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Plant extracts and essential oils in the dairy industry: A review

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Abstract:
Plants have been used as food additives worldwide to enhance the sensory qualities of foods and extend their shelf life by reducing or eliminating foodborne pathogens. They also serve as therapeutic agents due to their beneficial effects on human health through their anti-cancerous, anti-inflammatory, antioxidant, and immune-modulatory properties.

Plants can be added to food as a dry powder, grated material, paste, juice, or as an extract that can be produced by a variety of methods. Plant extracts and essential oils are concentrated sources of bioactive phytochemicals that can be added to food in small amounts in a variety of forms. These forms include liquid, semi-solid, or dry powder for easy and uniform diffusion. Encapsulation can protect bioactive compounds from temperature, moisture, oxidation, and light, as well as allow for controlling the release of the encapsulated ingredients. Nanoemulsions can enhance the bioactivity of active components.

This review explains how plant extracts and essential oils are used in the dairy industry as antimicrobial materials, analyzing their impact on starter bacteria; as natural antioxidants to prevent the development of off-flavors and increase shelf life; and as technological auxiliaries, like milk-clotting enzymes, stabilizers, and flavoring agents. Therefore, plant extracts and essential oils are a better choice for the dairy industry than plants or their parts due to a wide range of applications, homogeneous dispersion, and ability to control the concentration of the bioactive ingredients and enhance their efficiency.

Keywords: Plant extracts, essential oils, dairy products, natural antimicrobials, milk-clotting enzyme, natural antioxidants

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INTRODUCTION

Plants have been utilized as medicine and preservatives, as well as food flavorings, since ancient times. They are used fresh or dry and have many different forms of use, including plant parts such as leaves, roots, flowers, seeds, crusts, tubers, or herbs. They are also applied in crushed or ground forms, or as extracts prepared in different ways [1]. Plants rich in secondary components (alkaloids, organosulfur compounds, glycosides, flavonoids, tannins, phenols, coloring agents, and resins) are classified as medical and aromatic plants [2]. Medical and aromatic plants are used for aromatic, coloring, preservative, and antioxidant purposes as spices and food additives. Phenolics are free radical eliminators and metal chelators. They can inhibit the lipid peroxidation and exhibit various physiological activities as antioxidants. Many foodborne pathogenic and spoilage bacteria, as well as molds and yeasts, can be inhibited by phenols and extracts rich in such substances [1]. In addition, they have potential in the prevention and treatment of some chronic diseases, including cancer, diabetes, and cardiovascular disease [3]. Essential oils (terpenes, esters, alcohols, ketones, aldehydes, and phenols) are of great interest to the food and cosmetic industries, as well as medicine, due to their wide range of biological properties (antimicrobial, antifungal, antioxidant, anti-inflammatory, insecticide, analgesic, anticancer, cytotoxic, etc.) [4].

Milk and dairy products are the most common foods in the diets of all age groups. Their popularity can be attributed to milk's unique components and properties, as well as the fact that a wide variety of foods can be prepared using this ingredient. The market for value-added functional foods has expanded manifold due to the consumers' increased awareness of, and interest in, following healthy dietary strategies to achieve health benefits from foods beyond their basic nutrition [5]. With the introduction of fortified foods, there has been a surge in using plants and their extracts as valuable additives in dairy products because they contain numerous bioactive components that perform a variety of functions. Additionally, plants have been used for centuries in milk and dairy products as technological auxiliaries (e.g. milk-clotting enzyme preparations, cheese wrappers) or as natural preservatives due to their antimicrobial and/or antioxidant properties [6].

Plant extracts are concentrates of bioactive phytochemicals obtained through extraction technologies including steam distillation, cold pressing, or solvent extraction, with or without pretreatment. In addition to classic approaches, new extraction methods have also been investigated, such as ultrasonic, microwave, and supercritical fluid extraction. Essential oils can also be extracted from various parts of plants, depending on the species and variety [7]. The purpose of extraction is to obtain the largest quantity of bioactive components from plants. With the help of solvents, soluble plant metabolites are separated from the insoluble cellular marc. After the solvent is removed, the products can be used in liquid, semi-solid, dry-powdered, or encapsulated form. Nowadays, plant extracts are increasingly becoming important additives in the dairy industry due to their high content of bioactive compounds that have antimicrobial and antioxidant activity [8]. The aforementioned compounds also delay the development of off-flavors and improve the shelf life and color stability of food products. Due to their natural origin, they are excellent candidates to replace synthetic compounds, which are generally considered to have toxicological and carcinogenic effects [9]. Additionally, plant extracts can be added to food in low concentrations with efficient distribution and uniformity. Encapsulation protects them from temperature, moisture, oxidation, and light, while allowing scientists to control the release of encapsulated ingredients, as well as to mask off-flavors and unpleasant odors [10]. Therefore, we mainly aimed to review the possible uses of plant extracts as antioxidants, antibacterials, and antifungals in the dairy industry, as well as to study their effects on the starter bacteria. Furthermore, we analyzed the use of plant extracts instead of renin enzyme to coagulate milk and determined their effect on the yield of the resulting cheese, as well as its physiochemical and sensory properties.

RESULTS AND DISCUSSION

Plant extracts as natural antimicrobials. ***Mode of action.*** Antimicrobials are compounds used for food preservation by controlling the growth of spoilage-causing and pathogenic microorganisms. There are a range of natural compounds with antimicrobial activity that have been identified from various sources (plants, animals, or microbes). However, due to the structural differences between Gram-negative and Gram-positive bacteria, the efficacy of antimicrobial agents mayvary [11]. In plants, natural compounds exerting antimicrobial activity are phenolic compounds, alkaloids, sulfur-containing compounds, and terpenoids, as well as essential oils and their constituents [12–15]. Generally, natural compounds with different chemical groups can permeate or disrupt the cytoplasmic membrane, allowing the passage or release of non-specific compounds. Increased cell membrane permeability leads to the release of intracellular compounds, especially potassium, calcium, and sodium ions, causing irreversible damage [14, 16]. Natural compounds may also inhibit the ATPase enzyme responsible for the energy generation of the cell, which leads to cell death [8, 17].

In a study by Gonelimali *et al.*, the plant extracts significantly affected the cell membranes of Gram-positive and Gram-negative bacteria, as demonstrated by the decline in pH and the hyperpolarization of the cell membrane [18]. Some fatty acids, in particular, have the ability to interfere with the structure of the cell membrane, displacing phospholipids and increasing their permeability. Five of them are acetylenic: 6-hexadecinoic, 6-heptadecinoic, 6-octadecinoic, 6-nonadecinoic, and 6-eicosinoic acids, whereas the other three are saturated: palmitic, heptadecanoic, and stearic acids [13]. The activity of polyphenols depends on the number and position of hydroxyl groups. Polyphenols may inhibit the enzymes of microorganisms, possibly through interactions with sulfhydryl groups or through less specific interactions with proteins [19]. Miklasińska-Majdanik *et al.* reported that phenolic compounds partially damaged the bacterial membrane, inhibited virulence factors such as enzymes and toxins, and suppressed bacterial biofilm formation [20]. In addition, some natural polyphenols, aside from their direct antibacterial activity, exert a synergistic effect when combined with common chemotherapeutics.

Essential oils also have antibacterial, antioxidant, and antimutagenic properties, as well as possible health benefits. These natural compounds, which are generally recognized as safe (GRAS), reduce lipid oxidation in foods and hence hold potential as natural food additives [21]. There are many types of compounds in essential oils which have proven antimicrobial properties. They include phenolic monoterpenes (thymol and carvacrol), phenylpropanoids (eugenol), alcoholic monocyclic monoterpenes (α-terpineol and terpinen-4-ol), as well as bicyclic monoterpene hydrocarbons (α-pinene) and ketones (camphor). The acidic nature of the hydroxyl group of phenols facilitates a hydrogen bond with the enzyme active center, which is responsible for their high activity [22]. Terpenoids can rupture the cell membrane due to their lipophilic nature.

Challenges of using plant extracts as antimicrobials in the dairy industry. *In vitro*, several studies have demonstrated that plant extracts and essential oils of aromatic and medicinal plants have antimicrobial activity against pathogens and spoilage microorganisms associated with food contamination [23, 24]. However, these results cannot be strictly valid due to the complexity of the food matrix. Moreover, many factors interfere with the activity of these compounds, such as proteins, lipids, packaging, storage temperature, type of microorganism, and compound stability [17, 25]. Proteins and lipids, for example, can wrap around the surface of the microorganism, forming a physical barrier that prevents the bioactive compound from coming into contact with the microorganism, thus reducing its efficacy [17]. In a similar report, the antimicrobial activities of cinnamon and clove essential oils were lower in the high-fat milk samples than in the skim milk samples [26]. Dairy products are foods with a high content of proteins, lipids, minerals, and vitamins. So, when adding extracts and essential oils of aromatic plants to dairy products as antimicrobials, we must take into account the following factors:

1. Natural compounds added as antimicrobials should be in greater concentrations than those tested *in vitro*. According to Gammariello *et al*., the concentration of active compounds used to inhibit the growth of pathogenic microorganisms in Fior di Latte cheese was significantly higher than the level tested *in vitro* [27]. The minimum inhibiting concentration of pomegranate essential oil against *Listeria monocytogenes* and *Staphylococcus aureus* (105 CFU/mL each) was higher than 2.5 mg/mL in a culture medium, while its concentration of 40 mg/mL in Cheddar cheese failed to inhibit the same population of those microorganisms [28]. Hassanien *et al.* also mentioned that the 0.1% concentration of black cumin essential oil reduced the growth of *L. mononocytogenes*, *S. aureus*, *Escherichia coli*, and *Salmonella enteritidis* in a culture medium, while in cheese, such concentrations were not effective against *S. aureus* and *L. monocytogenes* [23];
2. In some cases, mixing some plant components at low concentrations has a higher antimicrobial effect than adding them separately, which proves their synergistic effect [17];
3. Dairy products contain all the nutrients necessary for the microbial growth of cultured cells, allowing for a faster recovery of cells damaged by natural antimicrobials [29];
4. The contents of natural compounds can decrease during processing and storage. Libran *et al.* reported a decrease in the content of compounds from basil and tansy essential oils added during cheese production [30]. In another study, rosemary essential oil added to sheep milk during cheese manufacturing had a loss of 37.49% [24]; and
5. Microencapsulation can improve the stability of natural substances throughout processing and storage [31]. Nanoemulsions of plant extracts can decrease the quantity of a required effective dose and enhance the material's bioactivity against bacteria by allowing them to penetrate the cell membrane and thus destabilize its lipid bilayers [32]. For example, a nanoemulsion of anise extract performed better than bulk extract as an antimicrobial agent against some foodborne pathogenic bacteria [33].

