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Dangke: unveiling Indonesian traditional fermented cheese from Enrekang, South Sulawesi

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Abstract

Dangke is a traditional cheese from South Sulawesi, initially produced by the *Massenrempulu* ethnic community in Enrekang. It is made by curdling the milk with papain enzyme from papaya sap, followed by spontaneous fermentation by lactic acid bacteria (LAB). Numerous studies have been conducted on *dangke*, however, no comprehensive review has integrated information from various aspects of *dangke*. This review addresses that gap by offering an in-depth understanding of *dangke*, including its history, philosophy, production methods, microbiology, nutritional value, health benefits, safety concerns, and shelf-life. It also highlights the challenges in *dangke* production and proposes directions for future advancements. *Dangke* is known for its high nutritional value, and its microbiota consists mostly of LAB species. These indigenous LAB in *dangke* may serve as potential probiotics, offering functional benefits such as antimicrobial, antioxidant, antihypertensive, antihyperglycemic, and antihypercholesterolemic effects, as well as improving anemia. However, challenges such as non-standardized production, uncontrolled fermentation, poor hygiene practices, and a short shelf-life pose significant risks to the quality and safety of *dangke*. To address these issues, it is crucial to standardize production methods, regulate fermentation, and improve hygiene protocols, all of which are essential for enhancing the overall quality and safety of the product. Additionally, extending *dangke*'s shelf-life can facilitate its broader commercialization. This study will provide crucial information for future research on *dangke*, paving the way to optimize its potential while promoting standardization and sustainable production.

Keywords Culinary heritage, *Dangke*, Enrekang, Probiotics, Traditional cheese

Introduction

Indonesia is renowned for its rich ethnic and cultural diversity, which has significantly influenced the development of its cuisine. The natural resources and cultural traditions have enriched Indonesian culinary practices, particularly its traditional delicacies. Among these, fermentation techniques play a prominent role in many regional specialties [1, 2]. In recent years, the global popularity of ethnic and traditional fermented foods has surged, leading to greater awareness and appreciation of Indonesia's unique culinary heritage [3]. This growing recognition extends not only to plant-based fermented foods but also to dairy products, which have been shaped

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by the availability of local livestock resources. One of the key factors influencing dairy fermentation in Indonesia is the domestication of buffalo, which has contributed to the use of buffalo milk in certain regions for the production of traditional dairy products [4]. This practice has also fostered the development of traditional cheese-making practices [5]. Traditional cheeses, passed down through generations, represent an important cultural legacy, embodying centuries of knowledge and craftsmanship, with their characteristics shaped by specific geographic origins and distinctive climatic conditions [6]. Enrekang, a region located in the scenic landscapes of South Sulawesi, Indonesia (Fig. 1), is renowned for its *dangke*, a traditional cheese that has been meticulously developed and refined over several decades.

Dangke is a traditional fermented delicacy from Enrekang that resembles cheese in flavor but has the appearance and texture of tofu. It is a soft cheese produced by curdling buffalo milk with the papain enzyme, derived from papaya sap, instead of using rennet, which is commonly used in cheese production [7]. After coagulation, the mixture is filtered through a coconut shell, which also serves as a mold, and then undergoes spontaneous fermentation overnight. The curd is molded into shape and traditionally wrapped in banana leaves, which not only serve as natural packaging but also enhance its artisanal identity [8]. Fresh *dangke* has a white to yellowish-white color (Fig. 2A), a mild milky aroma, and a creamy taste [9]. Its semi-elastic and slightly chewy texture, with a smooth and moist consistency [9], makes it firmer than mozzarella [10] but softer than paneer [11]. Unlike commercial cheeses that undergo fermentation or aging, *dangke* is consumed fresh, resulting in a distinct flavor profile [12]. It lacks the pronounced sourness of fermented dairy products like kefir or yogurt [13], and does not exhibit the strong umami or salty notes characteristic of aged cheeses [14]. While widely accepted in South Sulawesi, its sensory characteristics may influence consumer preferences outside its region of origin. Furthermore, as its production remains largely traditional and localized, *dangke* is less known than globally recognized cheeses [15].

Dangke is classified as a perishable food due to its high nutritional value and susceptibility to microbial contamination [9]. Its limited shelf-life presents challenges for commercial manufacturing and distribution [16]. Researchers have investigated various techniques to extend the shelf-life of *dangke*, including salting [12], and the use of enzymes such as the lactoperoxidase system, lactoferrin, and lysozyme [17–19]. These processes have also been shown to be effective in reducing the risk of contamination by pathogenic

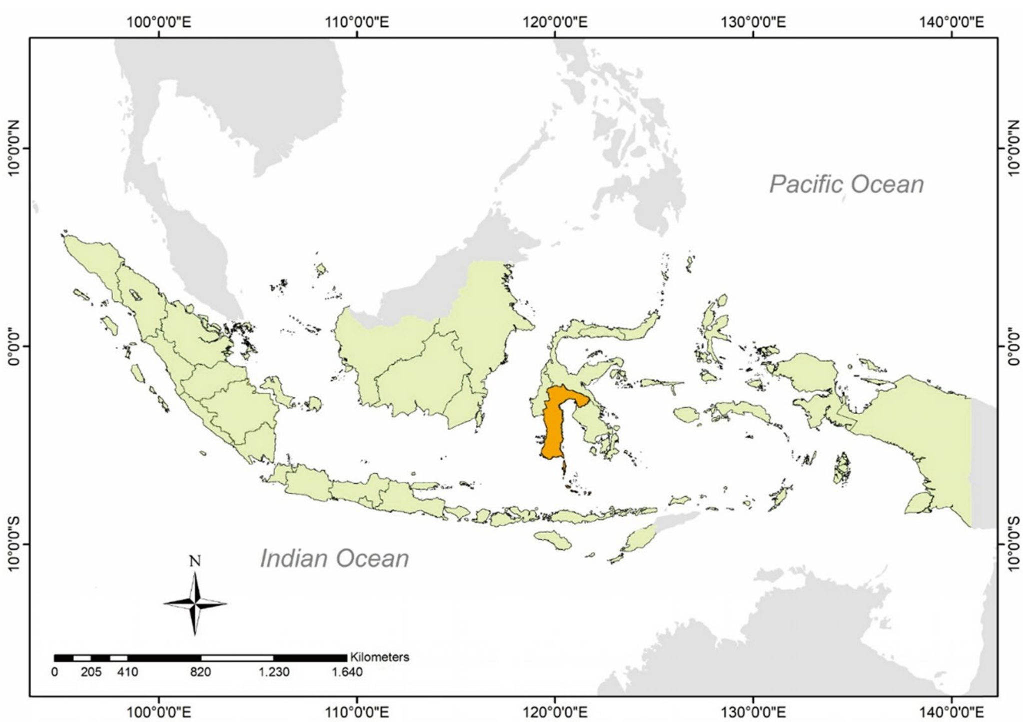

Fig. 1 The geographical map of South Sulawesi in Indonesia, renowned as the origin of the traditional Indonesian cheese, *dangke*. Its rich cultural heritage and agricultural practices contribute to the unique flavors of *dangke*, making it an important part of the local culinary landscape

Fig. 2 *Dangke*, a traditional Indonesian cheese originating from Enrekang, South Sulawesi. It is traditionally consumed in various ways, each offering distinct sensory experiences: **A** fresh *dangke*, served as a nutritious dish, provides a light yet satisfying meal; **B** fried *dangke*, prepared by deep-frying, is enjoyed as a crispy appetizer or snack and pairs well with a variety of dipping sauces; and **C** grilled *dangke*, which develops a smoky flavor through thermal processing, is commonly served with rice or incorporated into a larger meal. (Source: Primary data, personal documentation)

microorganisms [12, 18]. Furthermore, certain LAB isolated from *dangke* have demonstrated antimicrobial properties and could be employed as biopreservatives [20]. *Dangke* is also recognized as a potential probiotic due to its substantial quantity of LAB [21]. These probiotic LAB possess the capacity to enhance the host's health and longevity by reinforcing the intestinal barrier [22]. Additional health benefits of *dangke* were also reported, including antioxidant, antihypertensive [21], antihyperglycemic [23], and antihypercholesterolemic effects [24, 25]. These properties indicate that *dangke* has potential beyond its traditional culinary role, extending to functional food applications.

