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Fortification of Dairy Products using Plant-derived Bioactive Compounds

HUDA WAZZAN

Department of Food and Nutrition, School of Human Science and Design, king Abdulaziz University, Jeddah, Saudi Arabia.

Abstract

Dairy products are rich sources of essential vitamins, minerals, and various bioactive components crucial for biochemical and physiological well-being. Over the past decade, there has been a growing interest in dairy products fortified with antioxidants and plant extracts. This increased interest stems from the vital role dairy plays in human nutrition and the demand for "natural preservatives". One particularly promising approach involves enhancing dairy products with plant-derived antioxidants. Antioxidants are critical in neutralizing and scavenging free radicals, constantly produced within the body. Free radicals can damage vital molecules and contribute to the development of chronic diseases, such as cardiovascular disease, diabetes, and even cancer. This damage is often associated with oxidative stress, a condition where the body's natural antioxidant defenses are overwhelmed by free radical production. This review examines the growing trend of fortifying dairy products (milk, ice cream, cheese, and yogurt) with natural ingredients to enhance their nutritional value and functionality. The review focuses on using plant extracts, herbs, spices, and other natural sources, exploring their fortification potential without compromising organoleptic properties. Finally, the review focuses on the potential benefits of incorporating plant-derived bioactive compounds to fortify the antioxidant capacity of milk and dairy products.

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Introduction

Dairy products, including milk, yogurt, and cheese, have long been recognized as a cornerstone of a healthy diet.[1–4] Their rich content of calcium makes them essential for building and maintaining strong bones and teeth throughout life. Dairy is also a valuable source of high-quality protein, crucial for building and repairing tissues, and vitamin D, which aids in calcium absorption.[1,5,6] Additionally, dairy products contribute essential B vitamins for energy metabolism and nervous system function.[7,8]

CONTACT Huda Wazzan hwazzan@kau.edu.sa. Food and Nutrition, School of Human Science and Design, king Abdulaziz University, Jeddah, Saudi Arabia.

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Dairy consumption is limited, however, by lactose intolerance, a digestive condition that affects some people.[5,9–12] To address this challenge and ensure a wider population can benefit from the nutritional value of dairy, lactose-free alternatives, and dairy products with reduced lactose content have emerged.

Fortification of milk with essential nutrients like vitamin D and iron has become a critical public health strategy [13–16] This practice aims to address potential dietary deficiencies, particularly in populations where these vitamins are scarce in natural food sources. Vitamin D fortification is particularly important as it facilitates calcium absorption from dairy products, maximizing their bone-building potential.[17,18]

Iron fortification helps combat iron deficiency anemia, a prevalent health concern, especially among children and pregnant women. Milk fortification offers a cost-effective and efficient way to improve the overall nutritional profile of a widely consumed staple food, potentially leading to better public health outcomes. However, it is crucial to carefully consider the optimal levels and types of fortification based on specific population needs and potential interactions with other dietary components to ensure safety and effectiveness.[14,18]

As food safety concerns rise, the trend toward "healthier" and "eco-friendly" food production encourages using natural antimicrobials instead of artificial preservatives.[19–21] This trend encourages bio-preservation techniques using natural antimicrobial agents derived from plants instead of artificial preservatives. Fortifying dairy products with herbs, and natural sources aligns with consumer demand for minimally processed foods containing natural extracts. Spices and herbs, derived from various plant parts, not only enhance food's flavor and aroma, but many also boast medicinal properties like antibacterial and anti-inflammatory effects.[22] Fortifying dairy products with these herbs and spices could elevate their nutritional value and offer several therapeutic benefits.[22–24] This approach could also increase consumer appeal and market demand for spices. However, to ensure food safety, only the most effective herbs and spices should be used to prevent microbial contamination.[25]

The present study aims to explore the current literature on the utilization of plant extracts for the fortification of milk (cow) and its derivative products. The focus of the review lies in the efficacy of these extracts in augmenting sensory attributes, including taste, aroma, and color. Additionally, the potential for enhanced nutritional and medicinal value through extract incorporation is evaluated. These findings hold significance for the processed food industry, as they indicate the potential for natural plant extracts as functional ingredients in dairy product fortification. This strategy aligns with consumer preferences for organic additives and underscores the promising role these extracts may play in shaping the landscape of fortified dairy products within the broader context of processed food science.

