Inclusion of Probiotics into Fermented Buffalo (Bubalus bubalis) Milk: An Overview of Challenges and Opportunities

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Abstract: Buffalo-milk-based dairy products provide various health benefits to humans since buffalo milk serves as a rich source of protein, fat, lactose, calcium, iron, phosphorus, vitamin A and natural antioxidants. Dairy products such as Meekiri, Dadih, Dadi and Lassie, which are derived from Artisanal fermentation of buffalo milk, have been consumed for many years. Probiotic potentials of indigenous microflora in fermented buffalo milk have been well documented. Incorporation of certain probiotics into the buffalo-milk-based dairy products conferred vital health benefits to the consumers, although is not a common practice. However, several challenges are associated with incorporating probiotics into buffalo-milk-based dairy products. The viability of probiotic bacteria can be reduced due to processing and environmental stress during storage. Further, incompatibility of probiotics with traditional starter cultures and high acidity of fermented dairy products may lead to poor viability of probiotics. The weak acidifying performance of probiotics may affect the organoleptic quality of fermented dairy products. Besides these challenges, several innovative technologies such as the use of microencapsulated probiotics, ultrasonication, the inclusion of prebiotics, use of appropriate packaging and optimal storage conditions have been reported, promising stability and viability of probiotics in buffalo-milk-based fermented dairy products.

Keywords: buffalo milk; artisanal fermentation; probiotics; fermented milk; ultrasound; prebiotics; microencapsulation

1. Introduction

Buffaloes are currently being farmed in many parts of the world and have been used for many years. In general, there are two types of buffaloes, i.e., African wild buffalo (Syncerus caffer) and Asian buffaloes (Bubalus) in the world, of which, Asian buffaloes are domesticated. The wild relative of domestic Asian water buffalo, Bubalus arnee, is currently classified as being endangered [1]. Bubalus arnee contributes to both types of domestic Asian water buffaloes, riverine type (Bubalus bubalis bubalis) and swamp type (Bubalus bubalis carabensis), which are classified by Macgregor [2] based on the morphological and behavioral criteria. However, the divergence of these two types of buffaloes had occurred well before the domestication [3].
At present, a population of 206.60 million buffalos is distributed in the world, with 97.4% of them being in Asia [4]. The riverine type is more common in India and Pakistan, while swamp type is more common in China, which is strongly based on the purpose of buffalo rearing. Buffaloes present in Sri Lanka phenotypically represent swamp type, while having 50 chromosomes showing genetic similarities to the riverine type [5]. Irrespective of the type, domestic Asian water buffalo is economically and culturally important livestock, predominantly in developing countries. Buffaloes are responsible for providing draught power for agricultural activities, meat and milk as food commodities, manure as a fertilizer, horn and leather [6–8]. Swamp-type buffaloes are mainly reared for draught power and meat, whereas riverine buffaloes are preliminary important as milk producers [8].

The Asian water buffalo is the second most important livestock in the world, which is responsible for milk production after cows. Buffalo milk provides many health benefits over cow milk and it serves as a crucial protein source for humans, especially in the developing world. Moreover, buffalo milk is rich in calcium, fat and lactose compared to cow milk [7,9]. Hence, buffalo milk provides more energy per unit volume of milk in comparison to cow milk [10]. Buffalo milk also a rich source of iron, phosphorus, vitamin A and natural antioxidant (tocopherol), whereas the content of cholesterol is comparatively lower than cow milk.

However, consumption of raw buffalo milk is not popular compared to that of cow milk and production of value-added buffalo milk products such as butter, ghee, yoghurt and cheese helps to increase the demand for buffalo milk and also to obtain the health benefits associated with buffalo milk [7,11]. Among them, products derived by artisanal fermentation of buffalo milk have been consumed since ancient times. In the global scenario, commonly available artisanal fermented buffalo milk-derived dairy products include Meekiri (Sri Lanka), Dadih (West Sumatra Indonesia), Dahi and related products (South East Asian countries) and Lassie (India) [12–14]. These fermented dairy products consist of indigenous microflora, i.e., Enterococcus faecium, Lactobacillus plantarum and Lactobacillus fermentum, and their probiotic potentials have been described previously [15–18]. This reflects the possibility of inclusion of additional probiotics into the fermented buffalo milk products enhancing the health benefits to consumers. Inclusion of probiotics into cow milk is well established and extensively researched. Since artisanal fermentation of buffalo milk is a common practice in Asian rural communities and fermented buffalo milk is an integral part of Asian cuisines, probiotic-enriched fermented buffalo milk products could have a higher potential in ensuring a healthy diet for the people in the developing world. Although it is not a common practice, the inclusion of probiotics into fermented buffalo milk has also been reported to a much lesser extent [12,19,20]. However, research findings on the inclusion of probiotics into artisanal fermentation of buffalo milk are scarce; thus, there is a lack of updated knowledge on the potential of developing probiotic-enriched fermented buffalo milk products. Moreover, processing technology for the inclusion of probiotics into the fermented cow milk products is often not suited for buffalo milk processing due to the differences in compositional, physicochemical and functional properties between two types of milk, which may result in undesirable quality parameters in the final product [10,11]. This review focuses on elaborating the potential for inclusion of probiotics into the fermented buffalo milk products and technical prospects to develop probiotic-enriched fermented buffalo milk products.