Although many studies on *dangke* have been conducted, a comprehensive overview that synthesizes these studies from various aspects has yet to be published. This presents a significant research gap, particularly in integrating findings across various areas such as microbiology, nutrition, functionality, and safety. The absence of such a review has hindered a clear understanding of *dangke*'s potential. Therefore, this review aims to address this gap by integrating existing research on *dangke* from multiple perspectives, covering its historical background, microbiological and nutritional properties, functional benefits, food safety, shelf-life, and potential for future innovation. Through this comprehensive approach, the review aims to highlight *dangke*'s potential for wider commercialization and encourage further scientific exploration.

Method of review

A comprehensive literature review was conducted to gather relevant studies on various aspects of *dangke*, including its history, philosophy, traditional production methods, microbiological and nutritional properties, functional benefits, safety, shelf-life, and fermentation development. The literature search utilized keywords such as "*dangke*," "*dangke* cheese," "Enrekang fermented cheese," "*dangke* fermentation," "*dangke* microbiota," "lactic acid bacteria in *dangke*," "nutritional properties of *dangke*," "*dangke* for health," "safety of *dangke* consumption," and "*dangke* shelf-life." These terms were searched across scholarly databases and scientific repositories, including ScienceDirect, Web of Science, Wiley Online Library, Springer, PubMed, and Google Scholar. The publications selected ranged from 1999 to 2024. The reviewed studies included both qualitative and quantitative data, which were analyzed and discussed according to the methodologies outlined in the cited articles. Inclusion criteria for the review were articles published in peer-reviewed journals, conference proceedings, books, and final projects. In total, 22 national journals, 39 international journals, 6 conference proceedings, 5 books/book chapters, and 4 final projects were included in the review. To ensure consistency and accessibility, literature published in languages other than English or Indonesian was excluded.

The history and philopsophy of *dangke*

Dangke is believed to have originated in the eighteenth century, with its first production taking place in the Curio region of Enrekang Regency, South Sulawesi. Its development is closely associated with the *Massenrempulu* people, an indigenous tribe in Enrekang that developed unique methods for processing buffalo milk using locally sourced materials. The name

Massenrempulu comes from the local language, meaning "*stuck together like sticky rice*", which symbolizes the unity of the three sub-tribes—Duri, Maiwa, and Enrekang—that inhabit the region [26]. Historically, the *Massenrempulu* people relied on agriculture as their primary livelihood, cultivating rice, coffee, and vegetables, while also raising buffaloes, which played a significant role in their agricultural and cultural practices. In earlier times, nearly every household in the region raised buffalo, leading to a high production of buffalo milk. This practice was supported by the region's highland geography, which provided vast grazing lands and ideal conditions for livestock farming [27].

To manage surplus buffalo milk and prevent waste, the Curio people developed a method to coagulate milk, giving rise to *dangke*. This innovation not only preserved excess milk but also created a product that was more acceptable to the local population, many of whom were not accustomed to consuming fresh milk. *Dangke* was typically fried or grilled before consumption and served as a main dish or side dish (Fig. 2B and 2C). In earlier times, *dangke* was considered a luxury item, primarily consumed by noble families or honored guests during special occasions due to its high cost. Over time, its unique taste and cultural significance gained recognition, spreading its popularity across South Sulawesi [7]. Although the precise origin and name of *dangke* are not well-documented, it is known that the tradition of making this cheese has been practiced for centuries. One theory suggests that the name "*dangke*" originated from the Dutch phrase "*dank je wel*", meaning "*thank you*" [26]. During the Dutch colonial period, Dutch soldiers or settlers who encountered this local cheese-making tradition reportedly expressed their appreciation by saying "*dank je*", which was later adapted by the Enrekang people into *dangke* [7].

Dangke holds cultural, nutritional, and economic significance for the Enrekang community, especially the *Massenrempulu* people. Culturally, *dangke* is deeply embedded in local dietary customs and is commonly served at festivals and family gatherings [7]. Nutritionally, it is a valuable source of protein, contributing to food security and dietary diversity [21]. From an economic perspective, the production of *dangke* has evolved into a thriving local industry, providing a stable source of income for many families in Enrekang [28]. The philosophy behind *dangke* reflects principles of simplicity and sustainability, utilizing natural ingredients and traditional methods. The use of natural coagulants such as papaya sap and the reliance on local livestock symbolize a harmonious relationship with nature [27]. Additionally, *dangke* production is often a communal activity, passed down through generations, reinforcing the importance of shared knowledge and cultural continuity. Beyond being just a food product, *dangke* serves as a symbol of community identity and pride in local heritage. By continuing the tradition of making and consuming *dangke*, the people of Enrekang honor their cultural roots while positioning *dangke* as an essential part of Indonesia's culinary heritage on a broader scale [5].

Production of traditional *dangke*

Dangke is produced through a process that utilizes local resources and traditional techniques. The production of traditional *dangke* is illustrated in Fig. 3. The primary ingredient in making traditional *dangke* is fresh buffalo milk. Initially, the milk is heated over medium heat to a temperature range of 70–90 °C for 5 min. Subsequently, papaya sap (0.20–0.40% w/v) was added to the heated milk while continuously stirring until curds begin to form. The papaya sap is extracted by peeling the stems or skin of unripe papaya fruit [29]. The papaya sap serves as a natural coagulant containing the papain enzyme, which effectively coagulates the milk proteins, particularly casein. Papain is classified as a cysteine protease, a type of proteolytic enzyme that hydrolyzes peptide bonds in proteins. However, rather than fully hydrolyzing proteins into free amino acids, papain selectively cleaves peptide chains into smaller peptides [30]. This partial hydrolysis causes casein to lose its solubility characteristics and start aggregating to form curds. This highlights papain's dual role as both a coagulant and a proteolytic agent [31].

The curds are then placed in traditional molds made from coconut shells, which also help separate the whey from the curds. After being molded, the curds are left to set overnight, resulting in *dangke* with a distinctive texture, similar to that of soft cheese [29]. Some variations of *dangke* are also soaked in a salt solution to enhance both their flavor and preservation properties [12]. *Dangke* is typically wrapped in banana leaves, which impart a unique aroma and enhance its flavor. This wrapping method is also practical for both transporting and storing *dangke* [5].

The production of *dangke* has evolved to encompass not only buffalo milk as its primary raw material. In response to the scarcity of buffalo milk, farmers in Enrekang Regency have begun utilizing cow's milk as an alternative ingredient for *dangke* production. Cow's milk *dangke* offers several advantages over its buffalo counterpart, including comparable nutritional quality along with additional benefits such as greater availability of raw materials, lower costs, and enhanced accessibility. This variant has gained significant popularity among consumers in Enrekang and has also been favored by those from outside the region. Moreover, it exhibits a color and