Milk

Shehata *et al*. (2023) developed a functional fermented milk drink infused with Taro leaves and Lactobacillus paracasei. Fermented milk fortified with phenolic components from Taro leaves showed enhanced probiotic survival and antioxidant activity after simulating gastro-pancreatic digestion. As a result, fermented milk supplemented with taro leaves' polyphenols may prevent damage from free radicals in the gastrointestinal tract.[26]

Uruc *et al*. (2022) introduced plant-based fermented milk with kefir culture, incorporating apricot seed extract (ASE) as a valuable dairy substitute for vegans, lactose-intolerant individuals, seniors, and those with cardiac diseases or diabetes. Milk (cow) and ASE were combined to create kefir, which was stored at 4 °C for 21 days. Increasing ASE levels resulted in more yellowish shades, and decreased viscosity, stiffness, uniformity, and texture profiles in the kefir samples. Additionally, higher ASE levels correlated with increased synergy and improved antioxidants and angiotensin-altering enzyme-inhibitory (ACE-i) action.[27]

Dimitrellou *et al*. (2019) fortified milk using Lactobacillus casei ATCC 393 encapsulated in alginates. They studied the survival of *L. casei* cells in simulated gastrointestinal conditions and during the production and storage of fermented milk at 4 °C for up to four weeks. The fermented milk had a better aroma because of the presence of distinctive chemicals produced by *L. casei*. Results indicated that the alginate matrix has significant potential as a probiotic encapsulation. The incorporation of encapsulated cells in cultured milk products improved sensory properties and maintained cell viability under refrigeration. The use of encapsulated probiotic cells is a financially viable and sustainable approach to manufacturing fermented milk products.[28]

Alwazeer *et al*. (2020) examined yogurt bacteria's ability to acidify and reduce plant extract-enriched milk samples. Milk samples enriched with thyme and grape seed extracts showed enhanced acidification ability for Lactobacillus delbrueckii subsp. The study emphasizes the importance of assessing how different yogurt variants' acidification and reducing capabilities may change, potentially affecting starter biological processes, fermentation time, and final product quality.[29]

Asadi-Yousefabad *et al*. (2022) developed gelled-oil nanoparticles (GLNs) containing cinnamaldehyde(CA) and tannic acid (TA) to enhance the health benefits of milk. The samples containing CA and TA presented the highest essential nutrient concentration. Co-encapsulation of TA and CA shows protective effects on milk bioactive nutrients during storage. However, the CA sample received poor ratings for aroma and general acceptability. In dairy products, GLNs disseminated in the liquid phase offered an excellent solution for co-encapsulating both hydrophobic and hydrophilic chemicals.[30]

AlYammahi *et al*. (2023) produced camel milk powder fortified with date sugar (DCMP) using spray drying. The DCMP showed better functional properties and distinct morphological properties. Studies have reported the addition of DCMP has increased thermal stability, fiber content, poly and mono-unsaturated fats, and lower cholesterol levels making it an excellent dietary supplement.[31] Further Addition of date syrup to probiotic fermented camel milk increased its antioxidant properties, total phenolic contents, and titratable acidity. Fortification of milk with 8% date syrup could enhance the therapeutic potential of fermented camel milk.[32] Rajunaik *et al*. (2024) reported that fortification of milk with catechins-loaded nanofibres enriched milk with antioxidant properties. The catechins-loaded nanofibres did not alter the physico-chemical and sensory qualities of milk.[33] Wulansari *et al*. (2021) reported that supplementing Kefir samples with 2% Moringa leaf powder enhanced the antioxidant properties and shelf life of Kefir without compromising organoleptic qualities.[34] Park *et al*. (2019) encapsulated milk using curcumin extract nano-emulsion powder, and turmeric encapsulated milk and evaluated stability at different storage conditions. The findings indicate that encapsulation is an effective technique for enhancing the stability of