2. Buffalo Milk Production in the World

Global production of buffalo milk is steadily increasing according to (FAO) Food and Agriculture Organization/WHO [21]. Buffalo milk and its processed products are consumed around the world, in diverse forms, and the consumption is increasing with the improved understanding on nutritional benefits of buffalo milk, since it contains high amount of protein, iron, calcium and conjugated linolenic acid. Moreover, there is a potential of using buffalo milk as a cow-milk replacement for people with cow milk allergies [22]. The nutritional composition of buffalo milk depends on several factors, e.g., breed, season, climate, farm management practices, feeding, etc., of which shows a greater level of influences on the composition of buffalo milk than that of cow milk [23,24].
The domestication of buffalos has occurred more recently compared to the domestication of the cow (5000 and 10,000 years, respectively) [25]. Thus, domesticated Asian buffalos (Bubalus bubalis) is contributing the global buffalo milk production today, while the African Buffalo (Syncerus) remain in the wild [11]. The total buffalo milk production in the world is 127.34 million tons per year. Asia is the dominant buffalo milk producer, which accounts for 98.1% of global production, followed by 0.2% in Europe and 1.7% in Africa [4]. India is the largest and main buffalo milk producer in the world, where it produces more than half of the global produce, followed by Pakistan, China, Egypt, Nepal, Italy, Myanmar, Iran, Sri Lanka and Turkey, which are the other top-ten buffalo-milk producers in the world (Table 1).

### Table 1. Production statistics of whole fresh buffalo milk (tones) from the top twenty countries over the period of 2010–2018.

| Country   | 2010  | 2011  | 2012  | 2013  | 2014  | 2015  | 2016  | 2017  | 2018  |
|-----------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| India     | 62,350.00 | 65,352.00 | 67,675.43 | 70,442.62 | 74,709.90 | 76,459.00 | 81,266.30 | 86,261.68 | 91,817.14 |
| Pakistan  | 22,279.00 | 22,955.00 | 23,652.00 | 24,370.00 | 25,001.00 | 25,744.00 | 26,510.00 | 27,298.00 | 28,109.00 |
| China     | 3050.00  | 3050.00 | 3080.00 | 3050.00 | 3100.00 | 3005.20 | 3002.50 | 3002.50 | 3002.50 |
| Egypt     | 2653.24  | 2568.14 | 2564.64 | 2522.83 | 2923.03 | 2394.16 | 2334.29 | 2351.12 | 2120.37 |
| Nepal     | 1066.87  | 1109.33 | 1153.84 | 1188.43 | 1167.77 | 1167.15 | 1210.44 | 1210.44 | 1210.44 |
| Italy     | 177.46   | 192.54  | 192.46  | 194.89  | 292.00  | 2394.16 | 2334.29 | 2351.12 | 2120.37 |
| Myanmar   | 302.97   | 305.63  | 171.18  | 175.53  | 179.75  | 184.14  | 188.49  | 192.13  | 193.84  |
| Iran      | 215.25   | 222.43  | 120.22  | 125.00  | 126.00  | 113.91  | 133.56  | 145.77  | 129.90  |
| Sri Lanka | 46.99    | 46.33   | 61.71   | 54.06   | 45.85   | 36.12   | 66.13   | 68.59   | 85.91   |
| Turkey    | 35.49    | 40.37   | 46.99   | 51.95   | 54.80   | 62.76   | 63.09   | 69.40   | 75.74   |
| Indonesia | 129.01   | 93.37   | 100.55  | 82.62   | 95.83   | 96.51   | 96.99   | 99.17   | 71.17   |
| Iraq      | 64.54    | 27.21   | 67.62   | 43.25   | 30.72   | 31.59   | 33.35   | 33.35   | 49.89   |
| Bangladesh| 36.00    | 37.20   | 38.00   | 39.00   | 35.17   | 35.30   | 35.56   | 35.69   | 35.69   |
| Viet Nam  | 31.65    | 31.66   | 32.00   | 31.00   | 28.09   | 28.12   | 28.10   | 27.92   | 27.46   |
| Bulgaria  | 7.93     | 8.87    | 8.08    | 8.73    | 8.87    | 9.47    | 9.48    | 10.38   | 11.75   |
| Malaysia  | 9.20     | 9.50    | 8.90    | 9.00    | 8.34    | 8.22    | 8.25    | 8.26    | 8.19    |
| Syria     | 6.00     | 6.00    | 6.22    | 6.58    | 6.31    | 6.30    | 6.30    | 6.30    | 6.30    |
| Georgia   | 6.00     | 6.00    | 6.00    | 6.10    | 6.43    | 6.43    | 6.43    | 6.29    | 6.17    |
| Greece    | 0.11     | 0.15    | 0.39    | 0.45    | 0.27    | 0.53    | 3.03    | 2.89    | 0.40    |
| Bhutan    | 0.22     | 0.39    | 0.35    | 0.22    | 0.30    | 0.30    | 0.28    | 0.29    | 0.28    |

Data source: (FAO, 2018 [4]) Values are indicated in tons (×10³).

Buffalos play a pivotal role in livestock in countries where primary agricultural production is prominent, mainly because of their good adaptation and suitability for low-input systems (e.g., can thrive well in harsh conditions, consume low-quality roughages and provide draft power) in addition to their extensive uses of milk, meat and manure [9,26,27]. Buffalo milk is used to produce various dairy products. Production of butter from buffalo milk (0.89 million tons in 2014) is mainly (90.1%) reported in Asia (India) and the rest is in Africa (Egypt), whereas the production of Ghee from buffalo milk is only performed in Asia (India and Pakistan). However, the production of buffalo milk cheese (0.28 million tons in 2014) is predominant in Egypt (90%), Italy (5.6%) and China (4.4%) [28]. However, interpretations must be cautious concerning the buffalo milk production and processing in Asia, since often production is underreported due to the prevalence of small-scale rural family-level farms, who produce mainly for their consumption [11].