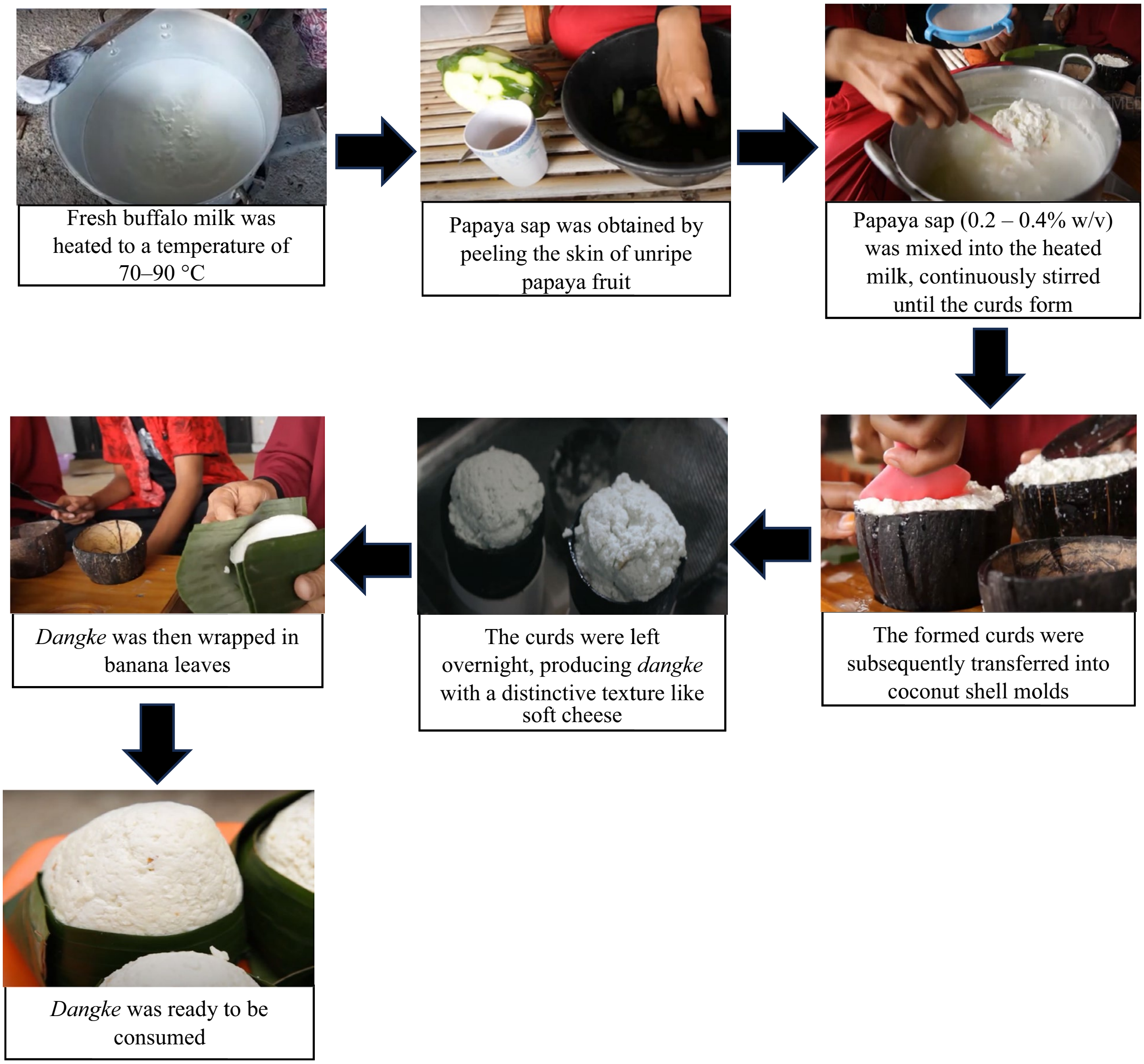

Fig. 3 The traditional *dangke* production process showcases the careful steps involved in transforming fresh buffalo milk into this unique Indonesian cheese product. From heating the milk to adding papaya sap for coagulation, molding the curds, and finally wrapping them in banana leaves, each step highlights the rich cultural heritage and artisanal techniques behind *dangke*. (Source: Primary data, personal documentation)

flavor profile that aligns closely with consumer preferences [12]. Additionally, several other coagulants, such as vinegar [32] and passion fruit [33], have been investigated in the production of *dangke*, with properties similar to those of traditional *dangke*. The production process has also advanced to include the use of probiotic starter cultures, such as *Lactococcus lactis* and *Lactobacillus plantarum*, aimed at enhancing its physicochemical, microstructure, and functional properties [34]. Furthermore, the application of other starter cultures, including *Streptococcus lutetiensis*, *Weissella confusa*, and *S. equinus*, has been adopted to improve both the quality and shelf-life of *dangke* [35].

In Enrekang, the tradition of consuming *dangke* is deeply intertwined with the local culture and customs of the community. However, despite its cultural significance, the production of *dangke* is limited, as evidenced by data from 2018, which reported production levels in the Sumbang Village, Curio District, Enrekang Regency, ranging from 60 to 210 pieces per month, with an average of 173 pieces. This limited production was mirrored in sales, fluctuating between 50 and 330 pieces per month, with an average of 157 pieces [36]. *Dangke* is typically consumed fresh, either as a snack or as a side dish served with rice. Due to its distinctive taste, it is often enjoyed on its own or paired with palm sugar or lime chili sauce, enhancing its flavor profile with a balance of spicy, sour, sweet, and savory notes [12]. Another unique tradition involves cooking *dangke* by baking or frying. These methods give the *dangke* a crispy exterior while maintaining a soft interior. Additionally, *dangke* can be incorporated into various dishes such as soups, *nasi goreng*, or stir-fries. For instance, *dangke* is commonly added to *pallu basa*, a traditional South Sulawesi dish, which is a spicy meat-based dish combined with vegetables [37].

Microbiological aspects of *dangke*

Naturally fermented products typically involve a diverse range of microorganisms, with LAB and yeasts being the most common. In *dangke* fermentation, indigenous LAB from buffalo milk are key contributors. These LAB dominate the microbial ecosystem during the process, suppressing pathogenic and spoilage bacteria while enhancing the flavor profile of the final product. The total viable LAB count in *dangke* was in the range of 7.16–8.50 log CFU/mL [21]. A detailed list of LAB species identified in *dangke* can be found in Table 1. The *L. plantarum*, *L. fermentum*, and *W. confusa* have been identified in *dangke* produced from both buffalo and cow milk [38]. *L. plantarum* and *L. fermentum* are commonly isolated LAB found in dairy products [39]. Additionally, *L. fermentum* strains have been shown to possess probiotic properties and the ability to produce bacteriocin-based antibiotics [38]. Djide et al. [20] also reported the presence of *L. fermentum* strain NBRC 15885 in buffalo milk *dangke*, which produces a bacteriocin with selective antimicrobial activity against *S. aureus*. The *W. confusa* is also naturally found in cow milk. These strains possess probiotic properties and have the ability to produce prebiotic oligosaccharides [40]. In addition to being present in *dangke*, *W. confusa* has also been successfully isolated from *nono*, a fermented cow milk product [40].

Razak et al. [41] reported that LAB isolated from *dangke*, such as *L. plantarum* DU15, *Enterococcus faecium* DU55, and *Leuconostoc mesenteroides* DU02, have antimicrobial potential. Other LAB strains found in *dangke* include *Lactococcus lactis* [42, 43], *L. acidophilus* [44], *L. bulgaricus*, *Leuconostoc dextranicum*, *S. thermophilus* [43], *S. lutetiensis*, and *S. equinus* [35]. In addition to LAB, various other microorganisms have been identified in *dangke*. Three yeast species, *Saccharomyces cerevisiae*, *Candida metapsilosis*, and *Kluyveromyces marxianus*, have been found in *dangke*, with *Saccharomyces cerevisiae* being the most predominant species [45]. Different yeast species, including *Candida guilliermondii*, have also been reported in *dangke*. Yeasts and LAB coexist

