes such as its stronger aroma, lower boiled milk scent, and higher spreadability. It also boasts better stability during storage, possibly due to its high α-tocopherol levels and the potential antioxidant benefits of CLA.

Adding UFA can reduce the risk of cardiovascular disease associated with SFA consumption. However, the instability of UFA causes the stability of butter fortified with UFA to decrease during storage, resulting in the formation of undesirable flavor compounds. For example, hexanal, heptanal, (E)-2-nonenal, (E, E)-2,4-heptadienal and (E, Z)-2,6-nonadienal may be generated from the autoxidation of arachidonic, linoleic, and linolenic acid. The metallic odor of butter caused by light may also arise from the production of trans-4,5-epoxy-(E)-2-decenal by linoleic acid [35,36]. Therefore, in order to improve the stability of fortified butter, additional methods are often required when adding UFA in butter. Furthermore, the potential applications of other functional oils in butter, including n-3 PUFA, n-6 PUFA, SDA-rich soybean oil, and oleic acid-rich olive oil, have not been explored. Future research could investigate the combination of these functional fats with butter to enhance its nutritional value.

2.2. Removal of cholesterol in butter

Among all dairy products, butter has the highest cholesterol content (2483.44 mg/kg), which is significantly greater than that of soft cheese (387.50 mg/kg) and cottage cheese (382.18 mg/kg) [37]. Adequate consumption of cholesterol contributes to the well-being of the human body. Cholesterol plays a vital role in cellular functions and hormone synthesis. Insufficient intake of cholesterol can lead to an increased risk of depression and diseases like cerebral hemorrhage [38]. Previous studies have consistently shown that excessive consumption of cholesterol elevates cholesterol levels in animals and humans, thereby raising the risk of atherosclerosis. Therefore, The US Dietary Guidelines in 1977 advised individuals to limit their daily cholesterol intake to 300 mg. However, subsequent research has found that diet is responsible for only a small percentage of the increase in cholesterol and low-density lipoproteins in the human body. Genetic metabolism is the primary factor contributing to the increase in cholesterol levels in the body. This suggests that cholesterol levels can rise even in the absence of dietary intake of cholesterol. In 2015, The US Dietary Guidelines removed the daily limit of consuming 300 mg of cholesterol-rich foods. However, this does not imply that cholesterol has no relation to cardiovascular diseases. Cardiovascular and cerebrovascular diseases caused by high-cholesterol diets are among the major diseases causing the most deaths today [39]. The 2018 American Clinical Practice Guideline for Cholesterol Reduction, jointly developed by the American Heart Association (AHA), the American College of Cardiology (ACC), and other academic institutions, has been officially issued. The primary recommendation underscores that adopting a healthy lifestyle is essential for mitigating the risk of atherosclerotic cardiovascular diseases, and emphasizes that a healthy lifestyle includes a healthy diet. A widely recognized healthy diet pattern focuses on consuming low-cholesterol foods, including fruits, vegetables, whole grains, and low-fat or fat-free dairy products. Meeting the growing consumers' need for low-cholesterol diets, manufacturing low-cholesterol butter has become an emerging trend in the butter industry.

Several techniques have been developed for cholesterol removal, such as organic solvent and supercritical fluid extraction [40–42]. Although effective in removing cholesterol, these methods lack selectivity and may result in the loss of other nutrients. Other studies have summarized using microorganisms or enzymes to remove cholesterol [43,44], phytosterols [45], pectin [46], β-cyclodextrin (β-CD) and other substances have also been used to remove cholesterol. Combined with butter's production process and characteristics, microorganism and β-CD are used to remove cholesterol in butter. However, the application of other methods in butter has hardly been studied. Table 1 showcases the production patents for various types of low-cholesterol butter.

2.2.1. Removal by microorganism

Lactic acid bacteria (mainly including *Lactobacilli* and *Bifidobacteria*) are often added to food as bioactive components, providing a variety of physiological functions such as antibacterial activity and anticarcinogenic activity [47]. Several studies have revealed that fermented dairy products that contain probiotics can decrease cholesterol levels significantly. Additionally, consumers typically prefer microbial methods for cholesterol reduction, as opposed to physical methods, as they perceive it can enhance the taste of dairy products while improving the texture of butter [48]. Kim et al. [49] assessed the ability of lactic acid bacteria obtained from traditionally fermented Korean kimchi to assimilate cholesterol. The fermenting butter contained 108 CFU/g of live cells, and the cholesterol levels dropped by 11%, compared to the control group. Albano et al. [50] employed *Lactobacillus casei* VC199, *Lactobacillus paracasei* ssp. paracasei SE160 and VC213, *Lactobacillus plantarum* VS166 and VS513, *Enterococcus faecium* VC223, and *Enterococcus lactis* BT161 for fermenting cheese, resulting in a cholesterol removal efficiency of up to 23% after 60 days of fermentation. The high-fat content present in cream causes bottleneck when removing bacterial cells via centrifugation, eventually limiting cholesterol elimination. Researchers have carried out studies using calcium alginate beads to increase the separation efficiency of bacterial cells in cream, hence minimizing the cholesterol content. As a result, the butter produced has 44% less cholesterol [51].

2.2.2. Removal by β-CD

β-CD is a torus-shaped oligosaccharide made up of α-(1,4) linked condensed glucose units obtained from the starch by the enzyme cyclodextrin glucosyltransferase [52]. The hydrophobic inner cavity and hydrophilic outer structure of β-CD allow it to envelop cholesterol molecules at a 2:1 ratio, forming a complex [53]. Since the cavity size in the β-CD molecular structure is ideal for cholesterol molecules, this procedure is highly selective for cholesterol. This technique enables the removal of cholesterol explicitly by the β-CD method, while having little

Table 1
Patents and their core technologies describing the production of various low-cholesterol butter.

International publish number	Title	Core technology	Inventors and publication date
KR2017043036	LRCC 5307 *pediococcus acidilactici* LRCC 5307 strain having ability of choloesterol assimilation and method for manufacturing cultured butter using the same	This invention pertains to a new lactobacillus strain, *Pediococcus acidilactici* LRCC5307, which was isolated from kimchi. The invention also covers a production method for cholesterol-lowering fermented butter using the strain.	S. M. Yoon; D. Y. Bang; S. Y. Yang; J. H. Lim; M. Y. Jo; K. B. Park; C. H. Kang; M. J. Yea 20 Apr 2017
KR2016054863	Preparation of low cholesterol butter	The butter is distilled at 190–220 °C to obtain low cholesterol butter. The method removes 50% of cholesterol, and does not use additives, and is eco-friendly.	M. Y. Jo; K. B. Park; H. H. Park; M. J. Yea 17 May 2016
CN 103601901	Low cholesterol dairy product and crosslinked β-CD, preparation method and application thereof	The β-CD and the adipic acid are in a mass ratio of 20:1–15:1 to form crosslinked β-CD. The crosslinked β-CD has a small residue amount, has no sweet taste and does not influence the product taste. Also, the crosslinked β-CD can realize reutilization.	T. Cai; B. H. Guo; Z. M. Liu; J. L. Miao; L. Ren; H. Wang; Y. Xiao; P. Yu 26 Feb 2014
CN 103844274	Low-cholesterol dairy product, grafted β-CD rice bran fibers and preparation method and application thereof	The production cost of grafted β-CD rice bran fibers is low. Only a few of the grafted β-CD rice bran fibers are retained in a final butter product, and the taste of the product cannot be affected.	T. Cai; B. H. Guo; Z. M. Liu; J. L. Miao; L. Ren; H. Wang; Y. Xiao; P. Yu 6 Nov 2014
WO 2012/025931	Low cholesterol butter and process of preparation	The preparation of butter of reduced cholesterol content by allowing formation of complex between cholesterol and β-CD with the efficiency about 85%–90% removal of cholesterol without affecting the quality of the product in terms of flavor and consistency	Soni; K Nain. 1 Mar 2012
EP1978811	Linseed butter and a method of producing linseed butter.	The linseed butter has lower contents of SFA and cholesterol, while it has higher levels of monounsaturated fatty acids and PUFA.	R. Kaniewski; J. Kozlowska; J. Gagalo 1 Jun 2011
WO2009140273	Systems and methods for producing reduced cholesterol dairy products	A reduced cholesterol cream, as compared to a conventionally prepared cream, is produced by pressurizing and shearing whole milk prior to separation of the whole milk into skim milk and cream	Salinas I. E.; Segovia E.; Salinas I.; Salinas E. 19 Nov 2009
BR9806644	Use of vegetable oil steroids in margarines consists of combating of high cholesterol in food, via the steroids and their isomers	The steroids obtained from vegetable oils during refining, which give enhanced quality of numerous types of food. Cholesterol levels in margarine, butter, cheese and edible refined oils, are greatly reduced	R. L. B. Penteado; Belmudes De Toledo C. 08 Aug 2000

to no impact on the remaining nutritional value and flavor profile of butter.