Two common subspecies of Asian buffalos, namely river and swamp types differ in their number of chromosomes (50 vs. 48, respectively) [27]. River buffalos primarily prefer clear water, while the swamp buffalos usually inhabit marshy lands. Among these two types, river buffalos are primarily reared for milk production, whereas the Swamp buffalos are primarily used for draught power in agricultural works [25]. Several popular buffalo breeds are commonly present in today’s production systems; Murrah, Nili-Ravi, Mehsana, Surti and Jafarabadi are a few common examples [29].
The composition and properties of buffalo milk are varying from the bovine milk, mainly due to the differences in constituents, properties of casein micelles, mineral concentration (Table 2) and therefore, the functionality of buffalo milk is unique. Particularly rennet induced coagulation properties (e.g., coagulation time, gel strength and moisture retention) are significantly different from bovine milk because of differences in composition and properties. However, these rheological properties and curd characteristics of fermented buffalo milk gels are not well defined and studied. In most cases, buffalo milk composition is based on milk of Murrah buffaloes, of which not significantly different from the rest.

| Constituents/Components | Buffalo Milk | Cow Milk | References |
|-------------------------|--------------|----------|------------|
| Fat (%)                 | 6.7          | 3.7      | [30]       |
| Total protein (%)       | 4.7          | 3.5      | [30]       |
| Calcium (mg/100 mL)     | 205.0        | 115.0    | [30]       |
| Water (%)               | 83.2         | 87.2     | [30]       |
| Total solids (%)        | 16.3         | 12.8     | [30]       |
| Folate (µg/L)           | 60.0         | 44.0     | [31]       |
| Size of the casein micelle (nm) | 110–160 | 70–110 | [30] |

Buffalo milk is a rich source of lactose, fat, protein, total solids, calcium and folate compared to that of bovine milk [30–32]. Thus, buffalo milk perceived to be thicker than cow milk.

Because of shortage in yellowish pigments carotene, relatively more whiteness can be seen in buffalo milk than that of cow milk, which is often used in visually differentiating these two types of milk. However, the levels of vitamin A is identical in both milk types, despite the absence of precursor, which comes with the feed since buffalo convert carotene to vitamin A [33]. The increased level of folate in buffalo milk is partly explained because buffalo milk contains more lactic acid bacteria (LAB) compared to cow milk [34], which can potentially generate folate. Furthermore, Lin and Young [35] reported that folate levels were higher in milk samples containing LAB and the highest and the lowest amount were reported from Bifidobacterium longum and Streptococcus thermophiles, respectively. Thus, fermented buffalo milk is likely to be a rich source of folate. Further, an approximately two-fold increase of phosphorus is reported in buffalo milk, compared to cow milk. Due to high peroxidase activity in buffalo milk, it can be preserved for a comparatively longer time than cow milk [36].

Buffalo milk has comparatively larger casein miscalls and higher proportion of β-casein and κ-casein compared to that of the cow milk. Moreover, casein micelles in the buffalo’s milk are highly mineralized with higher calcium content and less hydrated than cow milk [37–39]. Because of these differences, fermented buffalo milk shows higher gel strength compared to that of cow milk [40].

The buffering capacity of buffalo milk is comparatively higher than that of its counterpart’s, cow milk; thus, there are noteworthy differences in acidification process, and authors have argued that these differences can be attributed to the high casein content present in buffalo milk [37].

### 3. Artisanal Fermentation of Buffalo Milk

#### 3.1. Fermented Buffalo’s Milk Products in the World

Buffalo milk is considered as a suitable raw material in producing certain types of artisanal and modern fermented dairy products and cheeses. The richness of its constituent is superior when compared to the cow milk [41] and thus makes it highly suitable for processing into various dairy products that are widely appreciated across many food cultures. Range of fermented buffalo milk products is available, depending on differences in geographical regions, demographic factors, social cultures and lifestyles. Because of different processing parameters and conditions, coupled with undefined starter cultures and traditional practices, fermented buffalo milk products are further diversified [42]. The unique characteristics of buffalo milk, such as high total solid content, whiteness and
viscosity, provides the opportunities for buffalo milk to process into inimitable dairy product compared to cow milk. Fermented buffalo milk products are commonly consumed in regions where buffalos have been reared for centuries, as a traditional preservative method (e.g., extending shelf life) for their excess milk yield while adding value to the perishable milk. In addition to fermented milk, there are several other noteworthy popular buffalos’ milk products, which is out of the scope in the present study, such as 

Koha

(such as Mozzarella, Domiati, Queso Blanco, etc. [31], paneer (acid-coagulated) [43], butter and ghee (Clarified Butter Fat) [44].

Various fermented buffalo milk products available in the world are shown in Figure 1 and the product characteristics are described in Table 3.

**Figure 1.** An extensive buffalo dairy farm in Sri Lanka (A), and various fermented buffalo milk products in the world, i.e., Sri Lanka—Meekiri (B), Philippines—Kesong Puti (C), West Sumatra, Indonesia—Dadih (D) and India—Dahi, where whey removal of Dahi occurs by hanging the fermented coagulum (E.1) to produce Chakka (E.2), and then it can further be processed into Shrikhand (E.3), by adding optional fruit pulps (e.g., mango). Dahi can be prepared in drinkable format, by mixing with water, Lassi (F).

| Traditional Name | County of Origin | Product Characteristics | References |
|------------------|------------------|-------------------------|------------|
| Meekiri          | Sri Lanka        | Traditional buffalo curd fermented in clay pots that resembles
|                  |                  | a creamy yoghurt.     | [45]       |
| Kesong Puti      | Philippines      | Soft fresh (unripened) cheese made with rennet and natural
|                  |                  | fermentation process of LAB. | [46]       |
| Dadih            | West Sumatra, Indonesia  | Sour yoghurt obtained by fermenting raw buffalo milk
|                  |                  | spontaneously in a bamboo tube, for two days, at ambient
|                  |                  | temperature, with natural LAB. | [47]       |
| Lassi            | India            | A refreshing beverage, obtained by blending Dahi with other
|                  |                  | ingredients such as salt, sugar, spices, fruits and water until it
|                  |                  | becomes frothy. | [48]       |
|                  |                  | Fermented buffalo milk yoghurt, made with various naturally
|                  |                  | occurring strains of LAB, which are introduced into the fresh
|                  |                  | milk through back-slopping (from the previous
|                  |                  | fermentation vat). | [49]       |
| Dahi             | India            | A product obtained by partial separation of whey from Dahi. | [49]       |
| Chakka           | India            | Sweetened concentrated curd produced by further removing
|                  |                  | whey from Dahi. Served with fruit pulps. | [49]       |
| Shrikhand        | India            |                         |            |