Table 1 Microorganisms present in traditional Indonesian cheese, *dangke*

Samples	Microorganisms	Method	References
Buffalo milk *dangke*	*Streptococcus lutetiensis* *Weissella confusa* *Streptococcus equines*	Culture-independent method (16S rRNA sequencing)	[35]
Buffalo milk *dangke*	*Lactobacillus plantarum* *Lactococcus lactis* subsp. *lactis*	Culture-independent method (16S rRNA sequencing)	[22]
Buffalo milk *dangke*	*Limosilactobacillus fermentum*	Culture-independent method (16S rRNA sequencing)	[68]
Buffalo milk *dangke*	*Lactobacillus lactis* *Lactobacillus bulgaricus* *Leuconostoc dextranicum* *Streptococcus thermophillus*	Culture-dependent method (Gram staining and biochemical tested)	[43]
Buffalo milk *dangke*	*Candida guilliermondi*	Culture-dependent method (RapID Yeast Plus System and Electronic Code Compendium)	[46]
Cow milk *dangke*	*Lactobacillus plantarum* *Lacobacillus fermentum*	Culture-dependent method (Gram staining and biochemical tested)	[38]
Buffalo milk *dangke*	*Lactobacillus fermentum* *Weissella confusa*	Culture-independent method (16S rRNA sequencing)	[20]
Buffalo milk *dangke*	*Saccharomyces cerevisiae* *Candida metapsilosis* *Kluyveromyces marxianus*	Culture-independent method (PCR–RFLP)	[45]
Cow milk *dangke*	*Lactobacillus acidophilus Lactobacillus plantarum*	Culture-independent method (Multiplex PCR)	[44]

during fermentation, with LAB producing organic acids that reduce the pH of the medium, potentially promoting yeast growth. In turn, yeasts supply essential growth factors for LAB, including vitamins and soluble nitrogen components [46].

The unhygienic practices observed during *dangke* production may contribute to the presence of *Enterococci* group bacteria. Pyrosequencing results indicated a more diverse population of mesophilic LAB in *dangke* made from cow's milk, whereas samples derived from buffalo milk were predominantly dominated by the *Enterobacteriaceae* family [22]. Furthermore, the high nutritional value of *dangke* makes it susceptible to contamination by pathogenic bacteria such as *Eschericia coli* and *Salmonella spp.* These contaminations can often be traced back to the workers and the processing equipment used [47]. Other studies have also indicated that buffalo milk *dangke* contained contaminating bacteria, with *E. coli* and *Staphylococcus* levels recorded at 0.59 and 1.23 log CFU/mL, respectively [21].

Nutritional properties of *dangke*

The production of *dangke* is traditionally carried out without standardized methods [5]. As a result, it contains a diverse range of microorganisms and shows variability in its nutritional properties. Several factors significantly influence these characteristics, including the type of milk used [48], heating temperature [29], coagulant type and concentration [32], and fermentation conditions (e.g., spontaneous fermentation or the use of a starter culture) [21]. The nutritional properties of *dangke* under various treatments are summarized in Table 2. Based on its moisture content (Table 2), *dangke* is classified as a soft cheese, with a moisture content exceeding 40%. In comparison to cottage cheese, which has a moisture content of 79.1% and is also classified as a soft cheese [48], *dangke* generally has a lower moisture content resulting in a denser texture, except for *dangke* made with vinegar as a coagulant. Despite this, *dangke* has higher fat and protein levels than cottage cheese, with 3.90% fat and 13.8% protein [49]. The high protein content of *dangke* makes it a valuable source of essential amino acids. Additionally, its moderate fat content also contributes to energy provision. These nutritional characteristics suggest that *dangke* can be a part of a balanced diet, offering both protein and fat in moderate amounts. Buffalo milk, a common raw material for *dangke* production, has twice the protein content (6.30%) of cow's milk (3.20%) [7]. Additionally, buffalo milk typically contains higher total solids (17.2%) compared to cow's milk (12.7%), mainly due to its higher levels of casein (3.2%) and fat (7.4%) relative to cow's milk (2.8% casein and 3.7% fat) [50]. As shown in Table 2, *dangke* made from buffalo milk generally has a higher fat content than *dangke* made from cow's milk.

Table 2 The nutritional composition of *dangke*

Samples	Production process	Nutritional composition (%)					References
		Moisture	Ash	Crude fat	Crude protein	Carbohydrate	
Buffalo milk *dangke*	Spontaneous fermentation with papaya sap as coagulant	58.28	1.83	20.71	15.57	3.60	[75]
Buffalo milk *dangke*	Spontaneous fermentation with papaya sap as coagulant (0.3% v/v)	52.45	2.07	27.72	14.55	3.21	[21]
Buffalo milk *dangke*	Starter culture addition of *L. plantarum* IIA-1A5 (5% w/v) with papaya sap as coagulant (0.3% v/v)	55.29	1.90	26.45	15.33	1.03	[21]
Buffalo milk *dangke*	Starter culture addition of *L. plantarum* IIA-1A5 (10% w/v) with papaya sap as coagulant (0.3% v/v)	55.09	2.01	25.56	15.18	2.16	[21]
Buffalo milk *dangke*	Spontaneous fermentation with papaya sap as coagulant	52.70	2.30	15.90	21.30	7.80	[48]
Cow milk *dangke*	Spontaneous fermentation with papaya sap as coagulant	55.00	2.10	14.80	23.80	4.30	[48]
Cow milk *dangke*	Starter culture addition of *L. plantarum*	60.65	1.94	17.31	15.42	4.68	[76]
Cow milk *dangke*	Spontaneous fermentation with papaya sap as coagulant	41.82	2.57	5.53	0.52	49.56	[32]
Cow milk *dangke*	Spontaneous fermentation with vinegar acid as coagulant (0.5% w/v) and 2% salt	35.33	1.59	11.54	0.66	50.88	[32]
Cow milk *dangke*	Spontaneous fermentation with vinegar acid as coagulant (0.5% w/v) and 2% salt	35.82	1.44	5.06	0.47	57.21	[32]
Cow milk *dangke*	Spontaneous fermentation with vinegar acid as coagulant (0.5% w/v) and 2% salt	38.59	1.21	0.76	0.66	58.78	[32]

These components contribute to the creamy taste, dense texture, and custard-like consistency of *dangke* [50].

Mukhlisah et al. [29] conducted a study on the quality of cow's milk *dangke* produced at different heating temperatures (70, 80, and 90 °C) and papain concentrations (0.2%, 0.3%, and 0.4% w/v). The results indicated that the protein content of cow's milk *dangke* was significantly influenced by the processing temperature, while both the protein and carbohydrate contents were substantially affected by the papain concentration. The optimal quality of *dangke* was achieved when the milk was heated to 80 °C with 0.3% w/v papaya sap concentration, resulting in a product with 58.75% moisture, 16.86% protein, 15.19% fat, 2.31% ash, and 5.88% carbohydrate. The milk coagulation process in *dangke* production is notably influenced by the amount of papaya sap used, which serves as the source of the papain enzyme [29]. In contrast, Malaka et al. [51] found that the highest quality *dangke* was produced when the milk was heated to 75 °C with a 0.5% w/v papaya sap concentration. This treatment resulted in *dangke* with 17.94% protein, 24.29% fat, and 14.12% lactose. Similarly, Sulmiyati and Malaka [8] discovered that diluting crude papain at a 1:10 ratio with a 1% v/v concentration produced optimal results in cow's milk *dangke*, yielding 13.08% *dangke* and 86.92% whey.

Research on alternative coagulants for *dangke* production has also been conducted. The type of coagulant used significantly influences the nutritional properties of cow's milk *dangke* [32, 33]. Sukasri et al. [32] investigated the use of vinegar as a coagulant in cow's milk *dangke* production. Their findings showed that using 0.5% v/v vinegar and 2% salt resulted in *dangke* with higher nutritional value, containing 0.66% protein and 11.54% fat, compared to *dangke* produced with papaya sap as the coagulant, which had 0.52% protein and 5.53% fat. However, the application of vinegar as a coagulant reduced the organoleptic quality of the *dangke* compared to the use of papaya sap. Fermentation conditions also play a crucial role in determining the nutritional characteristics of *dangke*. Several starter cultures, such as *L. plantarum* and *L. lactis*, have been used to enhance the quality of *dangke* [21, 34]. The addition of *L. plantarum* IIA-1A5 notably affected the protein, fat, and carbohydrate content of *dangke*. *Dangke* inoculated with 5% *L. plantarum* IIA-1A5 exhibited higher protein content and lower fat content compared to *dangke* without starter culture [21]. Furthermore, Malaka et al. [34] investigated the effect of ripening time (0, 3, and 6 days at 5 °C) on *dangke* inoculated with a 1% *L. lactis* starter culture. Their results demonstrated that ripening time significantly influenced the nutritional profile of *dangke*. Specifically, longer ripening periods led to reductions in moisture, fat, and carbohydrate content, while protein content increased. These findings highlight the importance of fermentation and ripening conditions in determining the nutritional quality of *dangke*. Therefore, establishing standardized methods for *dangke* production is essential to ensure consistent product quality.