Plant extracts as antibacterials in dairy products. Several plants in various forms (powder, essential oils, extracts, etc.) have been successfully used in dairy foods. Plant extracts of cinnamon, garlic, lemongrass, cress, rosemary, sage, and oregano individually inhibited the population of *L. monocytogenes* in processed cheeses [34]. According to Shan *et al*., all the extracts of cinnamon stick, pomegranate peel, grape seed, oregano, and clove inhibited the growth of *S. aureus*, *L. monocytogenes*, and *S. enterica* in cheese [28]. As a result, these extracts, especially clove, have the potential to be employed as natural food preservatives. Cayenne and green pepper extracts also reduced the *S. aureus* population in Egyptian Kareish cheese [35]. Mahajan *et al.* reported that the aqueous extracts of pine needles improved the microbiological properties of low-fat Kalari, an Indian hard cheese, due to their antioxidant and antimicrobial properties [36]. Sulfur-containing compounds are credited with antimicrobial activity in plant-based compounds, particularly diallyl sulphides in *Allium* species, terpenoids (carvone and limonene) in spearmint essential oil, eugenol in clove oil, and thymol in thyme oil. Ginger's antimicrobial activity is attributed to several compounds, including gingerols, gingerdiols, and shogaols [37–39]. Table 1 lists bioactive components and their functional qualities in plants used to manufacture functional dairy products.

In addition, the essential oils of aromatic plants also showed anti-bacterial activity in food preservation, even with Gram-negative bacteria. Gram-negative bacteria have an effective permeability barrier consisting of a thin lipopolysaccharide exterior membrane, which could restrict the penetration by the extruding plant extracts. Gram-positive bacteria have a mesh-like peptidoglycan layer which is more accessible to permeation by plant extracts [40]. In Feta cheese and Iranian white cheese, oregano (0.1%) and thyme (0.1%), salvia (0.1%), basil (1%), and black cumin essential oils had antimicrobial activity against *L. monocytogenes* [41, 42]. In Iranian white cheese inoculated with *E. coli* O157:H7 and treated with black cumin essential oil, the pathogen growth was significantly lower compared to the control during storage [43]. Adding clove essential oil to Paneer cheese increased its shelf life to 10 days in the treated cheese compared to 5 days in the control sample. Furthermore, the control samples had a higher microbial count compared to the treated cheese. Clove essential oil added at concentrations of 0.5 and 1% dramatically reduced the growth rate of *L. monocytogenes* in cheese at 30 and 7°C. However, high concentrations of clove oil may adversely affect the sensory properties of food. Thus, small concentrations may be enough to ensure low bacterial load and, therefore, food safety [44].

The addition of aqueous licorice and cinnamon extracts to yoghurt exhibited the strongest inhibitory effect on *Helicobacter pylori* development when compared to the control yoghurt [45]. According to Mahgoub *et al*., adding 0.2% *Nigella sativa* essential oil to the cheese improved its physicochemical and sensory qualities. In addition, it provided the most effective antibacterial capability against *S. aureus*, *S. enteritidis*, and *E. coli* [46]. In goat milk-based yoghurt containing *Lactobacillus acidophilus* and roselle extract, higher antimicrobial activities were observed against *Bacillus cereus*, *E. coli*, *S. aureus*, and *Salmonella typhi*. This could be attributed to the production of higher antimicrobial compounds such as antimicrobial peptides and organic acids [47].

Plant extracts as antifungals in dairy products. Fungi are spoilage microorganisms that grow in foodstuffs during storage, reducing their nutritional value and sometimes producing mycotoxins. As a result, foods become unfit for consumption [8]. The growth of fungi on the cheese surface can be inhibited by using some plant-based compounds. For example, cinnamon leaf and bark essential oils (≤ 10% (v/v) showed the highest antifungal activity during the ripening of Appenzeller cheese [48]. Also, incorporating cinnamon oil with 5% cinnamaldehyde into a film coating of spreadable cheese delayed the growth of *Aspergillus niger* and *Penicillium expansum* [49]. Molds and yeasts were not detected in UF-soft cheese fortified with ginger and garlic extracts until the end of storage, 42 and 90 days, respectively [37, 50]. Sağdıc *et al.* found that garlic and thyme extracts inhibited most molds and yeasts in soft cheese [51]. Plant extracts can also help to delay or prevent the formation of mycotoxins. Vazquez *et al.* found that eugenol (200 µL/mL) added to Arza Ulloa cheese reduced the synthesis of citrinin, a toxin generated by *Penicillium citrinum* [37]. Sindhu *et al.* also found that the essential oil isolated from curcuma leaves (1.5%) inhibited aflatoxin formation [52]. At concentrations of 0.50–1.5%, the oil of *Satureja hortensis* L. exhibited antibacterial activity, while its alcoholic extract had no effect on *S. aureus* mycelia growth. Similarly, the *S. hortensis* essential oil implanted in fresh cow's cheese prevented *S. aureus* growth, but its ethanol extract did not appear to be effective [53]. Labneh, a concentrated yoghurt with 0.2 ppm essential oils of thyme, marjoram, and sage, had a 21-day shelf life compared to the control, with yeast and mold observed in the control from the 14th day onwards [54]. Labneh containing 0.3% cinnamon oil, on the other hand, had a longer shelf life (8 days) when stored at 6°C compared to the control product [55].

Effect of plant extracts on starter culture activity. Starter cultures are responsible for fermentation and provide the desired sensory qualities to the finished product. Plant extracts and essential oils, which are intended to suppress pathogenic bacteria, prevent spoilage, or improve sensory characteristics, have been demonstrated in numerous studies to have no effect on the activity of starting cultures. Lactic acid bacteria are the most resistant bacteria to antimicrobial agents in plant extracts and essential oils at concentrations that limit the growth of pathogenic microorganisms [17]. In particular, the count of lactic acid bacteria in sheep's cheese was not reduced when rosemary essential oil was added to inhibit the growth of *Clostridium tyrobutyricum* [25]. In a similar report, Gammariello *et al.* found that 13 extracts and essential oils of orange species, grapefruit, spring lemon, parsley, and lemon Boyajian did not affect the survival of lactic acid bacteria in Fior di Latte cheese, while decreasing the population of pathogenic bacteria [27]. Furthermore, treating Argentinean cheese with 200 mg/kg of oregano oil had no influence on *Lactococcus lactis*, *Lactobacillus bulgaricus*, or *Streptococcus thermophilus* growth or acidifying activity, compared to the control [56].

The addition of 0.03% *Mentha longifolia* oil to Feta cheese resulted in the highest viability of *Lacticaseibacillus casei* at low pH, compared with the other treatments containing < 0.03%. Electron microscopy showed that essential oils caused no harm to *L. casei* [57]. Other studies indicated that some plant extracts may improve starter activity. The total count of starter cultures (*L. lactis* ssp. *lactis* and *L. lactis* ssp. *cremoris*) was higher in the ginger-fortified UF-soft cheese and Egyptian white cheese pickled in a brine solution containing fresh ginger extract, compared to control cheese [38, 58]. Inversely, some studies indicate that some extracts have an adverse effect on the growth of starter cultures. For example, adding 2.5 µg/mL of thyme oil to Coalho cheese reduced the viable cell count of *L. monocytogenes* and the counts of starter cultures composed of *L. lactis* ssp. *cremoris* and *L. lactis* ssp. *lactis* [59].

Adding *Cinnamom umverum* and *Allium sativum* aqueous extracts to goat, cow, and camel milk had no significant effect on the acidification through fermentation [60]. The aqueous extracts of rose flower, spearmint, dill, and green tea, as well as chamomile essence increased *Bifidobacterium bifidum* and *L. acidophilus* growth in probiotic milk and yoghurt and kept the bacteria alive until the end of storage, with no need for additional nutrients [61–63].

In another study, adding *A. sativum* or *Cinnamomum verum* water extracts to both cow and camel milk yoghurts boosted *B. bifidum* viability for 21 days of storage, compared to the control yoghurts. This was correlated to the presence of vitamins, minerals, amino acids, and polyphenolics in *A. sativum* and *C. verum*, among other factors. Camel milk has more free amino groups and a higher buffering capacity than cow milk, which leads to increased *B. bifidum* viability [64]. Haddadin found that increasing concentrations of ethanol olive leaf extract accelerated bacteria growth and allowed them to attain optimal acidity in less time [65]. The samples containing 0.6% of the extract had the highest bacteria count and the bacteria were viable until the end of fermentation. Polyphenols (oleuropein and other secoiridoids), flavonoids (rutin, flavonol), and luteolin-7-glucoside are stimulatory components in ethanol olive leaf extract.

In a different study, adding *Diospyros kaki* L. leaf extract to yoghurt increased the rate of acidification and decreased the time required to complete fermentation, contributing to the viability of the starter culture. In particular, the increase in the counts of *S. thermophilus* and *Lactobacillus delbrueckii* ssp. *bulgaricus* was the highest (2.95 and 1.14 log CFU/mL, respectively) in *D. kaki* yoghurt [66]. The water cinnamon extract had no effect on the probiotic population, although *Lactobacillus* species and *S. thermophilus* counts in yoghurt increased for up to 7 days during storage [45].

Ziarno *et al.* showed that the herbal extracts from valerian, sage, chamomile, cistus, linden blossom, ribwort plantain, and marshmallow did not inhibit the growth of lactic acid bacteria in fermented milk, such as yoghurt [67]. However, they can gradually inhibit fermentation at concentrations above 2% (w/w) and hence can be used to prevent post-acidification of fermented milk. In general, the plant extracts significantly increased the growth and acidification rates of *S. thermophilus* and *L. delbrueckii* ssp. *bulgaricus*. Plant extract components, including monosaccharides, formic acid, and hydroxycinnamic acid, as well as neochlorogenic, chlorogenic, and caffeic acids, play a stimulatory role and cause a beneficial effect on the growth of yoghurt culture bacteria through fermentation [68].

The viability of probiotic bacteria in fermented milk is also affected by the addition of essential oils. The yoghurts with mint, bee balm, and ziziphora essential oils (0.001%) exhibited higher viability *of L. acidophilus* LA-14 and *Bifidobacterium animalis* ssp. *lactis* BB-12 than the control samples. However, the yoghurt with eucalyptus essential oil had lower viability [69]. The survivability of probiotic bacteria in yoghurt and cheese were unaffected by the essential oils of *M. longifolia*, *Teucrium polium*, *Cuminum cyminum*, *Allium ascalonicum*, and *Pimpinella anisum* [57]. The viability of *L. casei* in a bio-yogurt containing various amounts of *T. polium* essential oil was significantly reduced after 28 days of storage. A probiotic yoghurt without essential oils and a bio-yogurt containing 60 ppm of *T. polium* oil had the highest overall viable count of *L. casei* (6.47 log CFU/mL). However, higher concentrations of the oil resulted in decreased bacterial counts [70]. Sarabi-Jamab & Niazmand reported that the population of *L. acidophilus* in bio-yogurt with varied concentrations (25, 40, 70, 100, and 130 g/L) of *Mentha piperita* and *Ziziphora clinopodioides* essential oils considerably decreased after 7 days of storage [70]. Yet, their viability did not change significantly, compared to the control. In ice cream, the probiotic bacteria *L. acidophilus* La-5 and *B. bifidum* Bb-12 were more stable during storage at –20°C for 90 days when made with tiger-nut extract, compared to the control [71].

Plant extracts as natural antioxidants. ***Mode of action.*** Antioxidants are essential for lowering oxidative reactions in food systems and the human body. In food systems, they retard lipid peroxidation and the formation of secondary lipid peroxidation products. Antioxidants also help to reduce protein oxidation, as the interaction of lipid-derived carbonyls with proteins alters their function [72]. Dairy products contain lipids rich in polyunsaturated fatty acids and their esters are easily oxidized by molecular oxygen over time. This oxidation may occur during the manufacture, storage, or distribution of final products. Light, oxygen, and transition metal ions are important factors leading to oxidative changes. Deleterious changes in dairy products caused by lipid oxidation include not only off-flavors but also the loss of color and nutrients, and the accumulation of compounds that may be detrimental to consumers' health [73]. Objectionable odors and flavors in oxidized products are caused by product subcomponents forming compounds such as hydrocarbons, aldehydes, and ketones [74].