LAB, lactic acid bacteria.
3.2. Indigenous Microflora in the Fermented Buffalo Milk, their Probiotic Potentials and Effect on Product Technological Properties

Researchers are diligently working on the development of fermented buffalo milk to provide probiotic potentials through those products. Because of rich composition and associated health benefits (i.e., low-allergenic potential, beneficial effects for obesity, hypertension, osteoporosis, etc.) consumption of buffalo milk has gained significant popularity [50]. Nevertheless, consumption of buffalo milk with probiotic potentials may confer positive health benefits, since specific strains of bacteria in fermented milk has the potential of surviving and colonizing in the human gastrointestinal tract to deliver a potential probiotic effect [51].

Meekiri, also known as curd is a popular and sole buffalo milk-derived product in Sri Lanka. Comparing the syneresis values between Meekiri and fermented cow milk (also known as Deekiri in Sri Lanka) showed that Meekiri had lower syneresis than Deekiri [52], and, thus, fermented buffalo milk products are having superior gelling properties compared to fermented cow milk gels. Incorporation of Bifidobacterium longum into Meekiri showed that 10⁶ CFU/g of Bifidobacteria was found up to three days of storage, in clay pots, at 29 °C, while after 4 days of storage, an acceptable level of Bifidobacteria count was not reported [12]. Authors of this study confirmed the addition of Bifidobacteria into Meekiri did not alter its organoleptic properties and improved the consumer acceptability. However, the use of probiotic starter cultures compared to non-probiotic starter cultures in fermented cow milk gels (regular set-yoghurt) has shown to reduce the overall textural and sensorial properties [53]. Thus, natural probiotic strains containing in buffalo milk or using commercial probiotic starter cultures are not likely to interfere with the product physical characteristics, which harness to maximize the use of buffalo milk as a potential probiotic career. Isolating and purifying Lactobacillus strains from fifty different Meekiri samples collected from various regions in Sri Lanka reported thirty-nine different isolates, and the majority (80%) was heterofermentative lactobacilli [54]. Moreover, studying 26 Meekiri samples by Dekumpitya et al. [55], concluded that various LAB (i.e., Lactobacillus delbrueckii subsp. lactis, L. plantarum, L. helveticus, L. delbrueckii subsp. bulgaricus and L. casei subsp. casei, Streptococcus thermophilus and S. lactis) in addition to Saccharomyces cerevisiae, Micrococcus spp. and Bacillus spp. were present in Meekiri. Nine curd samples obtained from Kandy, Sri Lanka to isolate and characterize Lactobacillus species by Shuhadha et al. [56] reported that all isolated bacteria could grow at low pH (i.e., pH 3) and able to survive at 0.3% bile salt, while showing antimicrobial activity against E. coli and Pseudomonas aeruginosa. Further, those isolated Lactobacillus species have shown non-hemolysis and no DNase activity; thus, studied Meekiri samples were shown to contain probiotic potentials. A recent study conducted by Disanayaka et al. (2018) [57] found that Lactobacillus fermentum isolated from Sri Lankan homemade curd (Meekiri) can be used to control the Candida krusei and Candida tropicalis infections.

Buffalo milk is often adulterated with cow milk, because of relatively high availability on a year-round basis and lower farm gate price [58]. Thus, detecting cow milk in buffalo milk or products are of great interest. PCR assays [59] and capillary electrophoresis analysis can be used to detect the adulteration of buffalo curd with cow milk. Randiwela et al. [59] reported that two-thirds of the common market available Meekiri brands are adulterated with cow milk in Sri Lanka. This mixing of both types of milk has an impact on the fat%, where it could lower the fat% than the standards set by Sri Lanka Standard Institution [60], of which the minimum level of fat percentage in Meekiri should not be lower than 7.5%. In addition to the compositional and organoleptic quality changes of the final product, fraudulent incorporation of non-declared cow milk into buffalo milk will lead to food safety concerns, especially for people with allergies or intolerance for cow milk [22,61].

As per, Sri Lanka Standard Institution (SLSI) standards [60], minimum of 8.5 milk solid non-fat, 4.5 of maximum pH level and absent of E. coli, should comply with standards in Meekiri available in Sri Lanka. Fermentation of buffalo milk proved to be an effective strategy in eliminating the Listeria monocytogenes, in buffalo milk products, where the growth of Listeria was not observed below the pH level 5.5. This inactivation of Listeria is mainly due to low pH, increasing titratable acidity and production of bacteriocins, i.e., Nisin [62]. Kanthale is one of the popular regions in Sri Lanka for Meekiri production [63].
Thirty-six Lactobacillus strains were found in samples collected from spontaneously fermented traditional buffalo curd in clay pots from the Kanthale region [64]. Wickramaratne and Gunasena [64] reported strain-specific antimicrobial properties of those isolates against several pathogenic bacteria, while they observed the highest antibacterial activity against Listeria monocytogenes. Therefore, it can be argued that the natural microflora used in traditional Meekiri production in Kanthale have antibacterial activity, which could protect the curd from bacterial spoilage to enhance the shelf-life while increasing the food safety from food-borne bacterial diseases. Analyzing shelf available Meekiri in Sri Lanka to identify probiotic Lactobacillus species by Rajapakse et al. [65] confirmed the availability of Lactobacillus acidophilus (LA-5). The microbial count of L. acidophilus was higher than the minimum required level (10⁷ CFU/g) up to 12 days of shelf-life and survived up to low pH (decrease by acidification up to pH 1.5) and tolerance to bile salt (0.15%–0.3%) compared to other Lactobacillus species. However, they did not find Lactobacillus casei from the isolates.