Dangke contains various free amino acids (Table 3), which are released through enzymatic protein hydrolysis by microbial proteases during fermentation. In buffalo milk *dangke*, the total free amino acid content was 15.6%. However, fermentation with 5% and 10% *Lactobacillus plantarum* IIA-1A5 significantly reduced it to 13.3% and 9.64%, respectively ($p < 0.05$), suggesting that higher starter concentrations inhibit free amino acid release. A similar trend was observed in essential amino acids, with buffalo milk *dangke* containing 7.31%, which significantly decreased to 6.35% and 4.61% in samples fermented with 5% and 10% *L. plantarum* IIA-1A5, respectively ($p < 0.05$) (Table 3). Despite this reduction, starter culture addition may have promoted bioactive peptide formation [52]. The proteolytic activity of *L. plantarum* likely facilitated the production of functional peptides commonly found in fermented dairy products [53], enhancing *dangke*'s nutritional and functional value beyond free amino acids alone. Comparatively, cottage cheese had a significantly higher total free amino acid content (68.0%) and essential amino acids (41.9%) than any *dangke* sample. Glutamic acid was the most abundant amino acid, followed by leucine, lysine, and aspartic acid. Notably, umami-related glutamic and aspartic acids accounted for ~ 31% of total amino acids in all samples. In contrast, cottage cheese exhibited markedly higher aspartic acid levels (7.6%) (Table 3). A similar predominance of umami amino acids has been reported in other fermented dairy products [54]. These umami amino acids likely enhance the savory taste and overall sensory properties of *dangke*.

The fatty acid composition of *dangke*, as shown in Table 4, demonstrates significant variations influenced by the addition and concentration of the *Lactobacillus plantarum* IIA-1A5 starter culture. In *dangke* without a starter, elaidic acid (C18:1) is the predominant fatty acid, whereas in starter-inoculated *dangke*, stearic acid (C18:0) becomes the most abundant, reflecting changes induced by microbial fermentation. Despite these changes, short-chain fatty acids (SCFAs), such as butyric acid (C4:0) and caproic acid (C6:0), which contribute milk- or cheese-like aromas, remain stable across treatments ($p > 0.05$) (Table 4). Notably, the increased stearic acid content in inoculated *dangke* enhances its buttery flavor and dense texture, underscoring the starter's role in shaping sensory attributes. Additionally, the introduction of the starter significantly ($p < 0.05$) reduces the total fatty acid content, likely due to microbial metabolism converting fatty acids into secondary metabolites, including volatile

Table 3 The free amino acids composition of *dangke*

Amino acids (%)	Buffalo milk *dangke*	Buffalo milk *dangke* inoculated with 5% *L. plantarum* IIA-1A5	Buffalo milk *dangke* inoculated with 10% *L. plantarum* IIA-1A5
Essential amino acids (EAA)			
His	0.51	0.54	0.52
Ile	0.90	0.75	0.53
Leu	1.66	1.40	0.98
Lys	1.30	1.14	0.83
Met	0.40	0.35	0.25
Phe	0.84	0.73	0.51
Thr	0.68	0.60	0.43
Val	1.02	0.84	0.56
Total EAA	**7.31**	**6.35**	**4.61**
Non-essential amino acids (NEAA)			
Asp	1.14	0.95	0.69
Glu	3.94	3.28	2.32
Ala	0.51	0.43	0.31
Gly	0.31	0.27	0.19
Ser	0.87	0.75	0.54
Tyr	0.88	0.74	0.53
Arg	0.59	0.54	0.45
Total NEAA	**8.24**	**6.96**	**5.03**
Total amino acids	**15.55**	**13.31**	**9.64**
References	[21]	[21]	[21]

Bold text represents: Essential amino acids, which consist of eight types. Non-essential amino acids, which consist of seven types. Total amino acids, which is the sum of essential and non-essential amino acids

compounds that influence aroma and flavor [55]. Beyond fatty acid composition, *dangke* also contains bioactive volatile compounds such as ascorbic acid, provitamin D, squalene, cholesterol acetate, and tributin, all of which are associated with potential health benefits [5].

Table 4 The fatty acids composition of *dangke*

Fatty acids (%)	Buffalo milk *dangke*	Buffalo milk *dangke* inoculated with 5% *L. plantarum* IIA-1A5	Buffalo milk *dangke* inoculated with 10% *L. plantarum* IIA-1A5
Butyric acid (C4:0)	0.88	0.89	0.86
Caproic acid (C6:0)	0.56	0.50	0.48
Caprylic acid (C8:0)	1.20	1.14	1.07
Undecanoic acid (C11:0)	0.71	0.70	0.65
Tridecanoic acid (C13:0)	4.38	4.10	3.94
Myristic acid (C14:0)	1.50	1.46	1.43
Myristoleic acid (C14:1)	1.50	1.46	1.43
Cis-10-pentadecanoic acid (C15:1)	7.05	6.51	6.30
Palmitic acid (C16:0)	4.54	4.59	4.34
Palmitoleic acid (C16:1)	0.87	0.87	0.82
Cis-10-heptadecanoic acid (C17:1)	5.11	4.69	4.60
Stearic acid (C18:0)	6.79	8.24	7.96
Elaidic acid (C18:1)	7.63	7.40	7.03
Linolelaidic acid (C18:2)	0.57	0.61	0.54
Cis-11-Eicosenoic acid (C20:1)	0.33	0.39	0.36
References	[21]	[21]	[21]

Safety aspects and improving shelf-life of *dangke*

Dangke is predominantly produced at the household industry level using traditional methods. The production process is often characterized by minimal adherence to hygienic and sanitary practices due to limited knowledge within the local community [7]. The proper application of hygiene and sanitation protocols during *dangke* production is essential for ensuring its safety and potential health benefits [22, 23, 38]. Conversely, neglecting these practices heightens the risk of contamination by pathogenic microorganisms, which may compromise both the quality of the product and consumer safety. Such contamination poses a considerable public health risk, particularly since *dangke* serves as a food for the Enrekang community, both within the region and among those living outside it. For Enrekang residents residing in other regions, *dangke* remains a highly valued product, frequently ordered directly from its source or brought back as a traditional gift during visits. This extensive distribution increases the potential for foodborne illnesses, as contaminated *dangke* could lead to health issues not only within the local population but also in broader geographic areas [12].

The susceptibility of *dangke* to microbial contamination is influenced by several factors, including its high nutritional value, high moisture content, and normal pH, all of which provide optimal growth conditions for microorganisms [21]. Furthermore, the limited skills and knowledge of the workforce involved in *dangke* production contribute to an insufficient understanding of effective food processing technologies. A study conducted by Hatta et al. [9] on sanitation and hygiene practices among 60 respondents, who are both producers and workers in the *dangke* processing industry in Enrekang Regency, revealed that these practices are not fully implemented. Workers lacked proper attire, with over 50% not wearing head coverings while preparing *dangke*. Instances of inadequate handwashing before processing were observed in 20% of workers, and all workers frequently handled *dangke* while engaged in household tasks. The use of unwashed coconut shells as molds was noted in 50% of cases, with these molds stored in open spaces. Additionally, 25% of workers utilized unwashed banana leaves for wrapping materials. In terms of raw material handling, fresh milk was occasionally stored in open containers (42%), papaya sap was collected from unclean papayas (32%), and *dangke* was left uncovered during draining and molding (48%) [9].