Synthetic antioxidants are commonly used to increase the shelf life of food products, including TBHQ, BHA, and BHT. They reduce the rate of lipid oxidation and hydrolysis, as well as stabilize free radicals. According to the International Dairy Foods Association, these antioxidants are not allowed to be added to milk. Therefore, dairy products are fortified with natural antioxidants that delay lipid oxidation and hydrolysis, reduce nutritional losses, prevent free radical damage, and provide a variety of health benefits [75].

Antioxidants can be divided into primary and secondary based on how they work to reduce lipid oxidation. Primary antioxidants act as H donors to the lipid-free radicals formed during lipid oxidation and rearrangement into a stable form. Secondary antioxidants act as chelators of metal ions, decompose hydroperoxide into non-radical species, deactivate singlet oxygen, and absorb ultraviolet radiation. They can also act as oxygen scavengers to slow down the rate of radical formation [76].

Plant antioxidants can be divided into three categories: phenolic compounds, vitamins, and carotenoids [77]. Phenolic compounds have a large diversity of structures: from simple molecules (e.g., ferulic, gallic, and caffeic acids) to polyphenols (tannins and flavonoids) [78]. Vitamins E and C are the most important plant antioxidants. Vitamin E is a lipid-soluble vitamin made up of four tocopherols and four tocotrienols, each having four isomers (α, β, α, and δ), but only α-tocopherol can be absorbed by the human body. Vitamin C is a water-soluble vitamin found in a variety of fruits and vegetables [79]. Therefore, these compounds have been considered promising candidates as potential protectors against lipid oxidation. The presence of an antioxidant is one of the fastest ways to reduce fat oxidation [80, 81].

Plant extracts as antioxidants in dairy products. Plant extracts containing high amounts of phenolic compounds act as H donors, radical scavengers, or metal chelators. Scientists have studied the antioxidant properties of sedge, marjoram, wild marjoram, caraway, basil extract, ginger, plum concentrates, aloe vera, mustard, tea catechins, rosemary extracts, and other plant extracts [82–84]. The antioxidant activity of milk increased significantly when plant extracts were introduced before bacterial fermentation [85].

Santos *et al.* used rosemary extract to prevent fat oxidation in cow milk fortified with fish oil. When tested at 60 and 110°C, an ethanol extract of rosemary added to 400 mg/kg of butter increased the butter's oxidation stability [86]. Plant extracts enhanced the antioxidant activity and overall phenolic content in the fermented milk. For example, marjoram extract added to yoghurt had a significant antioxidant effect on both the first and the last days of storage (28 days) [85]. *Cudrania tricuspidata* L. and *Morus alba* L. leaf extracts improved yoghurt's antioxidant activity and total phenolic content. *C. tricuspidata* leaf extract exhibited the highest antioxidant activity [68]. Srivastava *et al.* found that the goat milk yoghurt fortified with 2% beet root or 2% ginger extracts had the highest antioxidant activity evaluated by the DPPH assay, followed by the cow milk yoghurt with 2% ginger extract [87]. Furthermore, fortifying milk and yoghurt with 2% red ginseng extract increased its oxygen radical absorption capacity and radical-scavenging activity (DPPH), but reduced the DNA damage caused by H_2O_2, compared to the control yoghurt [88]. The cheese fortified with clove extract was shown to have the strongest antioxidant and antibacterial qualities, compared to the cheeses fortified with other extracts (cinnamon stick, oregano, pomegranate peel, and grape seed) [28].

In recent years, herbal ghee has primarily been sold as medical ghee on the global market [89]. This product has a typical flavor, a bitter or pungent aftertaste, and a dark color. The antioxidant activities of vidarikand (*Pueraria tuberosa* L.), shatavari (*Asparagus racemosus* L.), and ashwagandha (*Withania somnifera* L.) extracts were evaluated against the synthetic antioxidant BHA. Compared to the aqueous extracts, the herbs' ethanol extracts were more effective in avoiding the formation of peroxide value and conjugated dienes in ghee. Puerarin, daidzein, genistein, and daidzin are active ingredients in vidarikand [90].

Table 1 Plants and their bioactive compounds with antimicrobial and antioxidant activities in some dairy products

Plants	Scientific name	Bioactive components	Applications	References
Thyme	*Thymus vulgaris* L.	Thymol (phenolic monoterpenes)	Ricotta cheese, Coalho cheese, Mimicking models, Fior di Latte cheese, Feta cheese, Labneh, Butter	[22, 27, 42, 51, 54, 59]
Basil	*Ocimum basilicum* L.	Carvacrol (phenylpropanoids)	Ricotta cheese, Serra da Estrela cheese, Ice cream	[30, 42, 82–84]
Cloves	*Eugenia caryophyllata* L.	Eugenol (*α*-terpineol and terpinen-4-ol)	Yoghurt, Paneer cheese, ArzaUlloa cheese	[28, 37, 44]
Cinnamon	*Cinnamomum zeylanicum*	Cinnamaldehyde	Cheddar-based media, Spreadable cheese, Appenzeller cheese, processed cheeses	[24, 25, 28, 48, 50, 55, 60]
Ginger	*Zingiber officinale* L.	Gingerols, Gingerdiols, Shogaols	Fortified cheese, UF-soft cheese	[38, 39, 58, 83, 87]
Oregano	*Origanum vulgare* L.	Carvacrol, Thymol, *γ*-terpinene, *p*-cymene, Carvacrol methyl ethers	Cheddar-based media, Feta cheese	[24, 25, 42, 56]
Black cumin	*Nigella sativa* L.	Thymoquinone, Thymol, *α*-hederin	Iranian white cheese, Feta cheese, Domiati cheese	[23, 41–43]
Roselle	*Hibiscus Sabdariffa* L.	Calyx, Chlorhexidine, Amoxicillin-clavulanic acid, Tetracycline, Metronidazole	Yoghurt	[47]
Garlic	*Allium sativum* L.	Oil-soluble organosulfur compounds: include Allicin, Ajoenes, Allyl sulfides, Actericidal, Antibiofilm, Antitoxin, and Anti-quorum	UF soft cheese, soft cheese, processed cheeses	[24, 38, 49, 51, 60]
Sage	*Salvia officinalis* L.	Geraniol, Pinene, Limonene, Carnosol, Saponin, Catechins, Apigenin, Luteolin, Rosmarinic, Carnosine, Vanillic, Caffeic acids	Sour cream, Fior di Latte cheese, Cheddar cheese, Yoghurt, Ghee, Butter oil	[24, 67, 82–84, 92]
Rosemary	*Rosmarinus officinalis* L.	1,8-cineole, Borneol, Camphor, Caffeic acid, Rosmarinic acid, Luteolin-7-O glucoside, Carnosic acid, Ursolic acid, Carnosol, di- and triterpenes	Ghee, Butter oil, Sour cream, Yoghurt, Sheep's cheese, Cheddar-based media, Cottage cheese, Herbed cottage cheese, Flavored yoghurt	[24, 86, 92]
Lemon grass	*Cymbopogon* L.	Myrcene, limonene, citral, geraniol, citronellol, geranyl acetate, neral, and nerol	Indian soft cheese, Yoghurt, Coalho cheese, processed cheeses	[24]
Dill	*Anethum graveolens* L.	Quercetin, Kaempferol, Myricetin, Catechins, Isorhamnetin, Carvone, Limonene	Milk	[62, 63]

Parmar *et al.* discovered that a 7% ethanol extract of *Terminalia arjuna* L. bark was particularly effective in preventing auto-oxidation of both cow and buffalo ghee during storage. The extract had a substantial ability to increase the antioxidant potential of ghee, with the efficacy being greater in cow ghee than in buffalo ghee. The Arjuna-fortified ghee had a shelf life of 8 days at 80 ± 1°C, compared to only 2 days for the control ghee sample [91].

Sage and rosemary extracts have been the most widely used herbs to prolong the shelf life of ghee and butter oil [92]. These extracts have many times the antioxidant activity of synthetic antioxidants like BHA and BHT [93]. Butter oil supplemented with dihydroquercetin (DHQ) as a natural antioxidant showed the strongest oxidative stability in the accelerated test. The addition of 50, 100, 150, and 200 ppm of DHQ increased the shelf life of butter oil by 1.9, 2.8, 2.99, and 3.53 times, respectively [94]. Similarly, adding 80 mg of olive mill waste water or pomace to 1 kg of butter provided oxidative stress resistance during storage both under ambient thermal conditions (25°C) and the oven conditions (60°C) for three months [95]. During storage, the butter made from sour cream supplemented with 2% sage or rosemary had higher oxidative stability and lower secondary oxidative products, including malonaldehyde and ketones, than the control butter. However, rosemary herb was found to be more efficient than sage in slowing lipolysis in butter [96].

Similarly, Merai *et al.* found that the ghee made from butter and 0.6% Tulsi (*Ocimum sanctum* L.) leaves extract was as stable as the ghee containing 0.02% of BHA after 8 days of high temperature storage (80 ± 2°C) [97]. The phenolics found in Tulsi leaves appeared to be the primary contributors to ghee's increased oxidative stability. Furthermore, Farag *et al.* reported that adding thyme and cumin essential oils to butter prevented it from spoiling at room temperature and was more efficient than butylated hydroxy toluene [98].

Plant extracts as natural milk-clotting enzymes. The global increase in cheese production, along with a decreased supply and higher prices of calf rennet, has led to the search for alternative milk-clotting enzymes as suitable rennet substitutes. Plant clotting enzymes, also known as plant proteases, have become a subject of growing interest in the cheese industry due to their availability, simple purification processes, and low cost, as well as stability [99, 100]. The selection of a suitable plant coagulant depends on the optimum conditions for enzyme activity (pH, temperature, salt, solvents, etc.), milk-clotting activity/proteolytic activity (MCA/PA ratio), and the rheological and sensory properties of final products [101].

Plant proteases. In general, the main classes of milk-clotting proteases are aspartic, serine, and cysteine proteases. The number and type of enzymes vary from one species to another and depend on the plant parts [101]. As chymosin, some plant proteases can cleave a few sites at *α*s1- and *β*-caseins, which may occur in maintaining the micelle stability. These regions of *α*s1- and *β*-caseins are sometimes near the micelle surface and contribute to electrostatic repulsion between casein micelles. The removal of these parts could greatly assist the gelling process. First, the initial instability of micelles is increased and coagulant access to *β*-casein is improved. Second, the removal of these parts increases the flexibility and/or susceptibility of caseins to rearrangements in gel [102].

Plant proteases also play a significant role in the early stages of cheese ripening. The hydrolysis of caseins in cheese by residual coagulants produces essential substrates for some bacterial microflora, whose breakdown allows for flavor development during maturation. The strength of these impacts on the cheese quality depends on the type of plant coagulant used, its amount, and its enzymatic activities [103]. Some plant milk-clotting proteases are presented in Table 2.