Raw buffalo milk analyzed for probiotic strains in Karnataka, India reported containing Lactobacillus acidophilus, Lactobacillus rhamnosus and Bifidobacterium longum [66]. In addition to those reported in Karnataka area, India Lactobacillus casei and Lactobacillus fermentum have been isolated from buffalo milk collected from Khulna division of Bangladesh, which demonstrated to exhibit probiotic potentials [67]. Packaging materials are of importance for optimal probiotic delivery [45], where shelf-life of Lassi was affected by the oxygen permeation rate. Lassi stored in ethylene-vinyl-alcohol copolymer and glass bottles could store up to 25 days at 5 ± 1 °C without deteriorating the organoleptic properties and probiotic survivability [68]. This observation applies to Sri Lankan Meekiri, where the survival of bifidobacteria was affected by the type of packaging materials. Jayamanne and Adams [12] investigate the effect of three packaging materials (i.e., clay pots, plastic cups and glass bottles) on the survival of Bifidobacterium longum NCTC11818 in buffalo curd and reported bifidobacteria survived better in curd stored in plastic cups and glass bottles than in clay pots. This difference in Bifidobacteria count was attributed to the differences in permeability of packages for oxygen and storage temperature since Bifidobacteria are obligate anaerobes [69].

Dahi, a popular fermented milk and the Indian version of Sri Lankan Meekiri is made with lactic acid fermentation of milk sugars. Dahi made with individual starter strain of Lactococcus, has demonstrated antidiabetic effects (e.g., lowered fasting blood glucose, glycosylated hemoglobin, insulin, free fatty acids and triglyceride levels) on rats fed with a Dahi-based diet [70]. Feeding Dahi made with starter culture consisting Leuconostoc citrovorum, Lactococcus lactis, Lactococcus diacetylactis and Lactococcus cremoris to experimental mice report to protect against the enteric infections caused by Shigella dysenteria and confirm that Dahi activates the non-specific immune systems in mice [71]. However, further clinical research is warranted to confirm these findings concerning human health. Sensory properties were not altered by adding L. acidophilus and Bifidobacterium to regular starter cultures in preparation of Dahi and therefore, technological properties of Dahi is usually well preserved while providing the advantages of delivering health benefits associated to the probiotic potentials [72] also as previously discussed for Meekiri.

Probiotic potential of bacterial strains isolated from Dadih samples sourced from three geographical regions in west Sumatera demonstrated varying levels of probiotic capacities [47], which emphasize the importance of preserving the traditional microflora in indigenous fermented products. Swamp buffalo milk screened for probiotic bacterial strains in west Sumatera by Melia et al. [18] reported that it possessed Lactobacillus fermentum strain L23, which shows probiotic potentials. This bacterial strain presents naturally in western Sumatera’s buffalo milk could confer probiotic effects, even when the milk is fermented to Dadih. Moreover, studying the microbial content of buffalo milk in west Sumatera reported containing higher levels of lactic acid bacteria (>1 × 10⁶ CFU/mL), which indicates that milk could contribute as a potential source of probiotic bacteria. However, due to the higher LAB count, cautious should be made during the handling of raw milk [34]. LAB isolated from buffalo milk (e.g., Lactobacillus fermentum strain L 23 (A 3.3), Lactobacillus fermentum strain 6704 (TD 7.2) and Lactobacillus oris strain J-1 (A 3.2)) in the same region showed antimicrobial activity against Listeria
monocytogenes [73]. Lactobacillus plantarum strain 8m-21 isolated from Dadih in West Sumatera reported containing probiotic properties because they inhibit the E. coli due to its antimicrobial properties [74]. Analyzing Dadih, we saw that it showed that its naturally occurring LAB can produce antimicrobial substances (i.e., class II bacteriosins) with the molecular weight of 10 kDa [75].

4. Inclusion of Probiotics into the Artisanal Fermentation of Buffalo’s Milk

4.1. Probiotics

Probiotics are living cultures of a single microbial strain or a mixture of different strains that beneficially affect the well-being of the host animal, directly or indirectly, by improving its intestinal microbial balance when administered in sufficient quantity. It was at the beginning of the 20th century that Nobel laureate Elie Metchnikoff (1845–1916) first proposed the concept of probiotics as it is known today [76]. However, it was later, in the 1960s, that Lilly and Stillwell proposed the term “probiotics”, meaning “for life” in Greek [77].

The definition of probiotics has evolved over the years and one of the most used definition was proposed by Fuller [78] which is “probiotics are the live microbial food/feed supplements that exert beneficial effects for the host by improving its intestinal microbial balance”. Besides, in 1992, Fuller extended the definition of probiotics to “live microbial food ingredients that beneficially affect the health of consumers by improving their intestinal microflora balance when ingested live in sufficient numbers” [79]. Furthermore, various scientists have given a definition of probiotics considering their activities and their survival in the digestive tract. According to Salminen et al. [80], probiotics are “microbial cell preparations or components of microbial cells that have a beneficial effect on the health and wellbeing of the host”. Tannock et al. [81] described probiotics as “microbes which transit the gastrointestinal tract and which, in doing so, benefits the health of the consumer”. In 2001, the current and most widely used definition was proposed by experts from the FAO (Food and Agriculture Organization of the United Nations) and WHO (World Health Organization) working group and they defined probiotics as “live microorganisms which when administered in adequate amounts confer health benefits on the host” [21]. This definition was endorsed in 2014 by the International Scientific Association for Probiotics and Prebiotics [82].