Kolaric et al. [37] reduced the cholesterol content of butter by 95.6% by adding 5.0% β-CD, resulting in a cholesterol content of 108.66 mg/kg, compared to the control sample. Alonso et al. [54] utilized β-CD to eliminate 90% of cholesterol in butter, resulting in a cholesterol content of 300.4 mg/kg for the final product. Dias et al. [55] optimized the use of β-CD to remove butter cholesterol, including the concentration of β-CD and the complexation method. The butter containing 10% β-CD demonstrated the highest cholesterol removal efficiency of 90.7%. Alonso et al. [54] proposed the use of β-CD treatment to efficiently eliminate cholesterol in butter without negatively affecting its color and texture. The total color difference (ΔE) ranged between 0.25 and 1.13, which is within an acceptable range. Table 2 [56–61] summarizes the conditions of low-cholesterol cream and butter productions using β-CD in previous studies.

Although the β-CD method is one of the most successful ways of reducing cholesterol in butter, some studies noted that this method can cause a decrease in consistency [62,63]. Nguyen et al. [64] reported that the addition of β-sitosteryl oleate can enhance the physicochemical properties of low-cholesterol butter, resulting in a firmer and stickier product. Furthermore, β-sitosteryl oleate can also hinder cholesterol absorption in the gut, further augmenting the health benefits of low cholesterol butter [65]. Butter produced through this method is comparable to regular butter with regards to texture, while only containing 4.9% of the cholesterol found in regular butter.

Removing butter cholesterol through microbiological processes can enhance the sensory qualities and texture of butter. The method of removing butter cholesterol using β-CD is simple, effective, cost-efficient, and can be implemented on current technological production lines. Furthermore, β-CD has been approved as a food additive by European authorities and is considered safe for consumption. Low cholesterol butter produced through these two methods holds the status of functional food, making it a meaningful step in mitigating health problems caused by long-term excessive consumption of cholesterol from animal-based foods.

3. Functional butter for improving nutrition

3.1. Butter fermented by probiotics

Probiotics refer to living microorganisms that provide health benefits

Table 2
Reports of cholesterol removal in cream and butter by β-CDs.

Product	CDs		Mixing processing			Centrifugation processing		Removal rate of cholesterol (%)	Ref.
	Type	Level (%)	Speed	Temperature (°C)	Time (min)	Speed	Time (min)		
Cream	*β*-CD	10	–	40	30	4000 rpm	10	91.12	[56]
Cream base	*β*-CD	2.85	–	–	30	700 ***g***	15	93.00	[57]
Commercial cream	Crosslinked *β*-CD	15	1400 rpm	40	30	10,000 rpm	10	91.42–92.09	[58]
Cream	Crosslinked *β*-CD	4–12	350 rpm	40	30	166 ***g***	10	73.20–91.40	[59]
Commercial butter	*β*-CD	10–20	–	–	180–720	1400–1800 rpm	–	89.52–91.54	[60]
Cream	Crosslinked *β*-CD	10	800 rpm	40	30	166 ***g***	–	91.40	[61]

to individuals when administered in adequate amounts [66]. Probiotics offer health benefits mainly by improving immune function and resistance through balancing the gut microbiota and suppressing the growth of pathogenic bacteria. Moreover, they have shown potential in decreasing cholesterol levels and alleviating lactose intolerance. Some studies have also shown that probiotics effectively treat and prevent neurological diseases [67].

Numerous genera of bacteria (and yeast) are used as probiotics, including *Lactobacillus, Leuconostoc, Pediococcus,* and *Bifidobacterium*. Probiotics for fermentation in the cream are mesophilic lactic acid bacteria, namely *Lactococcus lactis* ssp. *Diacetilactis*. The fermentation of cream with different microorganisms strongly influences butter's physicochemical properties, nutritional compositions and sensory qualities. Healthy foods that are advertised as containing probiotics are required to have an adequate amount of living bacteria. Some studies suggest that the concentration of probiotics in food reaches 10^7 CFU/g to reach the colon [68]. Foods with the added health benefits of probiotics should contain at least 10^8–10^9 CFU/g living cells to effectively avoid the loss of bioactives during storage and digestion [69,70]. The processing and storage of butter affect the viability of probiotics, and it is challenging to develop new butter products with sufficient probiotics levels [71]. Olszewska's research also showed that in the process of 4 weeks of cold storage, survival cells of *Bifidobacterium lactis* in butter reduced, with the number of live cells decreasing by more than one logarithmic cycle in the last week of storage [72]. Erkaya et al. [73] studied the survival of microbial strains in butter fermented with *Lactobacillus acidophilus* ATCC 4356 and *Bifidobacterium bifidum* ATCC 29521 after 60 days of cold storage. After 30 days of storage, butter still has probiotic characteristics, and the active probiotic level is larger than 10^6 CFU/g. However, this still falls short of the ideal level of probiotics.

Microencapsulation technology may enclose probiotics in a capsule, thereby safeguarding them from unfavorable conditions and enhancing their viability and stability [74]. The amalgamation of encapsulation technology and probiotics presents a viable solution to the issue of probiotic instability [75]. Naissinger da Silva et al. [76] used encapsulation technology to package *Lactobacillus acidophilus* in sodium-reduced butter and simulated its transit through the gastrointestinal tract to evaluate the survival rate of the probiotic. The findings revealed that a sample containing a 5 g/100 g probiotic capsule exhibited poor survival rates following gastrointestinal tract simulation. However, capsules containing 10 g/100 g probiotics exhibited more favorable outcomes.

Specific strains of probiotics used in the fermentation process of butter not only prevent spoilage but may also modify its sensory attributes. The physicochemical and rheological properties of butter produced from cream fermented with *Lactobacillus helveticus* were studied [77]. The post-fermentation analysis revealed that the fat content and acid value of the butter have increased noticeably, whereas the moisture and grey value have decreased. In addition, fermentation affects the texture and nutritional quality of butter. Fermented butter has a softer consistency and contains higher amounts of unsaturated fatty acids compared to the control group. In addition, the size of capsule particles added to food may affect consumers' acceptability. Naissinger da Silva et al. [76] used visible probiotic capsules to encapsulate *Lactobacillus acidophilus* and *Bifidobacterium bifidum* and add them to butter. Although large particles were visible in butter, butter containing 10% capsules still showed good acceptability in all the evaluation parameters, 81.1% of consumers have purchase intention.

The addition of probiotics in functional foods is becoming increasingly common, as they play an important role in achieving nutritional health. Integrating probiotics into many fermented dairy products faces many challenges, as the viability and stability of probiotics are often negatively affected in many dairy products, mainly due to low pH and storage conditions. Various techniques such as encapsulation technology and the use of cryoprotectants can help stabilize probiotics under different processing and storage conditions. Current research primarily focuses on the effects of adding probiotics to butter products on the physicochemical properties and sensory characteristics. Further research, through metabolomics studies, can provide a comprehensive understanding of the complete metabolite composition, offering insights into the aroma and nutrition-related compounds.

3.2. Antioxidative or antibacterial butter

Butter storage is accompanied by the breakdown and oxidation of lipids, which lead to spoilage. This fact leads to flavor defects [78], the loss of color and nutritional value, and may even be harmful to the health of consumers. The addition of antioxidants is an effective method for delaying lipid oxidation. However, strict regulations regarding synthetic food additives and the carcinogenic properties of some synthetic antioxidants have redirected manufacturers' attention to natural antioxidants [79]. While most commonly, butter spoilage is chemical in nature, undesirable microbes can also contribute to the development of a rancid taste. Butter stored below 5 °C can experience rot and lipolysis resulting in cold-loving bacteria, yeast, and mold strains proliferating. Certain pathogenic bacteria, including *Staphylococcus aureus* and *Listeria monocytogenes*, can also be present in butter stored at low temperatures, and cause spoilage [80].

To improve the oxidation and microbial stability of butter, many studies have investigated the addition of various natural antioxidants or antibacterial components. These additions can help ensure good stability throughout the butter's lifespan. Additionally, the biological activity of these substances can provide the desired function properties for consumers.

3.2.1. Green tea extract

Green tea is a natural substance rich in polyphenols, particularly flavanol monomers known as catechins, which contain a variety of potential health benefits [81]. Green tea has been used to treat cardiovascular heart disease, mouth, Parkinson's disease, Alzheimer's disease, diabetes, inflammatory bowel and skin diseases [82,83]. Adding green

tea extract has also improved the nutritional properties of many food and beverage products [84,85], Thakaeng et al. [86] utilized green tea extract as a means to produce high-value-added butter. The green tea butter exhibited significantly ($P < 0.05$) higher antioxidant properties regarding total phenolic content and DPPH activity than the control butter. After six weeks of storage, green tea butter shows lower peroxide value and yeast and mold count. Although the addition of green tea extract increased the redness of butter and significantly reduced lightness and yellowness, the addition of 6% extract was shown not to affect sensory acceptability. As a natural antioxidant and preservative, green tea extract have an ideal effect on the preservation of butter.