The contamination of *dangke* by pathogenic bacteria may lead to health concerns for consumers, including the risk of foodborne infections and poisoning. The *E. coli* and *Salmonella spp*. are common foodborne bacteria that frequently contaminate dairy products. *E. coli* is typically part of the normal microflora in the gastrointestinal tract of humans and warm-blooded animals, but some strains are pathogenic and responsible for diseases in humans. Several serotypes of *E. coli* are associated with both mild and severe diarrhea, particularly affecting children and adults in developing countries. The *Salmonella spp.* genus has been recognized as a pathogen responsible for several foodborne outbreaks, including cases in France associated with dairy products [56]. Hatta et al. [12] reported that in a study involving 30 randomly selected cow dairy processing businesses producing *dangke* in Enrekang Regency, contamination levels of *E. coli* were identified at 73% in the *dangke*, 40% on workers' hands, 63% in molds (coconut shells), and 40% in packaging materials (banana leaves). Furthermore, *Salmonella spp.* was detected in 7% of the *dangke* samples and in 3% of the molds. In another study conducted by Zakariah et al. [35], the contamination levels of *E. coli*, *Salmonella spp.*, *Bacillus cereus*, and *Staphylococcus aureus* in *dangke* were also evaluated. The microbiological assessments revealed no presence of *Staphylococcus aureus*, *Bacillus cereus*, and *Salmonella spp.* However, the most probable number (MPN) of coliforms and *E. coli* was 1,100 MPN/100 g, indicating significant microbial contamination.

The production of *dangke* involves several interconnected stages, each of which carries the risk of pathogenic bacterial contamination if *good manufacturing practices* (GMP) are not properly followed. For example, heating fresh milk at 70 °C for 20 min is generally believed to be effective in killing pathogenic microorganisms. However, contamination can still occur before and after this step, potentially compromising both the final product and its packaging. Workers handling the product during production also pose a risk, as direct contact with the cheese can introduce contaminants. In particular, the transfer of fecal microbes from humans or animals through workers' hands is a significant food safety concern. Therefore, maintaining proper hand hygiene is crucial to prevent microbial contamination and ensure the safety of the final product. Additionally, ensuring that all tools and equipment used after processing are clean is vital. Post-processing contamination may also result from unhygienic handling of coconut shells used as molds or banana leaves used as packaging. Moreover, it is important to avoid storing *dangke* in open conditions, as this can promote the growth of spoilage and pathogenic microorganisms. To mitigate microbial contamination, consumers often pour hot water over *dangke* or grill or fry it. This not only enhances the flavor and aroma, but also helps limit the growth of harmful microbes, ensuring the product is safer for consumption [47].

Dangke has a relatively short shelf-life of approximately six hours at ambient temperature [29]. Other studies indicate that *dangke* can be stored for up to two days at room temperature (27–30 °C), and 5–7 days when refrigerated at 4 °C [12]. This short shelf-life is attributed to the fact that *dangke* is derived from fresh milk, which contains various nutrients that promote bacterial growth [17]. Several factors influence the quality, microstructure, and shelf-life of *dangke*, including heating temperature [29], enzyme concentration [29], ripening [16], and coating [57, 58]. Mukhlisah et al. [29] reported that the most desirable characteristics of *dangke*, in terms of chemical, physical, and microbiological properties, as well as hedonic evaluation, were achieved at a heating temperature of 80 °C and a papain concentration of 0.3%. Because the local population consumes *dangke* daily, preservation methods were not initially a concern, as it was typically consumed immediately after production. However, demand has increased due to the growing number of local residents traveling to and from the region, highlighting the need for preservation strategies to extend its shelf-life [17]. As a result, several preservation methods have been explored to extend the storage period of *dangke.*

Chemicals are commonly used as preservatives to extend the shelf-life of *dangke*. However, growing concerns about health risks associated with synthetic additives have led to a preference for preservatives that are generally recognized as safe (GRAS). This has spurred interest in natural preservatives, such as lactoferrin. Marfiyanti et al. [19] investigated the microbial population and pH level of *dangke* after it was immersed in a lactoferrin enzyme solution. Lactoferrin is a natural antimicrobial agent known for its ability to inhibit microbial growth, primarily due to its glycoprotein-703 component, which effectively binds iron, depriving microbes of this essential nutrient [59]. After a 6-h observation period at room temperature, the results showed that the microbial count in the *dangke* soaked in the lactoferrin solution was significantly lower compared to the control group, which had been soaked in phosphate buffer solution [19]. In a separate study, Rasbawati et al. [17] assessed the microbial count and pH of *dangke* soaked for one hour in various solutions, including distilled water, phosphate buffer, whey, lactoferrin, lactoperoxidase, and a combination of lactoferrin and lactoperoxidase. Lactoperoxidase is a glycoprotein consisting of 608 amino acids with a molecular mass of 78 kDa, and it is naturally found in humans, animals, and plants [60]. When combined with thiocyanate and hydrogen peroxide, lactoperoxidase forms a natural antimicrobial system known as the lactoperoxidase system [61]. Rasbawati et al. [17] observed that after 12 h of storage at ambient temperature, the lactoperoxidase system significantly reduced the microbial count of *dangke* from 6.59 log CFU/mL to 5.95 log CFU/mL, while other treatment solutions showed no significant antimicrobial effects. The pH of the *dangke* remained stable when preserved with the lactoferrin and lactoperoxidase system. Furthermore, the total microbial count in *dangke* was significantly reduced from 7.78 to 5.30 log CFU/mL after 8 h of room temperature storage by the lactoperoxidase system and lysozyme preservation solutions [18]. Lysozyme is a hydrophilic protein widely used as a natural preservative. It is naturally found in egg whites and milk. Lysozyme exerts its antimicrobial action by hydrolyzing the 1,4-β-linkages between N-acetylmuramic acid and N-acetylglucosamine in the peptidoglycan layer of bacterial cell walls. Gram-positive bacteria are particularly susceptible to lysozyme due to the presence of peptidoglycan, which is a key component of their cell walls [62]. Given that both preservatives can be classified as safe, their application in *dangke* may provide an alternative method for its preparation.

The implementation of edible coatings and ripening techniques has been conducted to prolong the shelf-life of *dangke.* The coating is primarily designed to prevent the formation of a hard outer layer and to inhibit evaporation, particularly for cheeses that will be stored for extended periods [63]. Various edible coatings, including agar, CMC, and beeswax, were applied to *dangke* in multiple ripening durations (10, 20, and 30 days) to assess its quality. The findings demonstrated that employing an edible coating with prolonged ripening duration at refrigeration temperature can prolong shelf-life, enhance hardness, and yield a denser microstructure [58]**.** An edible film coating for *dangke*, composed of whey and konjac flour, was also observed. The findings indicated that a whey-based edible coating containing 1.5% konjac flour is the optimal formulation according to the criteria of gelation time, thickness, extensibility, tensile strength, and water vapor transmission rate (WVTR). *Dangke* that was coated with this edible coating was more durable (20 days) than *dangke* that was not coated (10 days) at a refrigerator temperature of 5 °C [57]**.** Malaka et al. [16] evaluated the shelf-life of *dangke* ripened with *L. lactis* using three different packaging methods: aluminum foil, vacuum-sealed plastic, and traditional banana leaves. The results showed that *dangke* inoculated with *L. lactis* and packaged in banana leaves or vacuum-sealed plastic maintained optimal physical quality when stored at refrigeration temperature, remaining intact for up to 15 days. In contrast, storage at room temperature led to a significant decline in quality. Although freezing maintained the physical quality for up to 15 days, consumer preference declined because of changes in texture. Additionally, coating *dangke* with beeswax during ripening with *L. lactis* extended its shelf-life to over 60 days when stored at 5 °C. However, when stored at room temperature (28 °C), the quality began to deteriorate after 10 days. Freezing at −12 °C maintained its quality for up to 60 days, but the product was still less favored by consumers. Zakariah et al. [64] compared the effects of banana leaf and plastic packaging on microbial contamination in *dangke*, finding that banana leaf packaging resulted in lower coliform counts (2×10^9 MPN/g) than plastic packaging (2.4×10^9 MPN/g) after one week of storage. Both packaging materials showed the same level of *E. coli* (3 MPN/g), which exceeds the national maximum microbial standards for cheese products. As a result, *dangke* could not be consumed after 7 days of storage due to microbial contamination. In a separate study, Mansur et al. [65] found that *dangke* packaged in aluminum foil and stored for 2 days remained suitable for consumption.