4.2. Commonly Used Probiotics

There is a rapid increase in the production of products containing probiotic bacteria, due to a better understanding of the role of these bacteria in maintaining the health of the host. Different strains of probiotics can be incorporated in the form of cell suspensions or lyophilized form, depending on the food product. In the context of dairy products, there are many popular delivery systems for probiotics, such as raw and fermented milk, yoghurt, ice cream, desserts, cheese, various milk-based drinks, cookies and powdered milk (Boylston et al., 2004 [83]; Dagmar et al., 2011 [84]). Bacteria mainly from the genera Lactobacillus and Bifidobacterium are mainly considered as probiotics with GRAS status (generally recognized as safe); however, some other bacteria and yeast species have been recommended as probiotics (Table 4). Some strains of Propionibacterium, Bacillus, Enterococcus and Escherichia have also been shown to have probiotic characteristics. The yeast Saccharomyces has also been shown to be probiotic in some food products [85].
Table 4. Commonly used probiotic microorganisms.

| Genus          | Species                                                                 |
|----------------|-------------------------------------------------------------------------|
| Lactobacillus  | L. acidophilus, L. casei, L. crispatus, L. delbrueckii subsp. bulgaricus, L. fermentum, L. gasseri, L. johnsonii, L. paracasei, L. plantarum, L. reuteri, L. rhamnosus, L. helveticus, L. lactis, L. sporogenes, L. amylovorus, L. brevis, L. salivarius |
| Bifidobacterium| B. bifidum, B. breve, B. infantis, B. longum                          |
| Propionibacterium | P. acidipropionici, P. freudenreichii, P. jensenii, P. thoenii          |
| Bacillus       | B. lactis, B. animalis, B. adolescentis, B. essensis, B. laterosporus   |
| Escherichia    | E. faecium                                                              |
| Saccharomyces  | S. boulardii, S. cerevisiae                                             |

Adapted from Gorbach [86]; Senok et al. [87]; Caplan and Frost (2011) [88]; Ranadheera (2012) [89]; Saad et al. (2013) [90]; Stefan et al. (2013) [91].

4.3. Incorporation of Probiotics into Buffalo Milk Fermentation for Product Development

Having higher fat and casein content, buffalo milk could be used to produce a range of quality products with good consistency and creaminess that are different from those traditionally made with cow milk [92]. Buffalo milk is an effective food matrix for transporting probiotics. There are different types of probiotic buffalo milk products. These products range from liquid products, such as beverages, to semi-solid products, such as yoghurt and Dahi. Furthermore, there are findings that probiotics have been successfully incorporated into a different type of cheeses [93–95].

4.3.1. Probiotic Buffalo Milk-Based Beverages

Buffalo milk has been successfully used to produce acidophilus milk. In the production process, buffalo milk is standardized to around 3.5% fat and 8.5% SNF and followed by pasteurization. The incubation is carried out using a pure culture of Lactobacillus acidophilus at around 40 °C until pH reaches 4.4 [96]. Recently, probiotic dairy beverages were developed from buffalo milk with different level of whey (0, 25 and 50%) using Streptococcus thermophilus, Lactobacillus bulgaricus and Lactobacillus acidophilus. The researches demonstrated that the bacteria used in the production of beverages had higher survival in buffalo milk beverage during in vitro stimulation of gastrointestinal stress compared to fermented cow milk products [92]. In another study, Macedo, Freitas, Pandey and Soccol [97] showed that a probiotic beverage could be successfully produced with a mixture of 35% skimmed cow milk, 35% buffalo cheese whey and 30% soymilk using co-cultures of Lactobacillus casei subsp. shirota and Bifidobacterium adolescentis. Kefir is a creamy and sour fermented probiotic dairy drink originating from the Caucasus Mountains and is produced using milk from various species such as cow, goat, sheep, camel and buffalo. Kefir production is done according to the traditional method using kefir grains containing a complex mixture of lactic acid bacteria, acetic acid bacteria and yeasts or on an industrial scale using kefir starter cultures [98]. There are many published articles on the successful use of buffalo milk in manufacturing kefir [99–103]. Kefir made from buffalo milk was reported to have improved water holding capacity, firmness, viscosity, storage and loss modulus values and consistency index when compared to those of kefir made with cow milk [104].

4.3.2. Probiotic Buffalo Yoghurt

Yoghurt is a semisolid fermented dairy product which is used as a popular carrier for probiotics [105]. Traditional yoghurt production involves a mixture of thermophilic starter cultures consisting of Lactobacillus delbrueckii subsp. bulgaricus and Streptococcus thermophilus, which are different from the cultures traditionally used for the fermentation of buffalo milk. However, the new trend is to use probiotic bacteria such as Lactobacillus acidophilus and Bifidobacterium spp. in the product for their potential health benefits [106]. Homogenization of milk is not typically practiced in the manufacturing of buffalo milk yoghurt. Moreover, milk solid fortification and the incorporation of thickeners are
not practiced in the manufacturing process due to the higher solid content of buffalo milk [107,108].
Different types of probiotic buffalo yoghurt have been reported such as plain [108], low fat [109], symbiotic [110] and fiber incorporated [111].

4.3.3. Probiotic Buffalo Curd

Buffalo curd is an acidic fermented dairy product with a texture similar to that of yoghurt. It is mainly produced on a small scale using a traditional blend of starter cultures. The culture blend includes *Lactococcus lactis* subsp. *lactis*, *Lactococcus lactis* subsp. *lactis* biovar *diacetylactis*, *Lactococcus lactis* subsp. *cremoris* singly or in combination with *Leuconostoc* spp. [12]. The production process includes pasteurization or boiling of milk which is followed by inoculation with the Meekiri/Dahi from the previous day as the starter. Incubation is normally carried out at room temperature (~30–35 °C) for overnight (~10–12 h). Various probiotic species, such as *Lactobacillus acidophilus* [112], *Lactobacillus casei* [113], *Lactobacillus plantarum* [114] and *Bifidobacterium bifidum* [112,115], have been used in producing buffalo Meekiri/Dahi.