3.2.2. By-product of tomato processing

Lycopene is a fat-soluble carotenoid with good antioxidant activity, has a certain protective effect on the heart, and has attracted people's attention in recent year [87]. Tomato processing by-products are rich sources of lycopene and some phenolic compounds. Some studies have successfully applied lycopene to some functional foods, including noodles [88], vegetable oils [89] and ice cream [90]. Abid et al. [91] successfully added tomato by-products to traditional Tunisian butter. The results showed that the peroxide value of butter samples supplemented with 400 mg/kg extract remained the lowest after 60 days of storage. Tomato processing by-products could be used as a protective agent against lipid peroxidation in butter.

3.2.3. Hazelnut powder

Hazelnuts are rich in monounsaturated fatty acids [92] and contain high levels of phytosterols [93], which inhibit intestinal absorption due to their structural similarity to cholesterol, therefore, lowering total plasma cholesterol and LDL levels. They may also protect against colon, breast and prostate cancer [94]. Emami et al. [95] studied the effects of hazelnut powder addition on chemical and sensory properties, fatty acid profile and tocopherol content of butter for the first time. The peroxide value of the fortified samples was significantly lower than that of the control butter, which may be related to the presence of antioxidant compounds such as tocopherols, phytosterols and squalene in hazelnuts. The addition of hazelnuts increased the level of α-tocopherol in butter. In addition to the nutritional benefits, adding hazelnuts also helps spread butter better. The study also showed that the butter rich in hazelnuts was as stable as the control regarding sensory and physicochemical qualities.

3.2.4. Cinnamon extract

The cinnamon extract contains a variety of antioxidant compounds that effectively scavenge superoxide anions and other free radicals. Cinnamon oil has been shown to inhibit the growth of mold and yeast. Cinnamaldehyde, as a preservative, also significantly inhibits the growth of microorganisms. It has been approved by the Food and Drug Administration of the U.S.A. for the use as a safe food additive [96]. The addition of cinnamon extract slows down the growth of microorganisms during butter storage, which can delay the deterioration of butter. The addition of 3% (*W/W*) of cinnamon extract obtained the highest consumer preference. The chemical composition of cinnamon butter met the standard requirements and also showed lower levels of free fatty acids compared to the control group and the sorbate-added sample, showing the potential of cinnamon extract as a natural preservative for butter production [97].

Antioxidants can prevent tissue damage caused by free radicals by either preventing their generation, removing them, or promoting their decomposition. Recent reports have suggested that synthetic antioxidants can be harmful to human health. Therefore, there has been increasing interest in finding naturally occurring compounds that are effective, non-toxic, and possess antioxidant activity. Natural plant extracts are currently the main source for the development of antioxidants. In addition to endogenous antioxidant defense systems, dietary intake of antioxidants is a suitable option. Therefore, the addition of antioxidants in functional foods is becoming an increasingly important strategy.

4. Butters prepared by functional milk

Although cow milk is typically used to produce butter, there has been growing interest in functional milk butter as consumers become more aware of the benefits of functional foods. These milks have been shown to have higher nutritional value than cow milk. Table 3 illustrates the composition differences associated with butter production between cow milk and other functional milks, such as sheep, goat, camel, donkey, mare, buffalo, and human milk [98–103].

4.1. Sheep milk butter

Sheep milk contains nearly double the amount of protein found in cow milk, is high in fat, and contains essential vitamins, lecithin, riboflavin, and some important minerals [104]. The amino acid composition of sheep milk is highly beneficial for human health. The proline levels, in particular, are conducive to the production of human hemoglobin. The most abundant fatty acid found in goat's milk fat is oleic acid, which is known to help reduce LDL cholesterol. Sheep milk fat contains high levels of linoleic and ALA. The presence of these polyunsaturated fatty acids is associated with a decreased risk of cardiovascular diseases like atherosclerosis and thrombosis [105]. Furthermore, the smaller fat globule size of goat milk compared to cow milk allows for easier digestion and a creamier texture, resulting in a superior quality of butter [106]. The unique composition of free fatty acids in sheep milk gives it a distinct flavor that carries over into its dairy products, such as sheep butter. This results in a more robust flavor profile compared to goat butter. Additionally, sheep milk may be a more suitable alternative for individuals who suffer from allergies and gastrointestinal issues with cow milk [107].

In recent years, the production of milk from small ruminants, such as sheep and goats, has been on the rise. The surplus of milk requires a new market opportunity. Many studies have confirmed the potential and advantages of using sheep milk for cheese, yogurt, and butter production. Morteza et al. [108] compared the differences in physical properties between conventional butter and sheep butter. Sheep butter is harder than conventional cow butter at 5 °C, but has a faster melting speed as it approaches room temperature. It begins to soften at around 18 °C. This temperature sensitivity necessitates higher ambient temperatures for production and transportation, which can limit the manufacturing of sheep butter.

In addition to affecting the physical properties, the type of milk used in butter production also influences its flavor profile. Historically, traditional cow milk butter has been regarded as the standard for superior flavor. Therefore, conducting sensory evaluations is a crucial step in the product development of sheep butter [104]. Tahmas-Kahyaoğlu et al. [109] identified volatile compounds in cow, sheep, and goat butter using the SPME/GC–MS method. The results show that 2-decanal, 5-methyl-2-hexanol, 6-methyl-1-heptanol, 3-methyl-2-butanol, α-terpinene, and γ-terpinene were detected only in sheep butter. 2,4-Hexadienal, 2-octanone, heptanol and 1-nonanol were detected only in goat butter. The findings suggest that sheep butter has unique flavor characteristics when compared to cow butter. While some consumers may find the distinct aroma of sheep milk appealing, others may perceive it as unpleasant. In an attempt to offer alternatives for those who are averse to the smell of sheep milk, Dias et al. [104] put forward the idea of blending cow milk and goat milk to produce butter. For the first time, they studied the characteristics of this product and its impact on consumer perception and behavior. The study found that samples made using 60% goat milk and 40% cow milk had a common butter flavor compared to those made exclusively from cow milk. Additionally, using goat milk in butter production resulted in a more adhesive and harder texture. These samples also had higher concentrations of short and medium-chain SFAs and polyunsaturated fatty acids, leading to greater

Table 3
Contents of main fractions related to butter production in milk from different animals.

Parameter	Protein (%)	Fat (%)	Lactose (%)	Vitamin A	Vitamin D	Vitamin E	Vitamin K (μg/100 mL)	β-carotene (μg/100 mL)	References
Cows	3.2–3.8	3.7–4.4	4.8–4.9	10.0–100.0[a]	–	20.0–184.0[a]	1.1–3.2	16.6–38.0	[99]
Sheeps	3.6–6.6	3.8–6.2	3.9–5.2	54.3–69.5[b]	0.1–0.2[b]	40.0–120.0[b]	–	–	[98]
Camels	3.1–3.4	3.3–4.1	4.2–4.7	10.0–39.0[a]	–	27.6–327.0[a]	–	–	[99,100]
Buffaloes	2.7–4.7	5.3–9.0	3.2–5.7	69.0[a]	3.0[b]	190.0–266.0[b]	–	–	[101]
Donkeys	1.1–2.1	0.2–1.3	6.0–7.2	1.7–58.0[a]	2.2–2.3[a]	2.1–38.4[a]	–	–	[102]
Mares	1.5–2.8	0.5–2.0	5.8–7.0	40.3[a]	0.5[a]	113.0[a]	1.9	38.8	[103]
Humans	1.1–1.3	3.3–4.7	6.8–6.9	30.0–200.0[a]	0.0–0.1[a]	237.0–800.0[a]	0.2–1.5	0.2–37.5	[103]

Note:[a] unit: μg/100 mL; [b] unit: μg/100 g.

satisfaction and ease of digestion among consumers.

The natural color of butter is derived from the carotenoids consumed by the animals in the pasture. Due to their greater efficiency at converting dietary carotenoids to vitamin A, the butter produced from goat milk is whiter compared to cow milk butter. And the higher carotene content of cow butter gives it the yellow color favored by consumers [106]. Researchers have explored the use of additives with natural pigments to enhance the appearance of goat butter. Sea buckthorn is a rich source of numerous health-promoting compounds, such as vitamins A, C, and E, unsaturated fatty acids, phenolic compounds (especially flavonoids), and phytosterols. Chudy et al. [110] demonstrated that the incorporation of sea buckthorn puree into goat butter as a natural colorant was successful. The addition of puree improved acidity and adhesiveness, enhanced the low-temperature dispersibility of the butter, and altered its natural whiter color. The number of customers liking goat butter increased by 35% after adding 1.5% sea buckthorn fruit pure.