Functional properties of *dangke* for health

Several studies have revealed the functional properties of *dangke* and its products, including antimicrobial [20], antioxidant [21], antihypertensive [21], antihyperglycemic [23], anti-hypercholesterolemic [24], and potential improvements in anemia [66], which can be seen in Table 5. The presence of a high amount of viable LAB (10^7–10^8 CFU/mL) in *dangke* [21], promotes *dangke* as a promising probiotic and influences its functional properties [38, 67, 68]. Djide et al. [20] have successfully isolated two LAB strains from *dangke* made from cow and buffalo milk, identified as *Weisella confusa* strain JCM 1093 and *L. fermentum* strain NBRC 15885. The crude bacteriocin synthesized by *Lactobacillus fermentum* NBRC 15,885 from buffalo milk *dangke* displayed selective antimicrobial activity against *Staphylococcus aureus*, with an inhibitory zone of 11.34 mm after 24 h of incubation at 37 °C. This activity was classified as intermediate when compared to ampicillin, which exhibited a zone of 40.49 mm. The bactericidal effect was also confirmed by the persistence of a clear zone following re-incubation. The proposed mechanisms of action for the bacteriocin include the formation of ion channels in the cytoplasmic membrane, nuclease activity, and interactions with amphipathic peptides, leading to ion leakage and cell death [20]. Moreover, *dangke* whey (by-product of *dangke* production) fermented with 3% v/v *L. plantarum* FNCC 0047 exhibits antimicrobial properties against *S. aureus* and *E. coli*, with inhibition diameters of approximately 13 mm and 25 mm, respectively [69].

Table 5 The functional properties of *dangke*

Functional properties	Method of analysis	Result	References
Antimicrobial	In vitro	Two LAB strains, *Weisella confusa* JCM 1093 and *L.fermentum* NBRC 15885, isolated from *dangke* made of cow and buffalo milk, produced a crude bacteriocin, with *L. fermentum* NBRC 15885 exhibiting antimicrobial activity against *Staphylococcus aureus*	[20]
Antimicrobial	In vitro	Antimicrobial activity against *S. aureus* and *E. coli* was detected in *dangke* whey, a byproduct of *dangke* production that was fermented with 3% v/v *L. plantarum* FNCC 0047	[69]
Antimicrobial	In vivo	Synbiotics from *dangke* lactic acid bacteria and Dahlia tuber inulin improved mice performance and reduced diarrhea by inhibiting *E. coli* (EPEC) proliferation and adhesion	[70]
Antioxidant	In vitro	*Dangke* showed high antioxidant activity by the FRAP method, which increased with the addition of 5–10% v/v *L. plantarum* IIA-1A5 as a culture starter	[21]
Antihypertensive	In vitro	*Dangke* exhibited moderate ACE inhibitory activity, which increased with the addition of 5–10% v/v *L. plantarum* IIA-1A5 as a culture starter, potentially offering benefits in hypertension management	[21]
Antihyperglycemic	In vivo	*Dangke* consumption for 14 days at doses of 0.5 g or 1.5 g improved glycemic control by reducing fasting blood glucose levels in rats treated with propylthiouracil, in combination with a high-fat diet and dextrose	[23]
Anti-hypercholesterolemic	In vitro	LAB isolated from *dangke*, including *L. fermentum* B111K and *L. plantarum* IIA-1A5, have cholesterol-lowering effects by assimilating cholesterol, with *L. plantarum* IIA-1A5 also possessing the bile salt hydrolase (BSH) gene and exhibiting BSH activity	[24]
Anti-hypercholesterolemic	In vivo	The administration of 50% whey *dangke* in drinking water for 15 days for broiler chickens has been reported to reduce cholesterol, lipoprotein, and triglyceride levels in the blood of broiler chickens by up to 15%	[8]
Antianaemia	In vivo	Consumption of *dangke* crackers, with 90 packs (100 g each) provided over 12 weeks along with blood-enriching tablets, significantly increased hemoglobin levels in second-trimester pregnant women with anemia compared o the control group receiving only the tablets	[66]
Anti dental caries	In vivo	Consuming 50 g of *dangke* twice a day for 7 days had a significant impact on preventing dental caries by increasing calcium and phosphate levels in saliva, promoting remineralization by reducing enamel microporosity, and decreasing the number of bacteria in dental plaque	[73]

Lactobacillus fermentum, isolated from *dangke*, exhibited survival in 0.3% bile salts and resistance to acidic conditions as low as pH 2 [68]. A study conducted by Djide et al. [67] further confirmed these findings, showing that *L. fermentum* strain NBRC 15885, isolated from *dangke*, exhibited tolerance to extreme acidity (pH 2) and bile salts (0.3%), as well as susceptibility to four types of antibiotics (ampicillin, cefotaxime, erythromycin, and tetracycline), suggesting its potential as a probiotic capable of inhibiting the growth of pathogenic bacteria in the digestive tract. The effect of synbiotics, derived from *Lactobacillus* strains in *dangke* and inulin from Dahlia tubers, on mice infected with enteropathogenic *Escherichia coli* (EPEC) was also investigated. The results demonstrated that the synbiotics enhanced the mice's performance and increased their resistance to EPEC infection. Specifically, the synbiotics reduced the duration of diarrhea by inhibiting the proliferation and adhesion of EPEC in the mice's intestines [70].

Other studies have shown that *dangke* exhibits remarkable antioxidant capacity and ACE inhibitory activity, which are significantly enhanced when *dangke* is supplemented with the probiotic *Lactobacillus plantarum* IIA-1A5 [21]. These beneficial characteristics may be attributed to the activity of functional microorganisms that break down milk proteins during fermentation, resulting in the production of bioactive peptides with functional properties, such as antioxidant activity and antihypertensive effects via angiotensin-converting enzyme (ACE) inhibition. In addition to these properties, Sasmita et al. [23] investigated the potential of fermented *dangke* to enhance glycemic control in hyperglycemic rats. The rats were fed *dangke* for an additional 14 days, along with a high-fat diet and dextrose. The results indicated that fasting blood glucose levels in the hyperglycemic rats were reduced by approximately 21% and 29% compared to the placebo group when *dangke* was consumed at doses of 0.5 g and 1.5 g per 200 g of body weight, respectively [23]. A study by Burhan et al. [24] reported the potential of LAB isolated from *dangke* as hypocholesterolaemic agent. The LAB strains demonstrating a cholesterol-lowering effect were *L. fermentum* B111K and *L. plantarum* IIA-1A5. The *L. fermentum* B111K demonstrated the capacity to assimilate cholesterol, whereas *L. plantarum* IIA-1A5 possessed the bile salt hydrolase (BSH) gene, exhibited BSH activity, and also displayed cholesterol assimilation [24]. LAB can influence serum cholesterol levels through direct binding to dietary cholesterol or by deconjugating bile salts. Bile salt hydrolase activity may facilitate cholesterol reduction, as free bile salts (deconjugated) exhibit lower intestinal re-absorption compared to conjugated bile salts, potentially leading to increased fecal excretion [71]. The addition of *dangke* whey in drinking water at a concentration of 50% for 15 days has also been reported to reduce cholesterol, lipoproteins, and triglyceride levels in the blood of broiler chickens [8].