4.3.4. Cheese

Cheese is a popular milk-based food product consumed around the world as an integral part of the diet of the population. Consumption of cheese containing probiotic bacteria has been linked to various human health benefits, such as improvements in the immune system, oral health in the elderly and gastrointestinal health [116]. Cheese is a good carrier for the target delivery of probiotics in the gastrointestinal tract compared to other fermented dairy products because cheese has a dense matrix, high pH, low oxygen levels, buffering capacity and high-fat content which could protect them during the entire shelf life and their transit in the gastrointestinal tract [117]. However, high-salt varieties of cheese are not suitable for incorporating probiotics as they can retard their growth [118]. Buffalo milk cheese has proven to be an effective carrier for various probiotics. Cheddar cheese from buffalo milk was produced using *Lactococcus acidophilus* LA-5, *Bifidobacterium bifidum* Bb-11 and *Bifidobacterium longum* BB536 and shown to have good probiotic viability during the storage [119]. *Lactobacillus casei*, *Lactobacillus plantarum* and *Lactobacillus brevis* were used in producing Himalayan cheese (Kalari) using buffalo milk and incorporation of probiotics improved quality characteristics of the cheese [118]. In another study, buffalo Minas Frescal cheese produced with *Bifidobacterium animalis* subsp. *lactis* was shown to have acceptable quality parameters [120]. *Lactobacillus casei*, *Lactobacillus rhamnosus* and *Bifidobacterium bifidum* were used to improve conjugated linoleic acid content in buffalo cheese [121]. Ricotta cheese made from buffalo milk is an appropriate carrier for the probiotic *Lactobacillus acidophilus* La-05, without affecting its sensory attributes and consumer acceptability [122].

4.4. Challenges of Probiotic Inclusions into Fermented Buffalo Milk Products

The probiotic bacterial strains have already been used for years in fermented milk products, they have inferior behavioral characteristics than those of the traditional lactic acid bacteria used in fermented milk products, which limits their possible applications. More precisely, they grow weakly in cow milk and require long fermentation times, anaerobic conditions and a low redox potential for their growth [123,124]. Their poor acidifying performance has a direct effect on the textural properties of fermented dairy products, which results in poor rheological properties of probiotic fermented dairy products. The rheological properties of fermented milk products are very important at the industrial level because they are considered as quality parameters of the end-up products [125].

Moreover, the viability of probiotics can be suppressed and reduced by environmental stress parameters, such as the presence of oxygen, mechanical damage, high processing temperatures and interaction with the foods in which they are added. Furthermore, poor compatibility with the traditional starter of fermented milk during fermentation and high acidity of dairy products or milk-based products with high acidity could lead to poor viability starter organisms [126]. Probiotics incorporated into
dairy products should not lead to poor sensory properties or texture. Therefore, sensory evaluation of the newly developed product must be carried out before it is introduced into the market [127].

5. Technological Prospects to Develop Probiotic Fermented Products Using Buffalo Milk

Several innovative technologies have been reported to increase the stability and viability of probiotic bacteria in fermented products. Some of these methods have been successfully adapted to overcome technological challenges associated with the probiotics such as the presence of the toxic by-products (organic acids and hydrogen peroxide) during the propagation of probiotics, mechanical stress caused by extreme temperature conditions employed during the preservation of probiotics such as freeze-drying or spray-drying, high rate of acidification of the buffalo set-yoghurts during storage and the presence of acidic conditions and the bile salts in the gastrointestinal tract of the consumer, which resulted in poor viability and survival of probiotic microorganisms [128]. Use of power ultrasound, application of encapsulation techniques and microbead coating are some of such innovative techniques attempted by many researchers to increase the viability of probiotics. Moreover, the selection of desirable probiotics for different carrier foods, determination of required doses of probiotics, use of appropriate packaging conditions, the addition of prebiotics and growth-promoting factors are some of the other potential measures, which enhances the survival of probiotics in bio-yoghurts.

5.1. Selection of Probiotic Strains for the Fermentation of Buffalo’s Milk

Type of the probiotic strains used for the development of probiotic-based functional food is one of the major factors affecting the viability of probiotics and the organoleptic, rheological and texture properties of yoghurts. A significant number of potential probiotic microorganisms have been isolated and identified using the traditional fermented buffalo milk. It was revealed that the probiotic characteristics were mainly depended on the strain of the bacteria. Most of the bacterial strains which were screened for the potential probiotic properties, using in vitro studies, showed promising characteristics, such as acid and bile tolerance, survival through the gastrointestinal tract, the ability to adhere to the intestinal mucosa, antimicrobial activity against potentially pathogenic bacteria, etc. [129], as summarized in Table 5.