Several studies have reported that most plant proteases with milk-clotting activity (MCA) are stable in various pH ranges (4.5–10) and temperatures (20–80°C), with the optimum pH around 6.5 and maximum activity around 60°C. The protease isolated from pumpkin seed extract curdled milk at a pH range of 4.5 to 8.5 and a temperature range of 20 to 80°C. It was resistant to solvents, salts, and surfactants, and was more effective on κ-casein than *β*-casein [100]. The best coagulation conditions for the pineapple, kiwi, and ginger extracts were pH 5, 6.6, and 6.6, respectively, and temperatures 45, 40, and 45°C, respectively [104]. A novel cysteine protease extracted from *Ficus johannis* L. by cation exchange chromatography was stable in a variety of pH ranges (3.0–10.5), with the optimum at 6.5, and showed maximal activity at 60°C. The purified protease had significant activity against κ-casein when compared to *α*- and *β*-casein. In the presence of high salt concentrations, the enzyme was virtually totally active [105]. Ben Amira *et al.* showed that when the pH was dropped to 3, the MCA/PA ratio rose, surpassing that of chymosin. The lowest ratio attributed to the extract at pH 6 was mainly related to its high proteolytic activity, as well as to its low MCA. Melon extracts also showed high milk-clotting activity over a wide range of temperatures (45–75°C), while kiwi and ginger extracts showed high activity over a lower temperature range, with a maximum of 40 and 63°C, respectively [101].

Effect of plant proteases on yield and physiochemical properties of cheese. The rheological properties of milk gels and sensory characteristics of cheeses produced by plant proteases vary according to the type of coagulant, its enzymatic activities, and its concentrations. Most plant enzymes are not suitable for industrial-scale cheese production, where a large portion of protein is lost due to excessive hydrolytic activities [106]. For example, the curd yield produced using kiwi (17.8%), melon (15.1%), and ginger (15.4%) extracts was lower than that produced using commercial rennet (20.2%). Kiwi extracts had textural properties comparable with those obtained using calf rennet, thus

Table 2 Some plant milk-clotting proteases

Plant	Scientific name	Type of protease	Names	Numbers
Cardoon	*Cynara cardunculus* L.	Aspartic	Cardosin	8 (A to B)
Artichoke	*Cynara scolymus* L.	Aspartic	Cynarase	3 (A , B, C)
Wild thistle	*Cynara humilis* L.	Aspartic	Cardosin	1 (A)
Asian rice	*Oryza sativa* L.	Aspartic	Oryzasin	1
Milk thistle	*Silybum marianum* L.	Aspartic	Enzymatic extract	–
Cotton thistle	*Onopordum acanthium* L.	Aspartic	Onopordosin	1
spear thistle	*Cirisum vulgare* L.	Aspartic	Cirsin	1
Red star-thistle	*Centaurea calcitrapa* L.	Aspartic	Enzymatic extract	–
Afghan fig	*Ficus johannis* L.	Cysteine	Ficin	1
Lebbeck	*Albizia lebbeck* L.	Cysteine	Enzymatic extract	–
Fig	*Ficus carica sylvestris* L.	Cysteine	Ficin	2
Golden kiwifruit	*Actinidia chinensis* L.	Cysteine	Actinidin	1
Crown flower	*Calotropis gigantea* L.	Cysteine	Calotropain	4 (FI, FII, DI, DII)
Ginger	*Zingiber officinale* L.	Aspartic & cysteine	Ginger	3 (GPA, GPB, GPC)
Chaguar	*Bromelia hieronymi* Mez	Serine	Hieronymain	3
Solanum coagulans	*Solanum dubium* Fresen	Serine	Dubiumin	1
Lettuce	*Lactuca sativa* L.	Serine	Cucumisin	1
Egyptian balsam	*Balanites aegyptiaca* L.	Aspartic & serine	–	2

Source: Ben Amira *et al.* [101]

holding the best potential as a milk coagulant in cheese production. Melon extracts, however, produced a fragile gel and a low curd yield [107]. The cheese made with the purified enzyme obtained from *F. johannis* had similar textural properties and chemical compositions to the cheese produced using commercial calf rennet [105]. All rheological parameters indicated a strong milk gel formed using pumpkin seed extracts. The peptidase sequence was homologous with that of cucumicin-like peptidase [99, 105].

Abebe & Emire used *Calotropis procera* L. enzyme leaf extract as an alternate milk coagulant to produce fresh cheese [108]. The highest cheese yield and the fastest clotting time were 17.89 kg of cheese/100 kg of milk and 14:50 min, acquired with 10 g of *C. procera* powder at 60°C extraction, respectively. There was no difference in coagulation time among the milk samples with varied milk fat structures. However, whey was extracted from homogeneous cream curds more quickly than from non-homogenized cream curds [109]. Camel milk is difficult to convert to cheese using regular rennet, so pineapple, kiwi, and ginger enzyme extracts are used to help make cheese from camel milk. Kiwi extract showed the highest curd yield (20.71%) when compared to pineapple (19.74%) and ginger (11.50%) extracts [106]. Mazorra-Manzano *et al.* reported that kiwi had a higher output than melon and ginger but was lower than chymosin in cow milk [107]. When compared to the camel cheese with pineapple and ginger extracts, the camel cheese with kiwi extract had higher amounts of water-soluble vitamins, primarily B_7 (3.75034 mg/g), B_{12}, and B_5, as well as higher mineral contents, primarily Na (605.2 ppm) and Ca (63.11 ppm). The water content was lowest in the camel milk cheese made with ginger extract, whereas the protein content was higher in the cheese made with pineapple extract than kiwi or ginger extracts [104]. Gad & Abd El-Salam mentioned that higher concentrations of rosemary extract increased the rennet coagulation time of skim milk. The antioxidant activity of the skim milk/rosemary extract blends was improved by heat treatment, calcium chloride addition, and pasteurization [110]. Furthermore, by suppressing oxidation, rosemary extract as a natural antioxidant could extend the shelf life of Cheddar cheese or cheese powder [111].

Plant extracts and sensory properties of dairy products. Flavor, an important sensory component, is one of the variables influencing customer preferences. The flavor of food is determined by the presence of volatile aromatic compounds, which take different forms in different foods [112]. Flavoring compounds can be roughly classified into plant-based, artificial, and biotechnologically formed flavors. Plant-based flavors are separated from plant-based sources rich in aromatic compounds, spices like vanilla, or herbs. Modupalli *et al.* reported that plant-based food flavoring agents are naturally occurring polyphenolic compounds, organic esters, acids, alkaloids, and carotenoids [113]. Dry aromatic plants, as well as their essential oils and extracts, are used in dairy products in order to give them a distinctive and attractive taste and smell [2]. In cheese, the ethanol cinnamon extract improved the flavor and overall quality of flavored processed cheese, whereas lemon grass and cress extracts improved its odor and color, respectively [35]. The UF-soft cheese produced with the ethanol ginger extract became more pleasant compared to the control cheese, especially during storage [38]. The major compounds responsible for the unique ginger flavor are gingerols and other volatile oils. Over storage, gingerols are converted into a series of homologous compounds known as shogaols, which are more pungent than gingerols [114]. Mahajan *et al.* improved the flavor, texture, and acceptability of low-fat Kalari cheese by using aqueous pine needle extracts [36]. Similarly, the aqueous extracts of *Inula britannica* L. increased the odor and flavor of a Cheddar-type cheese [115]. The cottage cheese with 8 and 9% aqueous green tea extract acquired a pleasant, moderately expressed green tea flavor and taste, whereas the cottage cheese with a high level of tea extract (> 9%) had a bitter and disagreeable tea flavor [116, 117].

Essential oils improve the flavor and smell of dairy products and also extend their shelf life. The highest overall acceptability during storage was achieved by Iranian white cheese containing 0.75% basil oil, followed by the sample containing 0.5% salvia oil. However, adding 0.75 and 1% salvia oil impaired the samples' odor and taste [43]. Iranian white cheese and Domiati cheese were also the most preferable and had the highest flavor scores when supplemented with 1 and 0.2% black cumin essential oil [38, 41]. Inversely, the goat cheeses treated with essential oils had a bitter flavor, whereas Feta cheese had a strong off-taste due to large quantities of clove and tea tree oils required for antibacterial activity [118]. Furthermore, Foda *et al.* observed that high concentrations of spearmint oil can generate concerns about changes in white cheese's sensory properties, to the point that the panel test revealed the highest acceptability at lower oil concentrations [119].

In fermented milk, adding the extracts of *D. kaki* leaf and *Nelumbo nucifera* L. leaf to yoghurt increased its viscosity, water-holding capacity, bitterness, and texture smoothness. The *D. kaki* – fortified yoghurt contained a high content of flavoring components such as acetaldehyde, acetoin, and diacetyl, which gave it the best taste in the sensory evaluation. The *N. nucifera*-fortified yoghurt showed the largest amount of acetic acid in the volatile complex analysis and the highest pH value [66]. According to Zaky *et al.*, adding 2 μL/100 mL of dill and caraway essential oils to Labneh made from buffalo's milk increased the total volatile fatty acids of Labneh during storage [120]. In addition, it improved its antioxidant activity and sensory qualities, compared to the control. Ghalem & Zouaoui added *Rosmarinus officinalis* L. oil to yoghurt at concentrations of 0.14, 0.21, 0.29, and 0.36 g/L and stored it for up to 21 days [121]. The herbal yoghurt enhanced with 0.14 g/L of the oil received the highest score for taste, flavor, and texture from the panel. Trivedi *et al.* tested basil in various forms (juice and dried powder) as an ice cream flavoring agent. Compared to the control, adding basil juice (up to 2%) lowered protein, fat, total solids, ash, and total carbohydrate contents, as well as melting resistance and pH [122]. Coffee extract was also used to produce a distinct probiotic coffee ice cream with the desired coffee flavor that improves the consumer's emotional state and aids in calorie burning [123]. Table 3 represents some dairy products fortified with flavoring plant extracts and their bioactive components.