The butter storage process can result in the loss of desirable flavors and the production of compounds that negatively impact its flavor. Çakmakçı et al. [111] examined the oxidative stability and sensory characteristics of cow, sheep, and goat milk butter. The peroxide values of sheep and goat butter increase throughout storage, with goat butter demonstrating the highest rate of oxidation, followed by sheep, then cow butter. Due to their increased acidity and putrid taste resulting from oxidation, goat and sheep butter receive a lower sensory evaluation compared to cow butter, which oxidizes at a slower rate. To increase the shelf life of sheep butter, Ines Carvalho Santos et al. [112] utilized gamma radiation during the manufacturing process. Irradiation technology can address issues of food quality and safety by preventing the proliferation of food-borne pathogenic microorganisms and controlling spoilage, without significantly altering the sensory characteristics of the food. Previous studies have found irradiation to be effective in preventing spoilage of dairy products [113]. However, Ines Carvalho Santos's study found no significant effect of gamma radiation on goat butter's shelf life [112].

Overall, while sheep butter boasts superior nutritional value and ease of digestion when compared to cow butter, its flavor, appearance, and storage stability differ, requiring further development.

4.2. Camel milk butter

Camel milk is a rich source of vitamins, minerals, and protective proteins with anti-cancer, anti-diabetic, and antibacterial properties [114,115]. The therapeutic effects of camel milk have been confirmed for numerous health concerns such as edema, jaundice, spleen issues, tuberculosis, asthma, anemia, and hemorrhoids. Patients with chronic hepatitis have reported improvements in liver function after consuming camel milk. In Saharan regions, butter made from camel milk is frequently used as a remedy [115]. Camel milk has balanced essential amino acids, a high percentage of easily hydrolyzed β-casein, and is free from the allergy-prone β-lactoglobulin [116]. The market for camel milk products is projected to experience moderate growth over the next few years.

Although camel milk has many health benefits, it is still not as widely used as cow milk in butter production [117,118]. The composition of fat and protein in camel milk is different from that of cow milk. Therefore, the production process used for cow milk butter is not suitable for camel milk butter [119]. Earlier studies suggested that camel milk was unsuitable for butter production because of the absence of lectin, which is a protein that promotes the aggregation of fat globules. What's more, the high proportion of long-chain fatty acids and thick fat globule membranes in camel milk cause camel butter to have a considerably higher melting point than cow milk butter.

Research on camel butter has been limited to the development of production technology. Although some nomads use fresh or fermented camel milk as the main ingredient in traditional manual processes to produce camel butter, the yield is often insufficient [120]. According to Ho et al. [121] the optimal method for producing camel butter involves stirring sweet creamers at 15–20 °C for 10–18 min. Farah et al. [122] indicated that a stirring temperature of 15–36 °C was necessary for making camel butter, with an optimal stirring temperature of 25 °C that can result in a butter yield of up to 85%. Berhe et al. [123] increased the yield of camel butter by altering the stirring process. They fermented the camel cream at room temperature and then stirred it vertically at 22–23 °C for 120 min, with increased stirring force and extended stirring time. This led to an increase in the yield of butter to 80%. Mtibaa et al. [116] argued that camel butter particles will only form when the solid fat content of the cream is below 27.5%, and the cream is stirred at exactly 21 °C. Some studies have investigated the impact of lactation on camel butter production. The chemical composition of camel milk is influenced by the genes associated with lactation. Increased protein and fat content of camel milk during the late lactation period results in a higher yield of camel butter [124].

Camel butter has a white appearance and a high melting point, but it has a low intensity of flavor. Thus, camel milk butter can not only function as a source of food or cooking oil but also as a probiotic nutritional supplement for consumers. In a study conducted by Maurad et al. [125], *L. plantarum* SH12 and SH24 were selected as starter cultures for the fermentation of camel milk, indicating that it is possible to produce a new probiotic butter using camel milk.

Apart from sheep and camel milk, other types of animal milk have the potential to be used in butter production. Research suggests that buffalo milk, due to its high-fat content, is an optimal raw ingredient for butter production. There are no significant differences in protein and fat composition between buffalo and traditional butter [126]. However, buffalo milk contains higher levels of fat-soluble vitamins, which can impart additional health benefits to butter products. In recent years, there has been increasing research interest in functional butter made from various animal milk. Different types of milk sources have the potential to be used as raw materials for the production of functional butter.

5. Butter substitutes with new raw material

With regard to composition, the high fat, saturated fat and cholesterol content of natural butter poses health risks to consumers. Compared to other dairy products and plants, butter, as an animal-

derived product, has a greater negative impact on the environment due to its high levels of greenhouse gas emissions throughout its life cycle. In response, research into natural butter substitutes [127], such as plant-based butter, microbe butter, insect butter, and cellular butter, is rapidly advancing to address both the potential health risks and environmental impact of natural butter.

5.1. New plant oils

Shea is a plant oil of high economic value, with a fat content of over 60% in its nuts. The fatty acid composition of extracted shea butter is optimal as a butter substitute, and it is dairy-free and more environmentally friendly than natural butter. While several papers have reported that shea butter blended with palm fat can be an ideal substitute for cocoa butter, it has not been explored for use in butter preparation [128,129].

In addition to shea, avocados are rich in polyunsaturated fatty acids and cholesterol-free, making them an ideal candidate for healthy butter substitutes. Yong et al. [130] demonstrated the innovative creation of a natural functional butter rich in n-3 fatty acids by blending grass-fed cow butter with avocado butter, avocado juice, and avocado meat, using natural antioxidant vitamin E.

Table 4
Yield and fatty acid composition of different microbial oils used in functional foods.

Microbial species	Microbial name	Year	Yield (%)	Composition and mass fraction of main fatty acids (%)	References
Yeast	*Yarrowia lipolytica*	2021	–	Oleic acid (56.0), LA (19.9), Palmitic acid (6.0)	[131]
	Rhodotorula glutinis	2017	–	Oleic acid (43.4), Palmitic acid (23.5), Stearic acid (9.0)	[132]
	Rhodosporidium kratochvilovae	2017	46.8	Oleic acid (45.3), Palmitic acid (21.9), LA (15.9)	[133]
Bacteria	*Rhodococcus opacus*	2016	–	Palmitic acid (38.5), Heptadecanoic acid (22.9), Oleic acid (13.7)	[134]
Fungus	*Mortierella alpina*	2015	31.0	ARA (35.0), EPA (30.0)	[135]
Algae	*Schizochytrium* sp.	2022	–	DHA (97.8), EPA (1.1), Methyl tricosanoate (0.8)	[136]
	Pavlova salina	2021	49.4	EPA (19.1), palmitic acid (15.1), oleic acid (3.8)	[137]
	Phaeodactylum tricornutum	2019	44.8	EPA (28.4), palmitic acid (11.3), oleic acid (2.8)	[138]
	Botryococcus braunii	2019	5.5	Oleic acid (59.6), ALA (11.2), palmitic acid (9.4)	[139]

5.2. Microbial butter

Microbial oil is produced through a combination of microorganism cultivation and oil processing technology. Table 4 presents a summary of reports detailing the fatty acid composition and yield of various microbial oils used in functional foods [131–139]. Fungi, yeast, bacteria, and algae are all capable of producing microbial oil, with the fatty acid composition and ratios varying depending on the specific microorganism. Edible microbial oils have many advantages, including high purity, functionality, safety, and unlimited production conditions. Single-celled algae, particularly *Schizochytrium* sp., are among the most studied oil-producing microorganisms used in food. The European Commission has authorized the use of oil from *Schizochytrium* sp. as a novel functional food ingredient [136]. Microbial oil is an essential source of functional oil for various food processes, such as margarine preparation, and provides new avenues for producing functional butter with a healthy fatty acid composition.

5.3. Insect butter

Lipids derived from Gadfly blackwater and Powdery mildew can be used as a replacement for natural butter. When 75% of the mass score was replaced with insect lipids, the color and coating properties of butter products remained unaffected [140]. In a separate study, substituting 25% of butter with insect fat in baked goods did not result in reduced sensory pleasure or product acceptance by consumers. The production of margarine using insect lipids, which are abundant in raw materials and help reduce environmental burdens, merits further study.

5.4. Cell butter

Recent breakthroughs in synthetic biology and its related cutting-edge fields, such as automation, 3D-bioprinting, and artificial intelligence, have spurred innovation in cell factories or cell agriculture. The method of yeast cell expression has been utilized to create artificial milk, and it can be applied to produce cell butter as well. Furthermore, the global push toward “carbon neutrality” and green practices is expected to propel future research into butter-producing cell factories.