However, it is crucial to consider the impact of novel ingredients from extracts on the overall quality of milk products. Alwazeer *et al*. (2020) investigated the impact of adding plant extracts on the acidification process in yogurt production. Their findings highlight the importance of selecting ingredients that complement starter cultures and fermentation processes.[29] Similarly, Asadi-Yousefabad *et al*. (2022) fortified milk with gelled-oil nanoparticles incorporated with cinnamaldehyde and TA. While the fortified milk presented enhanced storage stability, the addition of cinnamaldehyde and TA negatively impacted sensory characteristics.[30]

Icecream

Saremnezhad *et al*. (2020) added calcium to light-fat, no-sugar prebiotic ice cream and assessed its influence on the quality of ice cream. Three different calcium salts were incorporated into vanilla ice cream after it was supplemented with corn-soluble fiber. The influence of each salt on ice cream's physical, chemical, tactile, and microscopic structures was examined. Adding calcium salts resulted in reduced textural stiffness. The thicknesses of samples enriched with tricalcium citrate were comparable to those of control and containing 60 mg/L Cacl2. In tests for sensory assessment, neither of the samples containing calcium salt presented variation in flavor and sweetness or a color change.[36]

Goktas *et al*. (2022) developed a probiotic ice cream using *Saccharomyces boulardii* and *Lactobacillus rhamnosus* GG. These probiotics were added individually or together during ice cream production and aging. The ice cream formulations showed high levels of beneficial bacteria throughout storage, with co-inoculation enhancing the rheological characteristics. The addition of probiotics altered the aroma profile, with samples receiving favorable sensory scores.[37] Tipchuwong *et al*. (2017) aimed to develop vitamin D3-fortified ice cream using an emulsion method with milk protein as a surfactant. They examined the physicochemical stability of vitamin D3 suspensions using various milk protein emulsifiers, including low-fat dried milk, sodium caseinate (Na-Cas), and whey protein isolate. Results showed that employing milk protein as an emulsifier and integrating vitamin D3 as an emulsion improved its absorption in ice cream. According to their study, Sodium caseinate is an effective milk protein emulsifier which can enhance the stability and compatibility of vitamin D3 emulsion with dairy foods.[38]

Akalın *et al*. (2018) examined the effects of five dietary fibers - bamboo, oat, apple, wheat, and orange - on the physicochemical, rheological, and morphological properties, and TPA profile of probiotic ice cream stored at 18°C for 180 days. The addition of orange and apple fibers increased bitterness, reduced luminosity, and enhanced the color of the ice cream. Except for oat fiber, all dietary fibers improved uniformity scores and perceived viscosity levels compared to the control samples. Ice cream fortified with apple fiber exhibited the highest viscosity, while that with orange fiber displayed the greatest toughness after 60 days of refrigeration. Furthermore, the inclusion of orange and apple fibers significantly enhanced melting resistance.[39]

Overall, these studies showed that it is possible to enrich ice cream with various plant based ingredients without compromising sensory quality and organoleptic qualities. For example, calcium addition reduced stiffness but other types of supplements maintained thickness. Probiotics enhanced TPA profile and were preferred by customers because of the texture and enhanced color. Fortification of ice-cream samples with encapsulated Vitamin D3 improved vitamins and calcium absorption, facilitated by milk proteins. Finally, dietary fibers offered textural benefits and some enhanced melting resistance, although some impacted taste.