Encapsulated plant extracts in dairy products. Encapsulation is a process of entrapping one substance into another to improve the bioavailability of high-value compounds [129]. It can be used to mask undesirable

Table 3 Plants and their bioactive components used as flavoring agents in some dairy products

Plants	Scientific name	Bioactive components	Applications	References
Cinnamon	*Cinnamomum zeylanicum*	Cinnamaldehyde	Soft cheese, Processed cheese, Yoghurt	[124, 125]
Lemon grass	*Cymbopogon* L.	Eral, Citronellal, Linalool, Geranial, Limonene, 6-Methyl Hept-5-En-3-One, Caryophyllene, *β*-Myrcene	Indian soft cheese, Yoghurt, Coalho cheese, Processed cheese	[35, 125, 126]
Ginger	*Zingiber officinale* L.	Gingerols, Shogaols, other volatile oils	UF-soft cheese	[38, 114, 127]
Pine needle	–	–	Low-fat Kalari cheese	[36]
Green tea	*Camellia sinensis* L.	Theanine, caffeine, chlorophyll, and various types of catechins	Cottage cheese	[116]
Basil	*Ocimum basilicum* L.	Eugenol, *β*-caryophyllene	Iranian white cheese, Yoghurt, Ice cream	[43, 122, 128]
Black cumin	*Nigella sativa* L.	Thymoquinone, P-Cymene, T-Anethole, Sequiterpene Longifolene, Nigellicimine, Nigellicimine N-Oxide, Pinene, Thymol	Iranian white cheese, Domiati cheese	[38, 41]
Spearmint	*Mentha spicata* L.	Menthol, Epoxyocimene, Linalool, Menthone, Eucalyptol, *Neo*-menthol	White cheese	[119, 125]
Dill	*Anethum graveolens* L.	Quercetin, Kaempferol, Myricetin, Catechins, Isorhamnetin, Carvone, Limonene	Milk	[120]
Caraway	*Carum carvi* L.	Carvone and limonene	Labneh	[120]
Rosemary	*Rosmarinus officinalis* L.	Camphene, Pinene, Limonene, Myrcene, Camphor, Thujone, Verbenone, Cuminic Aldehyde	Yoghurt	[121]

flavors and odors, protect biologically active compounds from adverse interactions with other substances, and improve stability under a variety of environmental conditions, including temperature, moisture, oxidation, and light [10]. Salama *et al.* summarized numerous forms for encapsulating bioactive compounds, including nanocapsules, micro-capsules, nano-emulsions, micro-emulsions, solid lipid nanoparticles, liposomes, and others. The nano- or micro-capsules are excellent systems that deliver bioactive compounds for direct absorption. Dairy products fortified with encapsulated plant extracts have better nutrition and health benefits. There is a variety of materials used for encapsulation, including gum Arabic, modified starches, maltodextrins, alginates, pectin, carrageenan, hydrogenated vegetable oils, bees wax, soy proteins, gelatins, whey proteins, sodium caseinates, and others. Below are some examples of recent and most common applications of encapsulation technology in dairy products [130].

The encapsulation of sage extract in liposome improved its antimicrobial activity against pathogenic bacteria and affected the physicochemical properties of the resulting yoghurt. Particularly, acidity increased, while diacetyl and acetaldehyde decreased when the extract was added at rates of 5, 10, 15, and 20%. The yoghurt's viscosity first increased but then decreased during storage [131]. The low antioxidant activity in dairy products was corrected by fortifying them with doum fruit extract in a liposome form. The encapsulated doum extract has a significant impact on yoghurt's chemical analysis, especially at higher concentrations [132]. El-Messery *et al.* investigated the encapsulation of mango peel phenolic extract and its use in milk beverages [133]. They found that these flavored drinks were well-liked by consumers. They were high in antioxidants, phenolic compounds, and many other bioactive components. In addition, the encapsulated extract did not alter the chemical or rheological aspects of the beverage. In another study, chitosan microcapsules containing beetroot or ginger aqueous extracts were added to fermented camel milk in the presence of probiotic bacteria. The 10% concentration of the beetroot aqueous extract microcapsules increased the survivability of probiotic bacteria, whereas the amount of ginger was only 1%. The best effects were achieved by the chitosan beads with the beetroot aqueous extract [134]. Jaboticaba-loaded nanoemulsion (up to 15%) was added to cow milk to make it rich in phenolics and exhibit high antioxidant activity [135]. Adding the fig leaf extract microencapsulated with alginate and/or skim milk improved the cheese sauce's properties, microbiological quality, and shelf life [136]. The control cheese and the functional cheese supplemented with 2% liposomal encapsulated saffron extract showed the greatest difference in terms of chemical composition and color. The cheeses containing the encapsulated saffron extract were significantly harder and chewier, compared to the control. However there was no significant difference in adhesiveness, cohesiveness, and gumminess among the cheese samples. Based on the findings, liposomal encapsulation was considered an efficient method for the delivery of saffron extract to ricotta cheese as a novel functional food [137].

In another study, the encapsulated Arjuna herb extract improved the vanilla chocolate dairy drink in all the parameters tested by the response surface methodology [138]. Barretto *et al.* reported that the encapsulated anthocyanin provided yoghurt with high stability and large amounts of antioxidant and phenolic compounds. Encapsulation gave anthocyanin more efficiency and biological activity [139]. Sawale *et al.* studied the effect of heat treatment on the stability of the *T. arjuna* extract and its content of phenols and antioxidants when it was used in the free and encapsulated forms to fortify the vanilla chocolate-flavored milk drinks [140]. They found that sterilization had a negative effect on the extract in the free form and its content of antioxidants and phenols. The encapsulated extract, however, was stable enough to protect the bioactive compounds. Lourenço *et al.* studied the encapsulation of pineapple peel hydroalcoholic extract rich in phenolic compounds. To preserve these ingredients, maltodextrin, inulin, and Arabic gum were used as encapsulation materials by spray drying. The resulting powder had a good flow ability and suitable handling properties. Also, this encapsulation method ensured high antioxidant activity, while the non-encapsulated extract had low activity in the same conditions [141].

CONCLUSION

As compared to plants or their parts, the use of plant extracts and essential oils in the dairy industry has received a lot of positive feedback from both dairy producers and consumers. Plant extracts can be used to enhance the flavors, antioxidant and antibacterial properties of fortified dairy foods, as well as their visual appeal. Additionally, plant extracts can be added to dairy products in a variety of forms, free or encapsulated, to protect active ingredients from the external environment and control their release. They can also be incorporated as a nanoemulsion to enhance the compounds' bioactivity. Plant extracts and their essential oils have different effects on microorganisms, depending on the type of microbe, the type and concentration of the plant extract, and the interaction of antimicrobial chemicals with the food matrix. Most studies indicate that plant extracts and essential oils included in various dairy products increase the survival of probiotics and starter bacteria while acting as antimicrobials against pathogenic and spoilage-causing microorganisms. With the growing demand for cheese in the world, plant-based coagulants can be a good substitute for calf rennet, which is currently in low supply. Different plant-derived proteases can be used in milk coagulation and cheese-making. However, to produce cheeses that are comparable to those made with calf rennet, we need to select the right type of plant proteases (specific or non-specific action) and their enzymatic activity (milk-clotting activity/proteolytic activity ratio), depending on the type of cheese to be produced (ripened or non-ripened). In the dairy industry, plant extracts can also be used to either increase desirable ingredients (vitamins, fiber, and minerals) or to partially replace undesirable ingredients (salt and sugar).

CONTRIBUTION

The authors were equally involved in writing the manuscript and are equally responsible for plagiarism.

CONFLICT OF INTEREST

The authors state that there is no conflict of interest.

REFERENCES

1. Alezandro MR, Lui MCY, Lajolo FM, Genovese MI. Commercial spices and industrial ingredients: evaluation of antioxidant capacity and flavonoids content for functional foods development. Food Science and Technology. 2011;31(2):527–533. https://doi.org/10.1590/S0101-20612011000200038
2. Kaptan B, Sivri GT. Utilization of medicinal and aromatic plants in dairy products. Journal of Advancements in Plant Science. 2018;1(2).
3. Takó M, Kerekes EB, Zambrano C, Kotogán A, Papp T, Krisch J, *et al.* Plant phenolics and phenolic-enriched extracts as antimicrobial agents against food-contaminating microorganisms. Antioxidants. 2020;9(2). https://doi.org/10.3390/antiox9020165
4. Dhifi W, Bellili S, Jazi S, Bahloul N, Mnif W. Essential oils' chemical characterization and investigation of some biological activities: A critical review. Medicines. 2016;3(4). https://doi.org/10.3390/medicines3040025
5. Sukhikh SA, Astakhova LA, Golubcova YuV, Lukin AA, Prosekova EA, Milent`eva IS, *et al.* Functional dairy products enriched with plant ingredients. Foods and Raw Materials. 2019;7(2):428–438. https://doi.org/10.21603/2308-4057-2019-2-428-438
6. Dupas C, Métoyer B, El Hatmi H, Adt I, Mahgoub SA, Dumas E. Plants: A natural solution to enhance raw milk cheese preservation? Food Research International. 2020;130. https://doi.org/10.1016/j.foodres.2019.108883
7. Azmir J, Zaidul ISM, Rahman MM, Sharif KM, Mohamed A, Sahena F, *et al.* Techniques for extraction of bioactive compounds from plant materials: A review. Journal of Food Engineering. 2013;117(4):426–436. https://doi.org/10.1016/j.jfoodeng.2013.01.014
8. Ritota M, Manzi P. Natural preservatives from plant in cheese making. Animals. 2020;10(4). https://doi.org/10.3390/ani10040749
9. Proestos C. The benefits of plant extracts for human health. Foods. 2020;9(11). https://doi.org/10.3390/foods9111653
10. Yusop FHM, Manaf SFA, Hamza F. Preservation of bioactive compound via microencapsulation. Chemical Engineering Research Bulletin. 2017;19:50–56. https://doi.org/10.3329/cerb.v19i0.33796
11. Stan D, Enciu A-M, Mateescu AL, Ion AC, Brezeanu AC, Stan D, *et al.* Natural compounds with antimicrobial and antiviral effect and nanocarriers used for their transportation. Frontiers in Pharmacology. 2021;12. https://doi.org/10.3389/fphar.2021.723233
12. Tajkarimi MM, Ibrahim SA, Cliver DO. Antimicrobial herb and spice compounds in food. Food Control. 2020;21(9):1199–1218. https://doi.org/10.1016/j.foodcont.2010.02.003
13. Vila R, Freixa B, Cañigueral S. Antifungal compounds from plants. International Journal of Pharmaceutical Sciences. 2013;27(6):23–43.
14. Khameneh B, Iranshahy M, Soheili V, Bazzaz BSF. Review on plant antimicrobials: A mechanistic viewpoint. Antimicrobial Resistance and Infection Control. 2019;8. https://doi.org/10.1186/s13756-019-0559-6
15. Diao W-R, Hu Q-P, Zhang Z, Xu J-G. Chemical composition, antibacterial activity and mechanism of action of essential oil from seeds of fennel (*Foeniculum vulgare* Mill.). Food Control. 2014;35(1):109–116. https://doi.org/10.1016/j.foodcont.2013.06.056
16. Zhang Y, Liua X, Wanga Y, Jianga P, Quekb SY. Antibacterial activity and mechanism of cinnamon essential oil against *Escherichia coli* and *Staphylococcus aureus*. Food Control. 2016;59:282–289. https://doi.org/10.1016/j.foodcont.2015.05.032
17. dos Santos Gouvea F, Rosenthal A, da Rocha Ferreira EH. Plant extract and essential oils added as antimicrobials to cheeses: A review. Ciencia Rural. 2017;47(8). https://doi.org/10.1590/0103-8478cr20160908
18. Gonelimali FD, Lin J, Miao W, Xuan J, Charles F, Chen M, *et al.* Antimicrobial properties and mechanism of action of some plant extracts against food pathogens and spoilage microorganisms. Frontiers in Microbiology. 2018;9. https://doi.org/10.3389
19. Arif T, Bhosale JD, Kumar N, Mandal TK, Bendre RS, Lavekar GS, *et al.* Natural products – antifungal agents derived from plants. Journal of Asian Natural Products Research. 2009;11(7):621–638. https://doi.org/10.1080/10286020902942350

20. Miklasińska-Majdanik M, Kępa M, Wojtyczka RD, Idzik D, Wąsik TJ. Phenolic compounds diminish antibiotic resistance of *Staphylococcus aureus* clinical strains. International Journal of Environmental Research and Public Health. 2018;15(10). https://doi.org/10.3390/ijerph15102321