6. Conclusion and future perspectives

Concerns regarding the sensory quality and health risks of consuming butter have been brought to the attention of modern consumers. Functional butter has made significant advances due to its potential health benefits over traditional butter.

The addition of UFA supplements can directly or indirectly improve the fatty acid composition of butter. While the direct approach of adding these supplements is expeditious and uncomplicated, some of these supplements have a strong smell that can adversely impact the flavor of butter. In order to overcome the drawback, a cow’s diet can be indirectly supplemented with these additives by executing a complete feeding cycle, but the process is time-consuming. Incorporating β-CD or particular microorganisms into the butter can decrease cholesterol levels, β-CD is recognized for its superior potential in lowering cholesterol levels in butter. Probiotics fermentation enhances the health benefits of butter and positively influences its flavor and shelf life. Incorporating natural antioxidant and antibacterial constituents not only guarantees the stability of the butter products throughout the storage cycle, but also enhances the functional properties of the butter in the human body. Finally, the combination of new fats including plant, insect, and microbial oils can produce feasible butter alternatives. Plant, microbial, and insect oils are exceptional raw materials for producing butter alternatives since they can attain the plasticity, functionality, and environmental sustainability of margarine, contributing toward the sustainable progress of the food industry.

Functional butter research presents many challenges. Firstly,

verification of the functional characteristics of improved butter is necessary. While most studies discuss the existence of functional ingredients and their impact on butter products, there is insufficient data on the demonstration of improved butter's health effects in animals or humans. Therefore, more animal experiments or clinical trials should be conducted to clarify the correlation between functional butter and human or animal obesity, cardiovascular and cerebrovascular diseases. Secondly, consumers' demand for various functional food products is continually increasing with the continuous development of bioactive ingredients. Thus, it is necessary to expand functional ingredients that can be added to butter production in the future. In particular, the application of many functional plant extracts in functional foods is increasing year by year, such as curcumin. The effect of these functional natural additives in butter is worth studying.

CRediT Authorship Contribution Statement

Shujie Cheng: Conceptualization, Writing – original draft, Visualization. **Wei Li:** Writing – review & editing. **Shimin Wu:** Conceptualization, Funding acquisition, Project administration, Supervision, Writing – review & editing. **Yuxing Ge:** Writing – review & editing. **Caiyun Wang:** Conceptualization, Writing – review & editing. **Siyu Xie:** Investigation, Writing – review & editing. **Juan Wu:** Writing – review & editing. **Xiangke Chen:** Resources, Writing – review & editing. **Lingzhi Cheong:** Writing - review & editing.

Declaration of Competing Interest

The authors declare no conflicts of interest.

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References

[1] Z. Cheng, M.G.O. Sullivan, S. Miao, et al., Sensorial, cultural and volatile properties of milk, dairy powders, yoghurt and butter: a review, Int. J. Dairy Technol. 75 (2022) 761–790.
[2] W.F. Salas-Valerio, D.P. Aykas, B.A. Hatta Sakoda, et al., Infield screening of trans-fat levels using mid- and near-infrared spectrometers for butters and margarines commercialized in the Peruvian market, LWT-Food, Sci. Technol. 157 (2022), 113074.
[3] C. Weber, L. Harnack, A. Johnson, et al., Nutrient comparisons of margarine/margarine-like products, butter blend products and butter in the US marketplace in 2020 Post-FDA ban on partially hydrogenated oils, Public Health Nutr. 25 (2021) 1123–1130.
[4] C.L. Lee, H.L. Liao, W.C. Lee, et al., Standards and labeling of milk fat and spread products in different countries, J. Food Drug Anal. 26 (2018) 469–480.
[5] S.O. Yilmaz, A. Altinci, Incidence of aflatoxin M1 contamination in milk, white cheese, kashar and butter from Sakarya, Turkey, Food Sci. Technol. 39 (2019) 190–194.
[6] H. Bjermo, D. Iggman, J. Kullberg, et al., Effects of n-6 PUFAs compared with SFAs on liver fat, lipoproteins, and inflammation in abdominal obesity: a randomized controlled trial, Am. J. Clin. Nutr. 95 (2012) 1003–1012.
[7] J. Matos, C. Cardoso, N.M. Bandarra, et al., Microalgae as healthy ingredients for functional food: a review, Food Funct. 8 (2017) 2672–2685.
[8] L. Ferreira, A. Borges, D. Gomes, et al., Adding value and innovation in dairy SMEs: from butter to probiotic butter and buttermilk, J. Food Process. Preserv. 46 (2020), e14867.
[9] D. Sergi, L.M. Williams, Potential relationship between dietary long-chain saturated fatty acids and hypothalamic dysfunction in obesity, Nutr. Rev. 78 (2020) 261–277.
[10] G.S. Hotamisligil, Inflammation, metaflammation and immunometabolic disorders, Nature 542 (2017) 177–185.
[11] J.A. Luchsinger, D.R. Gustafson, Adiposity, type 2 diabetes, and Alzheimer's disease, J. Alzheimers Dis. 16 (2019) 693–704.
[12] P.N. Hyde, T.N. Sapper, R.A. LaFountain, et al., Effects of palm stearin versus butter in the context of low-carbohydrate/high-fat and high-carbohydrate/low-fat diets on circulating lipids in a controlled feeding study in healthy humans, Nutrients 13 (2021) 1944.
[13] P. Pourashouri, B. Shabanpour, S.H. Razavi, et al., Oxidative stability of spray-dried microencapsulated fish oils with different wall materials, J. Aquat. Food Prod. T. 23 (2014) 567–578.
[14] G. Boran, H. Karaçam, M. Boran, Changes in the quality of fish oils due to storage temperature and time, Food Chem. 98 (2006) 693–698.
[15] M.S. Ellulu, H. Khazaai, Y. Abed, et al., Role of fish oil in human health and possible mechanism to reduce the inflammation, Inflammopharmacology 23 (2015) 79–89.
[16] J. Matos, C. Cardoso, N.M. Bandarra, et al., Microalgae as healthy ingredients for functional food: a review, Food Funct. 8 (2017) 2672–2685.
[17] M. Shiota, H. Konishi, K. Tatsumi, Oxidative stability of fish oil blended with butter, J. Dairy Sci. 82 (1999) 1877–1881.
[18] T. Porsgaard, J. Overgaard, A.L. Krogh, et al., Butter blend containing fish oil improves the level of n-3 fatty acids in biological tissues of hamster, J. Agric. Food Chem. 55 (2007) 7615–7619.
[19] E. Subroto, R. Indiarto Tensiska, et al., Physicochemical and sensorial properties of recombined butter produced from milk fat and fish oil blend, Biosci. Res. 15 (2018) 3720–3727.
[20] S.M. Kitessa, S.K. Gulati, G.C. Simos, et al., Supplementation of grazing dairy cows with rumen-protected tuna oil enriches milk fat with n-3 fatty acids without affecting milk production or sensory characteristics, Brit. J. Nutr. 91 (2004) 271–278.
[21] N. Ramaswamy, R.J. Baer, Schingoethe, et al., Composition and flavor of milk and butter from cows fed fish oil, extruded soybeans, or their combination, J. Dairy Sci. 84 (2001) 2144–2151.
[22] R.J. Baer, J. Ryali, D.J. Schingoethe, et al., Composition and properties of milk and butter from cows fed fish oil, J. Dairy Sci. 84 (2001) 345–353.
[23] R. Alvarez, B. Gimenez, A. Mackie, et al., Influence of the particle size of encapsulated chia oil on the oil release and bioaccessibility during *in vitro* gastrointestinal digestion, Food Funct. 13 (2022) 1370–1379.
[24] M. Nadeem, C. Situ, M. Abdullah, Effect of olein fractions of milk fat on oxidative stability of ice cream, Int. J. Food Prop. 18 (2015) 735–745.
[25] R. Ullah, M. Nadeem, M. Imran, et al., Effect of microcapsules of chia oil on omega-3 fatty acids, antioxidant characteristics and oxidative stability of butter, Lipids Health Dis. 19 (2020) 10.
[26] M. You, R. Fan, J. Kim, et al., Alpha-linolenic acid-enriched butter promotes fatty acid remodeling and thermogenic activation in the brown adipose tissue, Nutrients 12 (2020) 136.
[27] A. Ramcharitar, N. Badrie, M. Mattfeldt-Beman, et al., Consumer acceptability of muffins with flaxseed (*Linum usitatissimum*), J. Food Sci. 70 (2005) 504–507.
[28] W. Kolanowski, D. Jaworska, J. Wei, Importance of instrumental and sensory analysis in the assessment of oxidative deterioration of omega-3 long-chain polyunsaturated fatty acid-rich foods, J. Sci. Food Agric. 87 (2007) 181–191.
[29] V.S. Pandule, M. Sharma, D. Hc, et al., Omega-3 fatty acid-fortified butter: preparation and characterisation of textural, sensory, thermal and physico-chemical properties, J. Dairy Sci. 74 (2020) 181–191.
[30] J.H. Kim, D. Gilliard, D.J. Good, et al., Preventive effects of conjugated linoleic acid on obesity by improved physical activity in nescient basic helix-loop-helix 2 knockout mice during growth period, Food Funct. 3 (2012) 1280–1285.
[31] C.A. Avramis, H. Wang, A.R. Hill, et al., Physical and processing properties of milk, butter, and Cheddar cheese from cows fed supplemental fish meal, J. Dairy Sci. 86 (2003) 2568–2576.
[32] E.L. Jones, K.J. Shingfield, C. Kohen, et al., Chemical, physical, and sensory properties of dairy products enriched with conjugated linoleic acid, J. Dairy Sci. 88 (2005) 2923–2937.
[33] W. Campbell, M.A. Drake, D.K. Larick, The impact of fortification with conjugated linoleic acid (CLA) on the quality of fluid milk, J. Dairy Sci. 86 (2003) 43–51.
[34] S. Mallia, F. Escher, S. Dubois, et al., Characterization and quantification of odor-active compounds in unsaturated fatty acid/conjugated linoleic acid (UFA/CLA)-enriched butter and in conventional butter during storage and induced oxidation, J. Agric. Food Chem. 57 (2009) 7464–7472.
[35] H.T. Badings, Cold-storage defects in butter and their relation to the autoxidation of unsaturated fatty acids, J. Dairy Sci. 24 (1970) 145–256.
[36] S. Widder, A. Sen, W.C. Grosch, Changes in the flavor of butter oil during storage-identification of potent odorants, Z. Lebensm. Unters. For. 193 (1991) 32–35.
[37] L. Kolaric, P. Kantorova, P. Simko, Beta-cyclodextrin as the key issue in production of acceptable low-cholesterol dairy products, Molecules 27 (2022) 2919.
[38] D.S. Schade, L. Shey, R.P. Eaton, Cholesterol review: a metabolically important molecule, Endocr. Pract. 26 (2020) 1514–1523.
[39] Y.Y. Hu, C.G. Ma, X.W. Chen, et al., Hydrophilic phytosterol derivatives: a short review on structural modifications, cholesterol-lowering activity and safety, Grain Oil Sci. Technol. 5 (2022) 146–155.
[40] S.V. Borges, Extraction of cholesterol from dehydrated egg yolk with acetone: determination of the practical phase equilibrium and simulation of the extraction process, J. Food Eng. 32 (1997) 365–373.
[41] R.S. Mohamed, M.D.A. Saldana, F.H. Socantaype, et al., Reduction in the cholesterol content of butter oil using supercritical ethane extraction and adsorption on alumina, J. Supercrit. Fluids 16 (2000) 225–233.
[42] G.W. Froning, F. Fieman, R.L. Wehling, et al., Supercritical carbon dioxide extraction of lipids and cholesterol from dehydrated chicken meat, Poult. Sci. 73 (1994) 571–575.
[43] F. Zhang, L. Qiu, X. Xu, et al., Beneficial effects of probiotic cholesterol-lowering strain of *Enterococcus faecium* WEFA23 from infants on diet-induced metabolic syndrome in rats, J. Dairy Sci. 100 (2017) 1618–1628.