It has also been reported that various food products derived from *dangke* offer health benefits. Riyandani et al. [66] reported that providing 90 packs of *dangke* crackers (each containing 100 g) for 12 weeks, along with blood-enriching tablets, could increase hemoglobin levels in second-trimester pregnant women suffering from anemia, compared to the control group, which was only given blood-enriching tablets. The consumption of *dangke* crackers is believed to support the body's nutritional needs while enhancing the metabolism of pregnant women, which in turn improves body function and appetite, leading to increased food intake. In another study, *dangke* chips were administered to children aged 3–5 years for 4 weeks, resulting in improvements in their nutritional status, as indicated by weight-for-age and height-for-age metrics [72]. Consuming 50 g of *dangke* twice a day for 7 days was also found to significantly help prevent dental caries. This effect was achieved by increasing calcium and phosphate levels in saliva, supporting remineralization by reducing enamel microporosity, and lowering the number of oral bacteria in dental plaque, including *Streptococcus pneumoniae*, *Streptococcus aureus*, and *Streptococcus* sp. [73].

Challenges and future prospects of *dangke*

The production and development of *dangke* face numerous challenges that significantly constrain its growth potential, with limited production capacity being a primary obstacle. *Dangke* is typically produced in small quantities by local farmers, mainly at the household level or within small-scale industries. These producers rely heavily on limited resources and the traditional skills of the local community [36]. One of the key challenges in *dangke* production is the limited availability of raw milk, particularly buffalo milk. *Dangke* is predominantly made from buffalo or cow milk sourced locally. According to Hatta et al. [9], the buffalo population in Enrekang Regency was 2156 in 2011, surpassing the number of dairy cows, which stood at 1065. However, buffaloes in the region are primarily used as draft animals rather than for milk production. This is reflected in the average buffalo milk production in Enrekang, which is only 1.5 L per head per day, relatively low compared to the average production of *Murrah* buffaloes in Indonesia, which yields around 5 L per head per day. In contrast, the average milk production from dairy cows is substantially higher, at 11.8 L per head per day [9]. The limited availability of raw milk directly impacts *dangke* production, as home-based industries produce only an average of 173 units per month [36]. The reliance on a limited local milk supply significantly affects *dangke* production, restricting its availability and scalability. Despite these challenges, there are promising opportunities for *dangke* development. Improving milk production through better livestock management, breeding programs, and feed quality optimization could help address raw material limitations. Moreover, strengthening farmer cooperatives could improve milk collection systems, enabling more efficient distribution and reducing losses. Encouraging collaborations between dairy farmers and *dangke* producers may also help stabilize milk supply, ensuring more consistent raw material availability for production. Strengthening these aspects would not only address the key limiting factors but also position *dangke* as a distinctive traditional cheese with broader economic and cultural significance.

Traditional *dangke* production, which involves spontaneous fermentation, often results in products with inconsistent quality and fails to meet hygiene and food safety standards, thereby posing additional challenges. Hatta et al. [9] reported that sanitation and hygiene practices are not fully implemented in *dangke* processing businesses in Enrekang Regency. The hygiene and sanitation conditions of workers, processing equipment, raw materials, and finished products were found to be inadequate, with 40% classified as "poor." These deficiencies in sanitation and hygiene practices are primarily attributed to insufficient dissemination of government regulations on proper food production methods, along with weak guidance, oversight, and suboptimal evaluation by relevant authoritie [9]. These shortcomings contribute significantly to microbial contamination, including the presence of pathogenic bacteria. Hatta et al. [12] found that *E. coli* contamination was detected in 73% of *dangke* samples, 40% of workers' hands, 63% of molds, and 40% of packaging materials, based on an investigation of 30 *dangke* processing businesses. Additionally, *Salmonella spp.* was detected in 7% of *dangke* samples and 3% of molds. To address these issues, the implementation of Good Manufacturing Practices (GMP) is crucial. This would involve establishing sanitation protocols, hygiene standards, and proper training for workers. Furthermore, the adoption of the Hazard Analysis Critical Control Point (HACCP) system can provide a more structured approach to food safety by identifying critical control points in the production process. This involves systematically evaluating all stages of production, including raw material selection, fermentation conditions (such as temperature and time), and packaging processes. Together, GMP and HACCP can help standardize *dangke* production and improve both its safety and quality.

Despite its local popularity, *dangke* has yet to achieve significant recognition outside South Sulawesi. The limited reach of *dangke* in broader markets can be attributed to the absence of strategic marketing and branding initiatives, which has hindered its visibility beyond the local context. Furthermore, *dangke*'s relatively short shelf-life presents a substantial challenge to its commercialization in regions outside its production area. Although various preservation methods have been explored to extend its shelf-life, none have proven sufficiently effective to facilitate its wider market distribution. Therefore, it is imperative to adopt innovative preservation technologies, such as advanced packaging solutions and efficient storage techniques. These innovations could not only enhance the shelf-life of *dangke* but also ensure that its quality is preserved throughout the distribution chain. Additionally, the current packaging of *dangke*, which tends to be simplistic, may not appeal to contemporary consumers who prioritize premium, visually appealing packaging. Although traditional *dangke* production methods are an important cultural heritage, it is essential to adopt modern cheese-making techniques and upgrade the technical skills of local producers, all while preserving the product's authenticity.

Dangke possesses favorable prospects due to the growing consumer interest in traditional foods that are nutritious, health-promoting, and authentic. The preservation and promotion of *dangke* as a fundamental aspect of local identity can enhance its value as a cultural asset, thereby attracting tourists and increasing market demand. Participation in national food festivals will enhance the presence of *dangke* beyond South Sulawesi, simultaneously showcasing its unique characteristics to a broader audience. The potential for agrotourism in South Sulawesi, where visitors can experience traditional *dangke* cheese while touring a dairy farm, might generate new economic opportunities and enhance the local tourism sector. Given the growing trend of healthy food consumption, there is potential to develop *dangke* into more varied processed products, including ready-to-eat cheese and snacks. Several studies have been undertaken to innovate *dangke*, including the production of *dangke* chips and *dangke* nuggets [74], in order to increase the added value of the product and support the community's economy through the creative economy. By integrating traditional values with relevant innovation, *dangke* can emerge as a distinctive flagship product that not only stimulates economic growth but also fosters cultural pride in the region.

Conclusion

Dangke, a traditional dairy product from Enrekang, reflects unique cultural importance and potential health advantages, making it an interesting topic for further scientific investigation and commercialization. Despite its resemblance to soft cheese, *dangke* is distinct in its production process, particularly the use of papain from papaya sap as a coagulant, contrasting with the rennin used in conventional cheese-making. Furthermore, the indigenous microorganisms, including LAB and yeasts, contribute to its distinctive flavor and potential probiotic properties. Recent studies indicate that *dangke* possesses potential health benefits, including antimicrobial, antioxidant, antihypertensive, and anti-hyperglycemic properties, as well as improvements in anemia, primarily attributed to its probiotic LAB. However, the production of *dangke* predominantly occurs at the household level, utilizing traditional methods and uncontrolled fermentation conditions, which present challenges to its consistency, quality, and safety. To guarantee the functional advantages and public health safety of *dangke*, it is essential to standardize and regulate fermentation processes, while prioritizing hygiene and appropriate handling practices. Moreover, to enhance its commercialization, the implementation of innovative preservation technologies, coupled with strategic marketing and branding that maintain the authenticity of *dangke*, is imperative. This review substantially enhances the existing knowledge on *dangke*, establishing a basis for future research and industrial applications focused on optimizing its production and broadening its market potential.

Abbreviations

CFU	Colony-forming units
FRAP	Ferric reducing antioxidant power
GMP	Good manufacturing practice
LAB	Lactic acid bacteria

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