21. Zengin H, Baysal AH. Antibacterial and antioxidant activity of essential oil terpenes against pathogenic and spoilage-forming bacteria and cell structure-activity relationships evaluated by SEM microscopy. Molecules. 2014;19(11):17773–17798. https://doi.org/10.3390/molecules191117773

22. Tampieri MP, Galuppi R, Macchioni F, Carelle MS, Falcioni L, Cioni PL, *et al.* The inhibition of Candida albicans by selected essential oils and their major components. Mycopathologia. 2005;159:339–345. https://doi.org/10.1007/s11046-003-4790-5

23. Hassanien MFR, Mahgoub SA, El-Zahar KM. Soft cheese supplemented with black cumin oil: Impact on foodborne pathogens and quality during storage. Saudi Journal of Biological Sciences. 2014;21(3):280–288. https://doi.org/10.1016/j.sjbs.2013.10.005

24. Moro A, Librán CM, Berruga MI, Carmona M, Zalacain A. Dairy matrix effect on the transference of rosemary (*Rosmarinus officinalis*) essential oil compounds during cheese making. Journal of the Science of Food and Agriculture. 2015;95(7):1507–1513. https://doi.org/10.1002/jsfa.6853

25. Calo JR, Crandall PG, O'Bryan CA, Ricke SC. Essential oils as antimicrobials in food systems – A review. Food Control. 2015;54:111–119. https://doi.org/10.1016/j.foodcont.2014.12.040

26. Cava R, Nowak E, Taboada T, Marin-Iniesta F. Antimicrobial activity of clove and cinnamon essential oils against *Listeria monocytogenes* in pasteurized milk. Journal of Food Protection. 2007;70(12):2757–2763. https://doi.org/10.4315/0362-028x-70.12.2757

27. Gammariello D, Di Giulio S, Conte A, Del Nobile MA. Effects of natural compounds on microbial safety and sensory quality of Fior di Latte cheese, a typical Italian cheese. Journal of Dairy Science. 2008;91(11):4138–4146. https://doi.org/10.3168/jds.2008-1146

28. Shan B, Cai Y-Z, Brooks JD, Corke H. Potential application of spice and herb extracts as natural preservatives in cheese. Journal of Medicinal Food. 2011;14(3):284–290. https://doi.org/10.1089/jmf.2010.0009

29. Smith-Palmer A, Stewart J, Fyfe L. Influence of subinhibitory concentrations of plant essential oils on the production of enterotoxins A and B and α-toxin by *Staphylococcus aureus*. Journal of Medical Microbiology. 2004;53(10):1023–1027. https://doi.org/10.1099/jmm.0.45567-0

30. Libràn CM, Moro A, Zalacain A, Molina A, Carmona M, Berruga MI. Potential application of aromatic plant extracts to prevent cheese blowing. World Journal of Microbiology and Biotechnology. 2013;29:1179–1188. https://doi.org/10.1007/s11274-013-1280-x

31. Caleja C, Barrosa L, Antonio AL, Carocho M, Oliveira MBPP, Ferreira ICFR. Fortification of yogurts with different antioxidant preservatives: A comparative study between natural and synthetic additives. Food Chemistry. 2016;210:262–268. https://doi.org/10.1016/j.foodchem.2016.04.114

32. Salvia-Trujillo L, Rojas-Graü MA, Soliva-Fortuny R, Martín-Belloso O. Impact of microfluidization or ultrasound processing on the antimicrobial activity against *Escherichia coli* of lemongrass oil-loaded nanoemulsions. Food Control. 2014;37:292–297. https://doi.org/10.1016/j.foodcont.2013.09.015

33. Ghazy OA, Fouad MT, Saleh HH, Kholif AE, Morsy TA. Ultrasound-assisted preparation of anise extract nanoemulsion and its bioactivity against different pathogenic bacteria. Food Chemistry. 2021;341. https://doi.org/10.1016/j.foodchem.2020.128259

34. Wahba NM, Ahmed AS, Ebraheim ZZ. Antimicrobial effects of pepper, parsley, and dill and their roles in the microbiological quality enhancement of traditional Egyptian Kareish cheese. Foodborne Pathogens and Disease. 2020;7(4):411–418. https://doi.org/10.1089/fpd.2009.0412

35. Tayel AA, Hussein H, Sorour NM, El-Tras WF. Foodborne pathogens prevention and sensory attributes enhancement in processed cheese via flavoring with plant extracts. Journal of Food Science. 2015;80(12):M2886–M2891. https://doi.org/10.1111/1750-3841.13138

36. Mahajan D, Bhat ZF, Kumar S. Pine needles (*Cedrus deodara* (Roxb.) Loud.) extract as a novel preservative in cheese. Food Packaging and Shelf Life. 2016;7:20–25. https://doi.org/10.1016/j.fpsl.2016.01.001

37. Vazquez BI, Fente C, Franco CM, Vazquez MJ, Cepeda A. Inhibitory effects of eugenol and thymol on *Penicillium citrinum* strains in culture media and cheese. International Journal of Food Microbiology. 2001;67(1–2):157–163. https://doi.org/10.1016/s0168-1605(01)00429-9

38. Abd El-Aziz M, Mohamed SHS, Seleet FL. Production and evaluation of soft cheese with ginger extract as a functional dairy food. Polish Journal of Food and Nutrition Sciences. 2012;62(2):77–83. https://doi.org/10.2478/v10222-011-0046-0

39. Al-Snafi AE. Therapeutic properties of medicinal plants: A review of their antibacterial activity (part 1). International Journal of Practical Theology. 2015;6(3):137–158.

40. Zgurskaya HI, López CA, Gnanakaran S. Permeability barrier of Gram-negative cell envelopes and approaches to bypass it. ACS Infectious Diseases. 2015;1(11):512–522. https://doi.org/10.1021/acsinfecdis.5b00097

41. Ehsani A, Hashemi M, Naghibi SS, Mohammadi S, Sadaghiani SK. Properties of *Bunium persicum* essential oil and its application in Iranian white cheese against *Listeria monocytogenes* and *Escherichia coli O157:H7*. Journal of Food Safety. 2016;36(4):563–570. https://doi.org/10.1111/jfs.12277

42. Govaris A, Botsoglou E, Sergelidis D, Chatzopoulou PS. Antibacterial activity of oregano and thyme essential oils against *Listeria monocytogenes* and *Escherichia coli* O157:H7 in feta cheese packaged under modified atmosphere. LWT – Food Science and Technology. 2011;44(4):1240–1244. https://doi.org/10.1016/j.lwt.2010.09.022

43. Azizkhani M, Tooryan F, Azizkhani M. Inhibitory potential of *Salvia sclarea* and *Ocimum basilicum* against chemical and microbial spoilage in cheese. Journal of Food Safety. 2016;36(1):109–119. https://doi.org/10.1111/jfs.12218

44. Vrinda Menon K, Garg SR. Inhibitory effect of clove oil on *Listeria monocytogenesin* meat and cheese. Food Microbiology. 2001;18(6):647–650. https://doi.org/10.1006/fmic.2001.0430

45. Behrad S, Yusof MY, Goh KL, Baba AS. Manipulation of probiotics fermentation of yogurt by *Cinnamon* and *Licorice*: Effects on yogurt formation and inhibition of *Helicobacter pylori* growth *in vitro*. International Journal of Scientific Research and Innovation. 2009;3(12):563–567. https://doi.org/10.5281/zenodo.1085692

46. Mahgoub SA, Ramadan MF, El-Zahar K. Cold pressed *Nigella sativa* oil inhibits the growth of food-borne pathogens and improves the quality of Domiati cheese. Journal of Food Safety. 2013;33(4):470–480. https://doi.org/10.1111/jfs.12078

47. Hanifah R, Arief II, Budiman C. Antimicrobial activity of goat milk yoghurt with addition of a probiotic *Lactobacillus acidophilus* IIA-2B4 and roselle (*Hibiscus sabdariffa* L) extract. International Food Research Journal. 2016;23(6):2638–2645.

48. Jeong E-J, Lee NK, Oh J, Jang SE, Lee J-S, Bae I-H, *et al.* Inhibitory effect of cinnamon essential oils on selected cheese-contaminating fungi (*Penicillium* spp.) during the cheese-ripening process. Food Science and Biotechnology. 2014;23:1193–1198. https://doi.org/10.1007/s10068-014-0163-8

49. Balaguer MP, Lopez-Carballo G, Catala R, Gavara R, Hernandez-Munoz P. Antifungal properties of gliadin films incorporating cinnamaldehyde and application in active food packaging of bread and cheese spread foodstuffs. International Journal of Food Microbiology. 2013;166(3):369–377. https://doi.org/10.1016/j.ijfoodmicro.2013.08.012

50. Farrag AF, El-Sheikh MM, Fouad MT, Sayed AF, Abd El-Aziz M. Properties of probiotic UF-white soft cheese fortified with garlic extract. Journal of Biological Sciences. 2019;19(1):65–73. https://doi.org/10.3923/jbs.2019.65.73

51. Sagdic O, Cankurt H, Tornuk F, Arici M. Effect of thyme and garlic aromatic waters on microbiological properties of raw milk cheese. Journal of Tekirdag Agricultural Faculty. 2017;14(2):22–33.

52. Sindhu S, Bhageerathy C, Leela NK, Bhai S. Chemoprevention by essential oil of turmeric leaves (*Curcuma longa* L.) on the growth of *Aspergillus flavus* and aflatoxin production. Food and Chemical Toxicology. 2011;49(5):1188–1192. https://doi.org/10.1016/j.fct.2011.02.014

53. Alexa E, Danciu C, Cocan I, Negrea M, Morar A, Obistioiu D, *et al.* Chemical composition and antimicrobial potential of *Satureja hortensis* L. in fresh cow cheese. Journal of Food Quality. 2018;2018. https://doi.org/10.1155/2018/8424035

54. Otaibi MA, Demerdash HE. Improvement of the quality and shelf life of concentrated yoghurt (labneh) by the addition of some essential oils. African Journal of Microbiology Research. 2008;2(7):156–161.

55. Thabet HM, Nogain QA, Qasha AS, Abdoalaziz O, Alnsheme N. Evaluation of the effects of some plant derived essential oils on shelf life extension of Labneh. Merit Research Journal of Food Science and Technology. 2014;2(1):008–014.

56. Marcial GE, Gerez CL, de Kairuz MN, Araoz VC, Schuff C, de Valdez GF. Influence of oregano essential oil on tradional Argentinean cheese elaboration: Effect on lactic starter cultures. Revista Argentina de Microbiologia. 2019;48(3):229–235. https://doi.org/10.1016/j.ram.2016.04.006

57. Mahmoudi R, Tajik H, Ehsani A, Farshid AA, Zare P, Hadian M. Effects of *Mentha longifolia* L. essential oil on viability and cellular ultrastructure of *Lactobacillus casei* during ripening of probiotic Feta cheese. International Journal of Dairy Technology. 2012;66(1):77–82. https://doi.org/10.1111/j.1471-0307.2012.00867.x

58. Abd El-Aziz M, Mohamed SHS, Seleet FL, Abd El-Gawad MAM. Effect of brine solution containing ginger extract on the properties of Egyptian white cheese. American Journal of Food Technology. 2015;10(1):37–47. https://doi.org/10.3923/ajft.2015.37.47

59. de Carvalho RJ, de Souza GT, Honorio VG, de Sousa JP, da Conceiçao ML, Maganani M, *et al.* Comparative inhibitory effects of *Thymus vulgaris* L. essential oil against *Staphylococcus aureus*, *Listeria monocytogenes* and mesophilic starter co-culture in cheese-mimicking models. Food Microbiology. 2015;52:59–65. https://doi.org/10.1016/j.fm.2015.07.003

60. Bakr SA, Salihi BA. Effects of inclusion of *Allium sativum* and *Cinnamomum verum* in milk on the growth and activity of lactic acid bacteria during yogurt fermentation. American-Eurasian Journal of Agriculture and Environmental Sciences. 2013;13(11):1448–1457.