[44] E.A. Choi, H.C. Chang, Cholesterol-lowering effects of a putative probiotic strain *Lactobacillus plantarum* EM isolated from kimchi, LWT-Food Sci. Technol. 62 (2015) 210–217.
[45] M. Noakes, P.M. Clifton, A.M.E. Doornbos, et al., Plant sterol ester-enriched milk and yoghurt effectively reduce serum cholesterol in modestly hypercholesterolemic subjects, Eur. J. Nutr. 44 (2005) 214–222.
[46] E.E. Garcia Rojas, J.S. dos Reis Coimbra, L.A. Minim, et al., Cholesterol removal in liquid egg yolk using high methoxyl pectins, Carbohydr. Polym. 69 (2007) 72–78.
[47] H. Aloğlu, Z. Öner, Assimilation of cholesterol in broth, cream, and butter by probiotic bacteria, Eur. J. Lipid Sci. Technol. 108 (2006) 709–713.
[48] M. Farias da Cruz, M. Barauna Magno, L. Alves Jural, et al., Probiotics and dairy products in dentistry: a bibliometric and critical review of randomized clinical trials, Food Res. Int. 157 (2022), 111228.
[49] Y. Kim, S. Yoon, H. Shin, et al., Isolation of the cholesterol-assimilating strain *Pediococcus acidilactici* LRCC5307 and production of low-cholesterol butter, Food Sci. Anim. Resour. 41 (2020) 300–311.
[50] C. Albano, S. Morandi, T. Silvetti, et al., Lactic acid bacteria with cholesterol-lowering properties for dairy applications: *in vitro* and *in situ* activity, J. Dairy Sci. 101 (2018) 10807–10818.
[51] M.F.B. Teixeira, S.P.M. Silva, M.F.P. Domingos-Lopes, et al., Production of low-cholesterol butter with *Lacticaseibacillus paracasei* immobilized in calcium-alginate beads, Food Chem. 393 (2022), 133419.
[52] L. Kolarič, P. Šimko, Application of β-cyclodextrin in the production of low-cholesterol milk and dairy products, Trends Food Sci. Technol. 119 (2022) 13–22.
[53] E. Christoforides, A. Papaioannou, K. Bethanis, Crystal structure of the inclusion complex of cholesterol in beta-cyclodextrin and molecular dynamics studies, Beilstein J. Org. Chem. 14 (2018) 838–848.
[54] L. Alonso, J. Fontecha, P. Cuesta, et al., Industrial application of β-cyclodextrin for manufacturing low cholesterol butter, Milchwissenschaft 65 (2010) 36–37.
[55] H.M.A.M. Dias, F. Berbicz, F. Pedrochi, et al., Butter cholesterol removal using different complexation methods with beta-cyclodextrin, and the contribution of photoacoustic spectroscopy to the evaluation of the complex, Food Res. Int. 43 (2010) 1104–1110.
[56] N.A.A. Elwahsh, Manufacture of cholesterol-reduced double cream cheese from buffalo's milk, J. Dairy Sci. 9 (2018) 395–398.
[57] M. Galante, Y. Pavon, S. Lazzaroni, et al., Effect of cholesterol-reduced and zinc fortification treatments on physicochemical, functional, textural, microstructural and sensory properties of soft cheese, Int. J. Dairy Technol. 70 (2017) 533–541.
[58] Y.K. Lee, P. Ganesan, H.S. Kwak, Optimisation of cross-linking β-cyclodextrin and its recycling efficiency for cholesterol removal in milk and cream, Int. J. Food Sci. Technol. 47 (2012) 933–939.
[59] H.J. Ha, J.E. Lee, Y.H. Chang, et al., Entrapment of nutrients during cholesterol removal from cream by crosslinked β-cyclodextrin, Int. J. Dairy Technol. 63 (2010) 119–126.
[60] H.M.A.M. Dias, F. Berbicz, F. Pedrochi, et al., Butter cholesterol removal using different complexation methods with beta-cyclodextrin, and the contribution of photoacoustic spectroscopy to the evaluation of the complex, Food Res. Int. 43 (2010) 1104–1110.
[61] E.M. Han, S.H. Kim, J. Ahn, et al., Comparison of cholesterol-reduced cream cheese manufactured using crosslinked β-cyclodextrin to regular cream cheese, Asian Austral. J. Anim. 21 (2008) 131–137.
[62] T.H. Jung, J.J. Kim, S.H. Yu, et al., Properties of cholesterol-reduced butter and effect of gamma-linolenic acid added butter on blood cholesterol, Asian Austral. J. Anim. 18 (2005) 1646–1654.
[63] J. Kim, T. Jung, J. Ahn, et al., Properties of cholesterol-reduced butter made with β-cyclodextrin and added evening primrose oil and phytosterols, J. Dairy Sci. 89 (2006) 4503–4510.
[64] A.T.L. Nguyen, P.G. Boakye, S.S. Besong, et al., Improvement of physicochemical properties of reduced-cholesterol butter by the addition of beta-sitosteryl oleate, J. Food Sci. 86 (2021) 404–410.
[65] C.H. Duncan, M.M. Best, Effects of sitosterol on serum lipids of hyper-cholesterolemic subjects, J. Clin. Invest. 34 (1956) 930.
[66] F. Yan, S.Q. Tian, H. Chen, et al., Advances in xylooligosaccharides from grain byproducts: extraction and prebiotic effects, grain oil, Sci. Technol. 5 (2022) 98–106.
[67] S. Sarkar, Probiotics as functional foods: documented health benefits, Nutr. Food Sci. 43 (2013) 107–115.
[68] C. Hill, F. Guarner, G. Reid, et al., Expert consensus document. The international scientific Association for Probiotics and Prebiotics consensus statement on the scope and appropriate use of the term probiotic, Nat. Rev. Gastroenterol. Hepatol. 11 (2014) 506–514.
[69] T. Vasiljevic, N.P. Shah, Probiotics-from metchnikoff to bioactives, Int. Dairy J. 18 (2018) 714–728.
[70] G. Poletto, B.D.S. Fonseca, G.C. Raddatz, et al., Encapsulation of *Lactobacillus acidophilus* and different prebiotic agents by external ionic gelation followed by freeze-drying, Cienc. Rural 49 (2019), e20180729.
[71] M. Naissinger da Silva, B.L. Tagliapietra, N.S.P.D.S. Richards, Encapsulation, storage viability, and consumer acceptance of probiotic butter, LWT-Food Sci. Technol. 139 (2021), 110536.
[72] M. Olszewska, B. Staniewski, Ł. Łaniewska-Trokenheim, Cell viability of *Bifidobacterium lactis* strain in long-term storage butter assessed with the plate count and fluorescence techniques, Czech J. Food Sci. 30 (2012) 421–428.
[73] T. Erkaya, B. Ürkek, Ü. Doğru, et al., Probiotic butter: stability, free fatty acid composition and some quality parameters during refrigerated storage, Int. Dairy J. 49 (2015) 102–110.