Cheese

To boost Himalayan cheese's health benefits, Bhat *et al*. (2021) investigated saffron's potential as a nutraceutical ingredient. They developed a saffron-enriched kradi cheese and analyzed its physicochemical, antioxidant, and therapeutic properties. The addition of saffron triggered significant changes in the investigated aspects of the cheese. Most notably, the enriched cheese displayed a shift towards a yellowish hue and a remarkable improvement in its antioxidant capacity compared to the control. Further, saffron significantly enhanced the therapeutic qualities of the cheese attributed to the traditionally reported medical benefits of the saffron.[40–42] This suggests the exciting potential of saffron-induced cheese as a bioactive ingredient in functional dairy products with positive health implications.[43]

El Hatmi *et al*. (2020) explored how ultrafiltration (UF), separation, and Allium roseum (AR) powder fortification influence the quality of soft cheese made from dairy milk. The process of milk for production of cheese, including fat removal and UF significantly impacts cheese production, physicochemical makeup, and texture.[44–46] Following the induction of the AR powder, a color variations were observed across samples. Further, LC-ESI-MS analysis revealed the presence of unique phenolic compounds and enhanced antioxidant properties in cheeses fortified with AR powder despite UF treatment. Most importantly, consumer acceptance scores were significantly higher for AR-fortified cheeses. This study suggests that AR powder holds promise as a novel ingredient for creating functional dairy products from milk.[47]

Degenek *et al*. (2023) investigated how wild thyme, in three different forms (ground, supercritical extract, and dry extract), influences fresh cheese during production and a ten-day storage period. The authors investigated the impact of the fortification using thyme on physicochemical properties, antioxidant capacity, and sensory quality of the cheese. Interestingly, all samples across storage exhibited increased ash content, acidity, and total phenol concentration, alongside a decrease in pH. Even more promising, sensory analysis revealed that the wild thyme fortification effectively preserved the appearance, color, consistency, odor, and taste throughout storage. This synergistic effect on the cheese's properties suggests wild thyme's potential as a novel functional ingredient for enhancing the shelf life and marketability of fresh cheese products.[48]

Sarkar *et al*. (2020) investigated the vitamin, organic acid, and carotene profiles of a traditional South Asian dairy dessert, rasgulla, for nutritional fortification. Pineapple pulp (Ananas comosus) was incorporated as a potential fortificant to enhance the overall nutritional value of the product. The employed drying technique involved a multi-step process utilizing heated air, cryopreservation, and subsequent reheating to achieve a dehydrated pineapple matrix. The resulting rasgulla fortified with this pineapple matrix exhibited statistically significant elevations in vitamin, organic acid, and carotene content compared to the control group.[49]

El-Fat *et al*. (2018) evaluated the antimicrobial and antioxidant properties of acetone, ethanol, aqueous ethanol, and water extracts derived from dried Moringa oleifera foliage in cream cheese. To elucidate the potential application of these extracts, cream cheese was subjected to a comprehensive analysis of its chemical composition, antioxidant capacity, microbial profile, physical attributes (color and texture), and flow properties (rheology). Results indicated that the ethanol extract exhibited the highest total phenol content and antioxidant capacity, alongside activity against a panel of foodborne pathogens. This suggests that Moringa oleifera leaf extracts, particularly ethanol extracts, could serve as effective preservatives and nutritional supplements, enhancing the health benefits and extending the shelf life of cheese.[50]

Chailangka *et al*. (2023) explored the use of cricket protein-saccharide conjugate (CPF) as a partial rennet casein substitute in simulated mozzarella cheese. They evaluated its impact on cheese properties (microstructure, color, texture, and sensory attributes) and vitamin D retention. CPF incorporation decreased cheese stiffness and elasticity but increased adhesiveness and free oil release. Importantly, it significantly improved vitamin D retention compared to the control, with a nearly threefold increase after processing and a 2.8-fold increase after storage (28 days at 4°C). This suggests CPF (10-20 g/100 g cheese) could enhance vitamin D stability without affecting consumer preference.[51]

Research suggests several possibilities for creating functional yet enriched cheese with enhanced health benefits. Saffron,[43] Allium roseum,[47] wild thyme,[48] and pineapple pulp[49] all demonstrate promise as nutraceutical ingredients, improving antioxidant properties, vitamin content, and consumer acceptability. Additionally, cricket protein-saccharide conjugate51 shows potential for boosting vitamin D content in cheese.