61. Marhamatizadeh MH, Afrasiabi S, Rezazadeh S, Marhamati Z. Effect of spearmint on the growth of Lactobacillus acidophilus and Bifidobacterium bifidum in probiotic milk and yogurt. African Journal of Food Science. 2011;5(13):747–753.

62. Marhamatizadeh MH, Shahriarpoor MS, Rezazadeh S. Effects of chamomile essence on the growth of probiotic bacteria, *Bifidobacterium bifidum* and *Lactobacillus acidophilus* in milk and yogurt. Global Veterinaria. 2012;8(6):605–611.

63. Marhamatizadeh MH, Ehsandoost E, Gholami P. The potential effect of aqueous extract of rose flower (*Rosa damascena* mill) upon probiotic bacterium performance in milk and yogurt for production of synbiotic fermented milk and yogurt. International JAPSBMS. 2013;2(4):260–271.

64. Shori AB, Baba AS. Survival of *Bifidobacterium bifidum* in cow-and camel-milk yogurts enriched with *Cinnamomum verum* and *Allium sativum*. Journal of the Association of Arab Universities for Basic and Applied Sciences. 2015; 18(1):7–11. https://doi.org/10.1016/j.jaubas.2014.02.006

65. Haddadin MSY. Effect of olive leaf extracts on the growth and metabolism of two probiotic bacteria of intestinal origin. Pakistan Journal of Nutrition. 2010;9(8):787–793. https://doi.org/10.3923/pjn.2010.787.793

66. Joung JY, Lee JY, Ha YS, Shin YK, Kim Y, Kim SH, *et al.* Enhanced microbial, functional and sensory properties of herbal yogurt fermented with Korean traditional plant extracts. Food Science of Animal Resources. 2016;36(1):90–99. https://doi.org/10.5851/kosfa.2016.36.1.90

67. Ziarno M, Kozłowska M, Scibisz I, Kowalczyk M, Pawelec S, Stochmal A, *et al.* The effect of selected herbal extracts on lactic acid bacteria activity. Applied Sciences. 2021;11(9). https://doi.org/10.3390/app11093898

68. Oh NS, Lee JY, Joung JY, Kim KS, Shin YK, Lee K-W, *et al.* Microbiological characterization and functionality of set-type yogurt fermented with potential prebiotic substrates *Cudrania tricuspidata* and *Morus alba* L. leaf extracts. Journal of Dairy Science. 2016;99(8):6014–6025. https://doi.org/10.3168/jds.2015-10814

69. Shahdadi F, Mirzaie H, Kashaninejad M, Khomeiri M, Ziaiifar AM, Akbarian, A. Effects of various essential oils on chemical and sensory characteristics and activity of probiotic bacteria in drinking yogurt. Agricultural Communication. 2015;3(1):16–21.

70. Sarabi-Jamab M, Niazmand R. Effect of essential oil of *Mentha piperita* and *Ziziphora clinopodioides* on *Lactobacillus acidophilus* activity as bioyogurt starter culture. American-Eurasian Journal of Agricultural and Environmental Sciences. 2009;6(2):129–131.

71. El-Shenawy M, Abd El-Aziz M, Elkholy W, Fouad MT. Probiotic ice cream made with tiger-nut (*Cyperus esculentus*) extract. American Journal of Food Technology. 2016;11(5):204–212. https://doi.org/10.3923/ajft.2016.204.212

72. Sardarodiyan M, Sani AM. Natural antioxidants: sources, extraction and application in food systems. Nutrition and Food Science. 2016;46(3):363–373. https://doi.org/10.1108/NFS-01-2016-0005

73. Gad AS, Sayd AF. Antioxidant properties of rosemary and its potential uses as natural antioxidant in dairy products – A review. Food and Nutrition Sciences. 2015;6(1):179–193. https://doi.org/10.4236/fns.2015.61019

74. Lee K-G, Shibamoto T. Determination of antioxidant potential of volative extracts isolated from various herbs and spices. Journal of Agricultural and Food Chemistry. 2002;50(17):4947–4952. https://doi.org/10.1021/jf0255681

75. Berardini N, Knodler M, Schieber A, Carle R. Utilization of mango peels as a source of pectin and polyphenolics. Innovative Food Science and Emerging Technologies. 2005;6(4):442–452. https://doi.org/10.1016/j.ifset.2005.06.004

76. Reische DW, Lillard DA, Eitenmiller RR. Antioxidants. In: Akoh CC, Min DB, editors. Food lipids: Chemistry, nutrition and biotechnology. Boca Raton: CRC Press; 2002. pp. 489–516. https://doi.org/10.1201/9780203908815

77. Carocho M, Barreiro MF, Morales P, Ferreira ICFR Adding molecules to food, pros and cons: A review on synthetic and natural food additives. Comprehensive Reviews in Food Science and Food Safety. 2014;13(4):377–399. https://doi.org/10.1111/1541-4337.12065

78. Abbas M, Saeed F, Anjum FM, Afzaal M, Tufail T, Bashir MS, *et al.* Natural polyphenols: An overview. International Journal of Food Properties. 2017;20(8):1689–1699. https://doi.org/10.1080/10942912.2016.1220393

79. Lourenço SC, Moldão-Martins M, Alves VD. Antioxidants of natural plant origins: From sources to food industry applications. Molecules. 2019;24(22). https://doi.org/10.3390/molecules24224132

80. Karpinska M, Borowski J, Danowska-Oziewicz M. The use of natural antioxidants in ready-to-serve food. Food Chemistry. 2001;72(1):5–9. https://doi.org/10.1016/S0308-8146(00)00171-0

81. Astley SB. Dietary antioxidants – past, present and future. Trends in Food Science and Technology. 2003;14(3):93–98. https://doi.org/10.1016/S0924-2244(02)00281-9

82. Abd El-Alim SSL, Lugasi A, Hóvári J, Dworschák E. Culinary herbs inhibit lipid oxidation in raw and cooked minced meat patties during storage. Journal of the Science of Food and Agriculture. 1999;79(2):277–285. https://doi.org/10.1002/(SICI)1097-0010(199902)79:2<277::AID-JSFA181>3.0.CO;2-S

83. Tsen SY, Ameri F, Smith JS. Effects of rosemary extracts on the reduction of heterocyclic amines in beef patties. Journal of Food Science. 2006;71(8):C469–C473. https://doi.org/10.1111/j.1750-3841.2006.00149.x

84. Nuñez de Gonzalez MT, Hafley BS, Boleman RM, Miller RK, Rhee KS, Keeton JT. Antioxidant properties of plum concentrates and powder in precooked roast beef to reduce lipid oxidation. Meat Science. 2008;80(4):997–1004. https://doi.org/10.1016/j.meatsci.2008.04.014

85. Muniandy P, Shorib AB, Baba AS. Influence of green, white and black tea addition on the antioxidant activity of probiotic yogurt during refrigerated storage. Food Packaging and Shelf Life. 2016;8:1–8. https://doi.org/10.1016/j.fpsl.2016.02.002

86. Santos RD, Shetty K, da Silva Miglioranza LH. Oxidative stability of butter with added phenolics from Lamiaceae herbs and *in vitro* evaluation of potential cytotoxicity of rosemary (*Rosmarinus officinalis* L.) extract. International Journal of Food Science and Technology. 2014;49(3):768–775. https://doi.org/10.1111/ijfs.12364

87. Srivastava P, Prasad SGM, Ali MN, Prasad M. Analysis of antioxidant activity of herbal yoghurt prepared from different milk. The Pharma Innovation Journal. 2015;4(3):18–20.

88. Park H, Lee M, Kim K-T, Park E, Paik H-D. Antioxidant and antigenotoxic effect of dairy products supplemented with red ginseng extract. Journal of Dairy Science. 2018;101(10):8702–8710. https://doi.org/10.3168/jds.2018-14690

89. Oraon L, Atanu J, Prajapati PS, Suvera P. Application of herbs in functional dairy products – a review. Journal of Dairy, Veterinary and Animal Research. 2017;5(3):109–115. https://doi.org/10.15406/jdvar.2017.05.00145

90. Pawar N, Gandhi K, Purohit A, Singh RRB. Effect of added herb extracts on oxidative stability of ghee (butter oil) during accelerated oxidation condition. Journal of Food Science and Technology. 2014;51(10):2727–2733. https://doi.org/10.1007/s13197-012-0781-1

91. Pankaj P, Khamrui K, Devaraja HC, Singh RRB. The effects of alcoholic extract of Arjuna (Terminalia arjuna Wight & Arn.) bark on stability of clarified butterfat. Journal of Medicinal Plants Research. 2013;7(35):2545–2550. https://doi.org/10.5897/JMPR2013.5114

92. Özcan M. Antioxidant activity of rosemary, sage and sumac extracts and their combinations on stability of natural peanut oil. Journal of Medicinal Food. 2003;6(3):267–270. https://doi.org/10.1089/10966200360716698

93. Estévez M, Ramirez R, Ventanas S, Cava R. Sage and rosemary essential oils versus BHT for the inhibition of lipid oxidative reactions in liver pâté. LWT – Food Science and Technology. 2007;40(1):58–65. https://doi.org/10.1016/j.lwt.2005.07.010

94. El-Hadad SS, Tikhomirova NA, Abd El-Aziz M. Biological activities of dihydroquercetin and its effect on the oxidative stability of butter oil. Journal of Food Processing and Preservation. 2020;44(7). https://doi.org/10.1111/jfpp.14519

95. Mikdame H, Kharmach E, Mtarfi NE, Alaoui K, Ben Abbou M, Rokni Y, *et al.* By-products of olive oil in the service of the deficiency of food antioxidants: The case of butter. Journal of Food Quality. 2020;2020. https://doi.org/10.1155/2020/6382942

96. Najgebauer-Lejko D, Grega T, Sady M, Domagała J. The quality and storage stability of butter made from sour cream with addition of dried sage and rosemary. Biotechnology in Animal Husbandry. 2009;25(5–6):753–761.

97. Merai M, Boghra VR, Sharma RS. Extraction of antioxygenic principles from Tulsi leaves and their effects on oxidative stability of ghee. Journal of Food Science and Technology – Mysore. 2003;40(1):52–57.