[74] A. Sohail, M.S. Turner, A. Coombes, et al., Survivability of probiotics encapsulated in alginate gel microbeads using a novel impinging aerosols method, Int. J. Food Microbiol. 145 (2011) 162–168.
[75] H.S. Jin, Y.S. Fei, C.K. Yan, et al., Effect of gums coating materials on the survival of microencapsulated probiotics under simulated gastrointestinal conditions, Mater. Today 29 (2020) 16–19.
[76] M. Naissinger da Silva, B.L. Tagliapietra, F.P. Pivetta, et al., Nutritional, functional and sensory profile of added butter from *Lactobacillus acidophilus* encapsulated and hyposodium salt, LWT–Food Sci. Technol. 161 (2022), 113385.
[77] J.A. Ewe, S.Y. Loo, Effect of cream fermentation on microbiological, physicochemical and rheological properties of *L. helveticus*-butter, Food Chem. 201 (2016) 29–36.
[78] E. Şenel, M. Atamer, F.Ş. Öztekin, The oxidative and lipolytic stability of Yayık butter produced from different species of mammals milk (cow, sheep, goat) yoghurt, Food Chem. 127 (2011) 333–339.
[79] V. Lobo, A. Patil, A. Phatak, et al., Free radicals, antioxidants and functional foods: impact on human health, Pharm. Res. 4 (2010) 118–126.
[80] O.A. Odeyemi, O.O. Alegbeleye, M. Strateva, et al., Understanding spoilage microbial community and spoilage mechanisms in foods of animal origin, Compr. Rev. Food Sci. F. 19 (2020) 311–331.
[81] D.G. Bortolini, C.W.I. Haminiuk, A.C. Pedro, et al., Processing, chemical signature and food industry applications of *Camellia sinensis* teas: an overview, Food Chem. X 12 (2021), 100160.
[82] C. Schneider, T. Segre, Green tea: potential health benefits, Am. Fam. Physician 79 (2009) 591–594.
[83] S. Perez-Burillo, B. Navajas-Porras, A. Lopez-Maldonado, Green tea and its relation to human gut microbiome, Molecules 26 (2021) 3907, https://doi.org/10.3390/molecules26133907.
[84] J. Ning, G.G. Hou, J. Sun, et al., Effect of green tea powder on the quality attributes and antioxidant activity of whole-wheat flour pan bread, LWT-Food Sci. Technol. 79 (2017) 342–348.
[85] M. Dastoorpoor, S.M. Nabavi, N. Majdinasab, et al., A case-control study of drinking beverages and the risk of multiple sclerosis in Iran, J. Health Popul. Nutr. 42 (2023) 22.
[86] P. Thakaeng, S. Wongsakul, M.M. Yusoff, Development of value-added butter through the addition of green tea (*Camellia sinensis* L.) extract, Int. Food Res. J. 27 (2020) 465–474.
[87] S. Przybylska, Lycopene – a bioactive carotenoid offering multiple health benefits: a review, Int. J. Food Sci. Technol. 55 (2019) 11–32.
[88] A.K. Sahoo, Developments of lycopene enrich noodles, S. Asian J. Hum. Re. Man. 6 (2014) 461–470.
[89] A. Bendini, G.D. Lecce, E. Valli, et al., Olive oil enriched in lycopene from tomato by-product through a co-milling process, Int. J. Food Sci. Nutr. 66 (2015) 371–377.
[90] E.M. Rizk, A.T. El-Kady, A.R. El-Bialy, Charactrization of carotenoids (lyco-red) extracted from tomato peels and its uses as natural colorants and antioxidants of ice cream, Ann. Agric. Sci. 59 (2014) 53–61.
[91] Y. Abid, S. Azabou, M. Jridi, et al., Storage stability of traditional Tunisian butter enriched with antioxidant extract from tomato processing by-products, Food Chem. 233 (2017) 476–482.
[92] C. Alasalvar, J.S. Amaral, F. Shahidi, Functional lipid characteristics of turkish tombul hazelnut, J. Agric. Food Chem. 54 (2006) 10177–10183.
[93] K.M. Phillips, D.M. Ruggio, M.A. Khorasani, Phytosterol composition of nuts and seeds commonly consumed in the United States, J. Agric. Food Chem. 53 (2005) 9436–9445.
[94] J.S. Amaral, S. Casal, I. Citova, et al., Characterization of several hazelnut (*Corylus avellana* L.) cultivars based in chemical, fatty acid and sterol composition, Eur. Food Res. Technol. 222 (2006) 274–280.
[95] S. Emami, S. Azadmard-Damirchi, J. Hesari, et al., Production of butter incorporated with hazelnut powder, J. Agric. Sci. Technol. 16 (2014) 1623–1632.
[96] B. Muhoza, B. Qi, J.D. Harindintwali, et al., Encapsulation of cinnamaldehyde: an insight on delivery systems and food applications, Crit. Rev. Food Sci. Nutr. 63 (2021) 2521–2543.
[97] S.A. Vidanagamage, P.M.H.D. Pathiraje, O.D.A.N. Perera, Effects of cinnamon (*Cinnamomum verum*) extract on functional properties of butter, in: C.N. Walpita, P. Sorgeloos, I. Karunasagar, I.K.K.D.S. Ranaweera (Eds.), Procedia Food Science, England, Colombo, 2016, pp. 136–142.
[98] C.F. Balthazar, T.C. Pimentel, L.L. Ferrao, et al., Sheep milk: physicochemical characteristics and relevance for functional food development, Compr. Rev. Food Sci. F. 16 (2017) 247–262.
[99] T.M. Ho, Z. Zou, N. Bansal, Camel milk: a review of its nutritional value, heat stability, and potential food products, Food Res. Int. 153 (2022), 110870.
[100] T. Berhe, E. Seifu, R. Ipsen, et al., Processing challenges and opportunities of camel dairy products, Int. J. Food Sci. (2017) 9061757.
[101] M.Z. Balos, D.L. Pelic, S. Jaksic, et al., Donkey milk: an overview of its chemical composition and main nutritional properties or human health benefit properties, J. Equine Vet. Sci. 121 (2023), 104225.
[102] R.S. Dias, C.F. Balthazar, R.N. Cavalcanti, et al., Nutritional, rheological and sensory properties of butter processed with different mixtures of cow and sheep milk cream, Food Biosci. 46 (2022), 101564.
[103] M. Pieszka, J. Łuszczyński, M. Zamachowska, et al., Is mare milk an appropriate food for people?-a review, Ann. Anim. Sci. 16 (2016) 33–51.
[104] V. Mudgal, A. Vipin, A. Bharadwa, et al., Vitamins supplementation affecting colostrum composition in murrah buffaloes, Indian, J. Anim. Res. 55 (2020) 900–904.