Yogurt

Tang *et al*. (2022) investigated the potential for fortifying yogurt with an aqueous extract (CLE) derived from waste cinnamon leaves. They assessed the effects of CLE addition and encapsulation on yogurt's chemical composition, antioxidant activity, and anti-inflammatory properties. The study also evaluated CLE's bioactivity and stability during yogurt digestion. While gelatin encapsulation offers some advantages, the authors suggest further research is needed to optimize CLE bioactive components delivery during consumption. Overall, this work highlights the potential of using leftover cinnamon leaves as a valuable source of health-promoting compounds for yogurt fortification.[52] Similar to Tang *et al*. (2022), Gaglio *et al*. (2019) explored saffron as a yogurt fortifier. They evaluated the impact of 0.0125% (w/w) saffron supplementation on yogurt's microbiological, physicochemical, antioxidant, and sensory properties. Notably, the saffron addition did not alter the yogurt's rheological characteristics and received a positive sensory evaluation. Importantly, saffron significantly enhanced yogurt's antioxidant capacity and extended starter cultures' shelf life. Furthermore, the fortified yogurt exhibited increased antioxidant activity throughout storage, suggesting sustained or improved saffron efficacy over time. Based on these findings, the authors propose a 30-day consumption window for saffron yogurt. They conclude that saffron incorporation into yogurt, a widely consumed product, could potentially improve human health by promoting dietary antioxidant intake.[53]

Corrêa *et al*. proposed the valorizing of discarded A. blazei fruiting bodies through the production of an ergosterol-rich extract for yogurt fortification. The extract exhibited potent antioxidant and antibacterial activities and its incorporation significantly enhanced yogurt's antioxidant capacity without altering the fatty acid profile or nutritional composition. This approach aligns with the circular economy concept by converting waste biomass into a high-value food additive with potential health benefits.[54]

Jaster *et al*. investigated the use of 30% strawberry cryoconcentrate as a fortifier for yogurt. They observed a decrease in pH (increased acidity) and significant improvements in anthocyanin content and antioxidant capacity. The yogurt color was comparable to commercial brands using synthetic dyes. Furthermore, the addition of intensified pulp improved texture by reducing cyclic components, a desirable quality trait in yogurt. All yogurt samples exhibited shear thinning and thixotropic behavior, characteristic of non-Newtonian fluids. Overall, strawberry cryoconcentrate presents a promising strategy for developing yogurt with enhanced nutritional value, antioxidant properties, and desirable color and texture attributes.[55]

Sahingil *et al*. investigated the effects of rosehip pulp fortification on yogurt quality. Increasing rosehip content led to a proportional rise in total phenolics and antioxidant capacity. Sensory analysis revealed that yogurt with 20% added rosehip pulp received the highest consumer acceptance. The addition of rosehip pulp improved the yogurt's water-holding capacity, volatile profile, and sensory characteristics. Further, rosehip pulp may contribute to prebiotics for probiotic bacteria and potentially enhance human health through increased polyphenols and synergistic antioxidant effects.[56–58] The study suggests that rosehip fortification is a promising strategy to improve the nutritional value, functionality, and sensory appeal of yogurt, while also serving as an effective delivery vehicle for the health benefits of rosehip.[59]

Bertolino *et al*. evaluated the potential of hazelnut peels (three varieties) as a source of antioxidants and dietary fiber for yogurt fortification. The study investigated the effects of peel incorporation on yogurt's physicochemical properties, antioxidant capacity, polyphenol content, and texture. The findings revealed that hazelnut peels could effectively enhance yogurt's antioxidant capacity and dietary fiber content in a dose-dependent manner, without altering other physicochemical parameters. Antioxidant capacity in fortified yogurt remained stable during storage, while phenolic content remained unchanged. These results suggest that hazelnut peels hold promise as functional ingredients for yogurt, potentially improving its health benefits and shelf life stability.[60]