98. Farag RS, Ali MN, Taha SH. Use of some essential oils as natural preservatives for butter. Journal of the American Oil Chemists' Society. 1990;67(3):188–191. https://doi.org/10.1007/BF02539623

99. Shah MA, Mir SA, Paray MA. Plant proteases as milk-clotting enzymes in cheesemaking: A review. Dairy Science and Technology. 2014;94:5–16. https://doi.org/10.1007/s13594-013-0144-3

100. Kumar A, Sasmal S. Rheological and physico-chemical properties of milk gel using isolate of pumpkin (*Cucurbita moschata*) seeds: A new source of milk clotting peptidase. Food Hydrocolloids. 2020;106. https://doi.org/10.1016/j.foodhyd.2020.105866

101. Ben Amira A, Besbes S, Attia H, Blecker C. Milk-clotting properties of plant rennets and their enzymatic, rheological, and sensory role in cheese making: A review. International Journal of Food Properties. 2017;20(S1):S76–S93. https://doi.org/10.1080/10942912.2017.1289959

102. Silva S, Barros RM, Malcata FX. Hydrolysis of caseins by extracts of *Cynara cardunculus* precipitated by ammonium sulfate. Journal of Food Science. 2002;67(5):1746–1751. https://doi.org/10.1111/j.1365-2621.2002.tb08717.x

103. Fox PF, McSweeney PLH, Cogan TM, Guinee TP. Cheese: Chemistry, physics and microbiology. Volume 1. General Aspects. Academic Press; 2004. 650 p.

104. Fguiri I, Atigui M, Sboui A, Samira A, Marzougui C, Dbara M, *et al.* Camel milk-clotting using plant extracts as a substitute to commercial rennet. Journal of Chemistry. 2021;2021. https://doi.org/10.1155/2021/6680246

105. Afsharnezhad M, Shahangian SS, Sariri RA. A novel milk-clotting cysteine protease from *Ficus johannis*: Purification and characterization. International Journal of Biological Macromolecules. 2019;121:173–182. https://doi.org/10.1016/j.ijbiomac.2018.10.006

106. Khan RS, Masud T. Comparison of buffalo cottage cheese made from aqueous extract of *Withania coagulans* with commercial calf rennet. International Journal of Dairy Technology. 2013;66(3):396–401. https://doi.org/10.1111/1471-0307.12048

107. Mazorra-Manzano MA, Perea-Gutiérrez TC, Lugo-Sanchez ME, Ramirez-Suarez JC, Torres-Llanez MJ, González-Córdova AF, *et al.* Comparison of the milk-clotting properties of three plant extracts. Food Chemistry. 2013;141(3):1902–1907. https://doi.org/10.1016/j.foodchem.2013.05.042

108. Abebe B, Emire S. Manufacture of fresh cheese using east African *Calotropis procera* leaves extract crude enzyme as milk coagulant. Food Science and Nutrition. 2020;8(9):4831–4842. https://doi.org/10.1002/fsn3.1765

109. Ado RI, Lopez C, Lechevalier V, Gounga ME, Robert B, Harel-Oger M, *et al.* Dairy curd coagulated by a plant extract of *Calotropis procera*: Role of fat structure on the chemical and textural characteristics. Food Research International. 2018;105:694–702. https://doi.org/10.1016/j.foodres.2017.11.056

110. Gad AS, Abd El-Salam MH. The antioxidant properties of skim milk supplemented with rosemary and green tea extracts in response to pasteurisation, homogenisation and the addition of salts. International Journal of Dairy Technology. 2010;63(3):349–355. https://doi.org/10.1111/j.1471-0307.2010.00585.x

111. Deeth HC. Lipoprotein lipase and lipolysis in milk. International Dairy Journal. 2006;16(6):555–562. https://doi.org/10.1016/j.idairyj.2005.08.011

112. Menis-Henrique MEC. Methodologies to advance the understanding of flavor chemistry. Current Opinion in Food Science. 2020;33:131–135. https://doi.org/10.1016/j.cofs.2020.04.005

113. Modupalli N, Devraj L, Natarajan V. Plant extracts as flavoring agent. In: Mir SA, Manickavasagan A, Ahmad Shah M, editors. Plant extracts: Applications in the food industry. Academic Press; 2022. pp. 165–186. https://doi.org/10.1016/B978-0-12-822475-5.00006-5

114. Bandyopadhyay M, Chakraborty R, Raychaudhuri U. Process for preparing a natural antioxidant enriched dairy products (Sandesh). LWT – Food Science and Technology. 2007;40(5):842–851. https://doi.org/10.1016/j.lwt.2006.05.007

115. Lee N-K, Jeewanthi RKC, Park E-H, Paik H-D. *Short communication*: Physicochemical and antioxidant properties of Cheddar-type cheese fortified with *Inula britannica* extract. Journal of Dairy Science. 2016;99(1):83–88. https://doi.org/10.3168/jds.2015-9935

116. Evstigneeva T, Skvortsova N, Yakovleva R. The application of green tea extract as a source of antioxidants in the processing of dairy products. Agronomy Research. 2016;14(S2):1284–1298.

117. Laranjo M, Fernández-León AM, Agulheiro-Santos AC, Potes ME, Elias M. Essential oils of aromatic and medicinal plants play a role in food safety. Journal of Food Processing and Preservation. 2019;46(8). https://doi.org/10.1111/jfpp.14278

118. Selim S. Antimicrobial activity of essential oils against Vancomycin-Resistant enterococci (VRE) and *Escherichia coli* O157: H7 in Feta soft cheese and minced beef meat. Brazilian Journal of Microbiology. 2011;42:187–196.

119. Foda MI, El-Sayed MA, Hassan AA, Rasmy NM, El-Moghazy MM. Effect of spearmint essential oil on chemical composition and sensory properties of white cheese. Journal of American Science. 2010;6(5):272–279.

120. Zaky WM, Kassem JM, Abbas HM, Mohamed SHS. Evaluation of salt-free Labneh quality prepared using dill and caraway essential oils. Life Science Journal. 2013;10(4):3379–3386.

121. Ghalem BR, Zouaoui B. Microbiological, physico-chemical and sensory quality aspects of yoghurt enriched with *Rosmarinus officinalis* oil. African Journal of Biotechnology. 2013;12(2):192–198. https://doi.org/10.5897/AJB12.1257

122. Trivedi VB, Prajapati JP, Pinto SV, Darji VB. Use of basil (tulsi) as flavouring ingredient in the manufacture of ice cream. American International Journal of Contemporary Scientific Research. 2014;1(3):47–62.

123. Shazly AB, Fouad MT, Elaaser M, Sayed RS, Abd El-Aziz M. Probiotic coffee ice cream as an innovative functional dairy food. Journal of Food Processing and Preservation. 2022;46(12). https://doi.org/10.1111/jfpp.17253

124. Muhammad DRA, Gonzalez CG, Doost AS, de Walle DV, der Meeren PV, Dewettinck K. Improvement of antioxidant activity and physical stability of chocolate beverage using colloidal cinnamon nanoparticles. Food and Bioprocess Technology. 2019;12:976–989. https://doi.org/10.1007/s11947-019-02271-5

125. Salama HH, El-Sayed HS, Kholif AMM, Edris AE. Essential oils nanoemulsion for the flavoring of functional stirred yogurt: Manufacturing, physicochemical, microbiological, and sensorial investigation. Journal of the Saudi Society of Agricultural Sciences. 2021;21(6):372–382. https://doi.org/10.1016/j.jssas.2021.10.001

126. Laswai HS, Mpanalile JJ, Silayo VCK, Ballegu WR. Use of soybeans in food formulation in Tanzania. Proceedings of the first national soybean stakeholders workshop; 2009; Morogoro. Morogoro; 2009. p. 52–59.

127. Gaur GK, Rani R, Dharaiya CN, Solanki K. Development of herbal milk using tulsi juice, ginger juice and turmeric powder. International Journal of Chemical Studies. 2019;7(2):1150–1157.

128. Azizkhani M, Parsaeimehr M. Probiotics survival, antioxidant activity and sensory properties of yogurt flavored with herbal essential oils. International Food Research Journal. 2018;25(3):921–927.

129. Nedovic V, Kalusevic A, Manojlovi V, Levic S, Bugarski B. An overview of encapsulation technologies for food applications. Procedia Food Science. 2011;1:1806–1815. https://doi.org/10.1016/j.profoo.2011.09.265

130. Salama HH, Trif M, Rusu AV, Bhattacharya S. Application of functional and edible coatings and films as promising strategies for developing dairy functional products – A review on yoghurt case. Coatings. 2022;12(6). https://doi.org/10.3390/coatings12060838

131. Salama HH, El-Said MM, Abdelhamid SM, Abozed SS, Mounier MM. Effect of fortification with sage loaded liposome on the chemical, physical, microbiological properties and cytotoxicity of yoghurt. Egyptian Journal of Chemistry. 2020;63(10):3879–3890.

132. El-Said MM, El-Messery TM, El-Din HMF. The encapsulation of powdered doum extract in liposomes and its application in yoghurt. Acta Scientiarum Polonorum Technologia Alimentaria. 2018,17(3):235–245. https://doi.org/10.17306/J.AFS.2018.0571

133. El-Messery TM, El-Said MM, Salama HH, Mohammed DM, Ros G. Bioaccessibility of encapsulated mango peel phenolic extract and its application in milk beverage. International Journal of Dairy Science. 2021;16(1):29–40. https://doi.org/10.3923/ijds.2021.29.40

134. El-Abd MM, Abdel-Hamid M, El-Sayed HS, El-Metwaly HA, El-Demerdash ME, Mohamed ZFA. Viability of microencapsulated probiotics combined with plant extracts in fermented camel milk under simulated gastrointestinal conditions. Middle East Journal of Applied Sciences. 2018;8(3):837–850.

135. Maio GD, Pittia P, Mazzarino L, Maraschin M, Kuhnen S. Cow milk enriched with nanoencapsulated phenolic extract of jaboticaba (*Plinia peruviana*). Journal of Food Science and Technology. 2019;56(3):1165–1173. https://doi.org/10.1007%2Fs13197-019-03579-y

136. El-Sayed SM, El-Sayed HS, Salama HH, Abd-Rabou NS. Preparation and evaluation of microencapsulated fig leaves extract for production novel processed cheese sauce. Egyptian Journal of Chemistry. 2020;64(4):1665–1678.

137. Siyar Z, Motamedzadegan A, Milani JM, Rashidinejad A. The effect of the liposomal encapsulated saffron extract on the physicochemical properties of a functional Ricotta cheese. Molecules. 2022;27(1). https://doi.org/10.3390%2Fmolecules27010120

138. Sawale PD, Patil GR, Hussain SA, Singh AK, Singh RRB. Development of free and encapsulated *Arjuna* herb extract added vanilla chocolate dairy drink by using response surface methodology (RSM) software. Journal of Agricultural and Food Research. 2020;2. https://doi.org/10.1016/j.jafr.2020.100020

139. Barretto FJFP, Clemente HA, Santana ALBD, da Silva Vasconcelo MA. Stability of encapsulated and non-encapsulated anthocyanin in yogurt produced with natural dye obtained from *Solanum melongena* L. bark. Revista Brasileira de Fruticultura. 2020;42(3). https://doi.org/10.1590/0100-29452020137

140. Sawale PD, Patil GR, Hussain SA, Singh AK, Singh RRB. Effect of sterilization treatment on polyphenol content, antioxidant activity and stability of free and encapsulated herb (*Terminalia arjuna*) added milk drink. Indian Journal of Dairy Science. 2019;72(2):148–154. https://doi.org/10.33785/IJDS.2019.v72i02.004

141. Lourenço SC, Moldão-Martins M, Alves VD. Microencapsulation of pineapple peels extract by spray drying using maltodextrin, inulin, and Arabic gum as wall matrices. Foods. 2020;9(6). https://doi.org/10.3390%2Ffoods9060718

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