[105] Z. Flis, J. Szczecina, E. Molik, The role of sheep's milk bioactive substances in the prevention of metabolic and viral diseases, J. Anim. Feed Sci. 31 (2022) 211–216.
[106] C.F. Balthazar, T.C. Pimentel, L.L. Ferrao, et al., Sheep milk: physicochemical characteristics and relevance for functional food development, Compr. Rev. Food Sci. F. 16 (2017) 247–262.
[107] A. Carolina dos Santos Costa, D.E. Pereira, R. de Cássia de Araújo Bidô, et al., Consumption of clarified goat butter added with turmeric (*Curcuma longa* L.) increase oleic fatty acid and lipid peroxidation in the liver of adolescent rats, Food Biosci. 39 (2021), 100799.
[108] K. Morteza, M.A. Seyed, M.T.M. Razavi, et al., Fatty acid composition, rheological and thermal properties of butter from sheep's and omega-3 cow's milks, Iranian Food Sci. Technol. Res. J. 13 (2017) 66–79.
[109] D. Tahmas-Kahyaoğlu, S. Cakmakci, A.A. Hayaloglu, Changes during storage in volatile compounds of butter produced using cow, sheep or goat's milk, Small Rumin. Res. 211 (2022), 106691.
[110] S. Chudy, Colour and textural typologies of goat cream butter with sea buckthorn (*Hippophae rhamnoides* L.) puree: instrumental, sensory, and consumer input for product development, Mljekarstvo 71 (2021) 237–247.
[111] S. Çakmakçı, D.T. Kahyaoğlu, A comparative study on some properties and oxidation stability during storage of butter produced from different animals' milk, Gida 43 (2018) 283–293.
[112] I.C. Santos, J. Pinto, A.I. Pimenta, et al., Use of gamma radiation in sheep butter manufacturing process for shelf-life extension, Int. Dairy J. 71 (2017) 43–49.
[113] J.S. Ham, S.G. Jeong, S.G. Lee, et al., Quality of irradiated plain yogurt during storage at different temperatures, Asian Austral. J. Anim. 22 (2009) 289–295.
[114] Z. Zou, C. Bouchereau-De Pury, A.K. Hewavitharana, et al., A sensitive and high-throughput fluorescent method for determination of oxidase activities in human, bovine, goat and camel milk, Food Chem. 336 (2021), 127689.
[115] M.H.A. El-Salam, S. El-Shibiny, Bioactive peptides of buffalo, camel, goat, sheep, mare, and yak milks and milk products, Food Rev. Int. 29 (2013) 1–23.
[116] I. Mtibaa, A. Zouari, H. Attia, et al., Effects of physical ripening conditions and churning temperature on the butter-making process and the physical characteristics of camel milk butter, Food Bioprocess Technol. 14 (2021) 1518–1528.
[117] G. Konuspayeva, B. Faye, G. Loiseau, The composition of camel milk: a meta-analysis of the literature data, J. Food Compos. Anal. 22 (2009) 95–101.
[118] G. Konuspayeva, B. Faye, Recent advances in camel milk processing, Animals 11 (2021).
[119] R. Yagil, O. Zagorski, C. Van Creveld, et al., Science and camel's milk production, in: G. Saint Marin (Ed.), Actes du Colloque: Dromadaires et chameaux animaux laitier, Expansion Scientifique Francais, Paris, 1994, pp. 75–89.
[120] E.I. El-Agamy, R. Ruppanner, A. Ismail, et al., Purification and characterization of lactoferrin, lactoperoxidase, lysozyme and immunoglobulins from camel's milk, Int. Dairy J. 6 (1996) 129–145.
[121] T.M. Ho, Z. Zou, N. Bansal, Camel milk: a review of its nutritional value, heat stability, and potential food products, Food Res. Int. 153 (2022), 110870.
[122] Z. Farah, Effect of heat treatment on whey proteins of camel milk, Milchwissenschaft 41 (1986) 763–765.
[123] T. Berhe, E. Seifu, M.Y. Kurtu, Physicochemical properties of butter made from camel milk, Int. Dairy J. 31 (2013) 51–54.
[124] A.M. Nowier, S.I. Ramadan, Association of beta-casein gene polymorphism with milk composition traits of Egyptian Maghrebi camels (*Camelus dromedarius*), Arch. Anim. Breed. 63 (2020) 493–500.
[125] K. Maurad, K.H. Meriem, Probiotic characteristics of *Lactobacillus plantarum* strains from traditional butter made from camel milk in arid regions (Sahara) of Algeria, Grasas Aceites 59 (2008) 218–224.
[126] A.H. Md Asif, M.A.H. Sarker, G.K. Deb, et al., Fatty acid and amino acid profiles of cheese, butter, and ghee made from buffalo milk, J. Adv. Vet Anim. Res. 9 (2022) 144–154.
[127] C.G. Ma, S.B. Wang, T.L. Si, et al., Study on crystallization behavior of Tibet butter, Grain Oil Sci. Technol. 4 (2021) 62–70.
[128] B.W.F. Goumbri, T.L.T. da Silva, R.D. Marini, et al., African shea butter properties related to common extraction technologies: a review, Food Bioprocess Technol. 15 (2021) 231–248.
[129] A.C. Charles, Y. Dadmohammadi, A. Abbaspourrad, Food and cosmetic applications of the avocado seed: a review, Food Funct. 13 (2022) 6894–6901.
[130] P. Yong, Functional Avocado Butter with Increased Omega-3 Content Comprises Grassland Grazing Cream, Avocado Pulp, Avocado Fruit Juice, and Antioxidants Having Function of Improving Body Nutrition and Skin Health by Increasing Content of Omega-3, KR2020141829, 2021, 01-13.
[131] P. Dayras, C. Bialais, I. Sadovskaya, et al., Microalgal diet influences the nutritive quality and reproductive investment of the cyclopoid copepod paracyclopina nana, Front. Mar. Sci. 8 (2021), 697561.
[132] A. Patel, N. Arora, V. Pruthi, et al., Biological treatment of pulp and paper industry effluent by oleaginous yeast integrated with production of biodiesel as sustainable transportation fuel, J. Clean. Prod. 142 (2017) 2858–2864.
[133] R. Poontawee, W. Yongmanitchai, S. Limtong, Efficient oleaginous yeasts for lipid production from lignocellulosic sugars and effects of lignocellulose degradation compounds on growth and lipid production, Process Biochem. 53 (2017) 44–60.
[134] M. Gientka, S. Gadaszewska, M. Błażejak, et al., Evaluation of lipid biosynthesis ability by rhodotorula and sporobolomyces strains in medium with glycerol, Eur. Food Res. Technol. 243 (2016) 275–286.
[135] R.P. Mason, R.F. Jacob, Eicosapentaenoic acid inhibits glucose-induced membrane cholesterol crystalline domain formation through a potent antioxidant mechanism, BBA-Biomembranes 2015 (1848) 502–509.
[136] L. Ran, J. Yu, R. Ma, et al., Microalgae oil from *Schizochytrium* sp. alleviates obesity and modulates gut microbiota in high-fat diet-fed mice, Food Funct. 13 (2022) 12799–12813.
[137] A.S. Pereira, S.M. Miranda, M. Lopes, et al., Factors affecting microbial lipids production by *Yarrowia lipolytica* strains from volatile fatty acids: effect of co-substrates, operation mode and oxygen, Biotechnol. J. 331 (2021) 37–47.
[138] S. Deshmukh, R. Kumar, K. Bala, Microalgae biodiesel: a review on oil extraction, fatty acid composition, properties and effect on engine performance and emissions, Fuel Process. Technol. 191 (2019) 232–247.
[139] G.F. Ferreira, L.F. Ríos Pinto, R.M. Filho, et al., A review on lipid production from microalgae: association between cultivation using waste streams and fatty acid profiles, Renew. Sust. Energ. Rev. 109 (2019) 448–466.
[140] C. Delicato, J.J. Schouteten, K. Dewettinck, et al., Consumers' perception of bakery products with insect fat as partial butter replacement, Food Qual. Prefer. 79 (2020), 103755.

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Corrigendum

Corrigendum regarding previously published articles

Declaration of Conflict-of-Interest statements were incorrect for the following articles that appeared in previous issues of *Grain & Oil Science and Technology*. The appropriate Declaration/Conflict of Interest statements are included below.

1. "Advances in xylooligosaccharides from grain byproducts: Extraction and prebiotic effects" (Grain & Oil Science and Technology, 2022; 5: 98–106)

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2. "Insight into synergistic antioxidation mechanisms of butyl hydroxyanisole with common synthetic antioxidants" (Grain & Oil Science and Technology, 2022; 5: 114–130)

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3. "Effect of the degree of milling on the microstructure and composition of japonica rice" (Grain & Oil Science and Technology, 2022; 5: 194–203)

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4. "Interactive effect of hot air roasting processes on the sensory property, allergenicity, and oil extraction of sesame (*Sesamum indicum* L.) seeds" (Grain & Oil Science and Technology, 2023; 6: 71–81)

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