Almusallam *et al*. investigated the effects of various date palm spikelet extract (DPSE) concentrations on yogurt's physicochemical and microbiological properties during refrigerated storage (4 °C) for 21 days. The DPSE addition significantly impacted yogurt's physicochemical properties and microbial profile. Fortified yogurts exhibited improved physical characteristics and enhanced microbiological stability compared to the control. These positive effects are attributed to the antioxidant compounds present in the DPSE and the exo-polysaccharides (EPS) produced by lactic acid bacteria during fermentation. Notably, DPSEs maintained stable microbial activity throughout storage, suggesting potential health benefits. However, DPSE incorporation also increased yogurt's viscosity, affecting its texture and appearance. Overall, the study demonstrates that DPSEs can improve the yogurt's rheological properties during storage and handling, potentially enhancing consumer acceptance. The authors propose that these findings encourage the utilization of date palm waste in yogurt production, promoting improved product quality, shelf life stability, and consumer appeal.[61]

Šeregelj *et al*. (2021) investigated the fortification of yogurt with encapsulated carrot waste extract (CWE) as a source of carotenoids. Following characterization, carotenoids were recovered from carrot leftovers using electrostatic extrusion. The resulting CWE beads were then incorporated into yogurt at two defined concentrations during the final processing. Fortified and control yogurts were compared throughout a 28-day storage period at 4 °C. Both fortification levels provided a portion of the daily recommended β-carotene intake. Notably, the physicochemical and microbiological properties of the enriched yogurt remained stable during storage. The significant enhancement of antioxidant activity observed in CWE-fortified yogurt suggests its potential as a functional food with improved nutritional value.[62]

Xu *et al*. (2022) developed a novel cultured yogurt recipe incorporating hemp protein and evaluated the impact of protein content on physicochemical and sensory characteristics. Hemp protein addition resulted in a rapid decrease in yogurt pH and a corresponding increase in tartness due to lactic acid production. Higher protein concentrations influenced these parameters. Compared to the control, hemp protein-fortified yogurt exhibited reduced whey precipitation, improved smoothness, and enhanced rheological properties. Sensory analysis revealed high consumer acceptance, further supported by physicochemical and flavor profile analysis. These findings suggest hemp protein's potential as a valuable source of nutrients for yogurt development.[63]

Conclusion

Herbaceous plants and their various extracts contribute to both enhanced flavor and fragrance in dairy products. Including herbs and spices with different medicinal qualities has the potential to enhance the functional properties of dairy products. The addition of herbs and spices to dairy products could help create functional dairy products with various nutritional and therapeutic benefits. Throughout the world, herbs and spices have also been used as nourishing supplements to enhance food taste and aroma while extending shelf life by reducing or eliminating foodborne microorganisms. Using dietary herbs, spices, and plant extracts can improve human health because of their anti-mutagenic, anti-inflammatory, anti-oxidative, and immune-modulating qualities.

Future Directions

This paper reviews the existing literature on the fortification of various dairy products, including milk, yogurt, ice cream, and cheese, with herbs and plant extracts. While researchers have employed diverse extracts for dairy product fortification, further exploration is crucial for optimizing the concentrations of different extracts needed to achieve desired health benefits without compromising the taste or sensory qualities of the final product. The current extraction methods for bioactive compounds from plants should also be improved. Developing more efficient and sustainable methods for extraction and purification would benefit the industry.[64,65] Further, novel approaches are needed to incorporate these extracts into dairy products while ensuring stability and functionality throughout processing and storage. 24 Additionally, quality issues like solubility, potential interactions with other dairy components, and impact on functionality or sensory characteristics (e.g., texture, taste) of the product should also be explored. A deeper understanding is required regarding how these added herbs and extracts might affect the absorption of other macronutrients present in dairy products (e.g., protein, calcium).

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Conflict of Interest

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

Authors' Contribution

The author confirms sole responsibility for the following: study conception, interpretation of results, and manuscript preparation.

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