| Type of Microorganisms Isolated/Investigated | Beneficial Characteristics Revealed in the Study | Products Associated | References |
|--------------------------------------------|-------------------------------------------------|---------------------|------------|
| Enterococcus faecium IS-27526              | Stimulating the total salivary serum IgA level in underweight preschool children, increase of secretory IgA level | Traditional fermented buffalo milk in Indonesia (Dadih) | [16] |
| Lactobacillus plantarum IS-10506           | Inhibitory, competitive and displacing properties against pathogens and reduced pathogen adhesion to mucus | Traditional fermented buffalo milk in Indonesia (Dadih) | [130] |
| Enterococcus faecium, Lactobacillus plantarum | Ability to auto aggregate, together with cell surface hydrophobicity and co-aggregation abilities with pathogen strains | Traditional fermented buffalo milk in Indonesia (Dadih) | [15] |
| Le. Lactis subsp. Lactis IS-10285, IS-7386, IS-16183, IS-11857, IS-29862, L. brevis IS-27560, IS-26958 and IS-23427, Leu. mesenteroides IS-27526 and L. casei IS-7257 | Possessed a good survival rate at low pH (PH 2 and 3), bile tolerance and lysozyme tolerance | Traditional fermented buffalo milk in West Sumatra (Dadih) | [131] |
| Lactobacillus casei subsp. casei R-68, Lactobacillus casei strain Shirota | Inhibited the growth of Staphylococcus aureus FNCC-15, Listeria monocytogenes FNCC-0156 and Escherichia coli FNCC-19 | Antibacterial activity was resistant to heat treatment (60–95 °C), amylase, various proteolytic enzymes and various types of antibiotics. | [132] |
| L. Lactis subsp. Lactis IS-10285, IS-7386, IS-16183, IS-11857, IS-29862, L. brevis IS-27560, IS-26958 and IS-23427, Leu. mesenteroides IS-27526 and L. casei IS-7257 | Possessed a good survival rate at low pH (PH 2 and 3), bile tolerance and lysozyme tolerance | Traditional fermented buffalo milk in West Sumatra (Dadih) | [131] |
| Lactobacillus casei subsp. casei R-68, Lactobacillus casei strain Shirota | Inhibited the growth of Staphylococcus aureus FNCC-15, Listeria monocytogenes FNCC-0156 and Escherichia coli FNCC-19 | Antibacterial activity was resistant to heat treatment (60–95 °C), amylase, various proteolytic enzymes and various types of antibiotics. | [132] |
Numerous in vitro studies and animal studies, together with the limited number of clinical studies, reported the probiotic properties of bacteria isolated from fermented buffalo milk. It was observed that *Lactobacillus reuteri* IS-27560, *Lactococcus lactis* IS-16183 and *L. rhamnosus* IS-7257 that were isolated from “Dadih” (fermented buffalo milk product popular in Indonesia) showed adhesion to the human intestinal mucosal surface and Caco-2 cells, which were used as the model for human intestinal cells. Moreover, *L. lactis* IS-16183 and *L. rhamnosus* IS-7257 significantly inhibited the adhesion of *Escherichia coli* O157:H7 to the human mucosa [138]. It was revealed that the adhesion properties of IS-16183 and IS-7257 were similar to the *L. casei* Shirota and *L. rhamnosus* GG, which are used as commercial probiotic strains. A similar study of Collado et al. [130], using *L. plantarum* IS-10506 and IS-20506, and *Enterococcus faecium* IS-27526, IS-23427 and IS-16183, which were isolated from Dadih, showed competitive exclusion of pathogens in the mucosa.

However, all of the selected strains with promising probiotic properties are not suitable for the production under the industrial scale because of low yields in the growth medium or poor survival during downstream processing [139]. Therefore, these selected bacterial strains with potential probiotic properties should be further investigated for their technological properties, such as the capability for mass production and ability to incorporate into the target food without reducing cell viability and undesirable flavor or texture [128]. Furthermore, such selected probiotic strains should be evaluated for high survival rates in downstream processing (such as freeze-drying or spray-drying) before commercialization.
5.2. Addition of Prebiotics

Prebiotics are indigestible nutrients having health-promoting benefits for the host through promoting growth or activity of one or more probiotic bacteria [110]. Prebiotics should not be hydrolyzed or absorbed in the upper part of the gastrointestinal tract; they should be a selective substrate to stimulate the growth of one or a limited number of beneficial bacteria in the colon and capable of altering the composition of colonic microflora in a healthy manner [140]. The most commonly used prebiotics for the production of functional dairy products are fructans and resistant starches. Several authors have reported the use of prebiotics in the fermentation of buffalo milk incorporated with probiotic bacteria.

Ehsani et al. [110] observed a higher population of *Lactobacillus acidophilus* and *Bifidobacterium bifidum* (above 7 logs CFU/mL) in buffalo set-yoghurts incorporated with lactulose, oligofructose and inulin, under refrigerated storage (4 °C), for 21 days. Furthermore, incorporation of prebiotics reduced the syneresis and post-acidification of buffalo set-yoghurts. A similar study on the effects of mannan extracts from yeast cell walls on the probiotic buffalo milk yoghurts containing *Lactobacillus acidophilus, Bifidobacterium* sp. and *Streptococcus thermophilus* increased the viability of probiotic bacteria in between 10^7 and 10^9 CFU/mL after fermentation [141,142], which is the recommended dose of viable probiotic bacteria at the time of consumption of a probiotic product [110]. Moreover, post-processing acidification of buffalo milk yoghurts reduced with the addition of prebiotics. Karki, Shrestha, Bohara and Jyakhwa [143] reported similar findings, that addition of lactulose, galactomannan (Sunfibre®) and inulin into buffalo milk yoghurts increased the viable cell counts of *L. rhamnosus* up to 8 logs CFU/ML, until 15 days of storage (4 °C). Similarly, incorporation of prebiotics reduced the titratable acidity and pH of buffalo yoghurts.

Buffalo milk contains a comparatively high amount of carbohydrates than cow milk, resulting in high titratable acidity [144]. The concentration of undissociated organic acids in fermented products enhances the bactericidal effect; therefore, the survival of probiotics during storage is considerably reduced by the low pH and high titratable acidity of the products [145]. Inclusion of prebiotics into buffalo milk may be an effective method to reduce the post-fermentation acidification of buffalo yoghurt and enhance the viability of probiotics, which is one of the major constraints associated with the production of functional buffalo milk products.

5.3. Microencapsulation

Microencapsulation is a process of enclosing the probiotic cells by covering them with an appropriate material, which leads to protecting the cells during digestion and releases into the intestinal medium [145]. Different materials have been used to encapsulate probiotics such as sodium alginate [146–148], calcium alginate [148,149], xanthan gum [150], chitosan [151], starch, κ-carrageenan [152,153], cellulose acetate phthalate, gelatin [154,155], caseinate [156] and whey proteins [157]. These encapsulating materials were acting as physical barriers to protect the sensitive probiotic cells against a harsh gastrointestinal environment, thus increasing their survival in the colon [158]. Additionally, encapsulation helps to protect probiotic bacteria during processing and storage, such as high oxygen stress.

Several encapsulation techniques have been reported such as emulsification [159], extrusion [160] and spray-drying [161], fluid-bed method [162] and freeze-drying [163]. Selection of the appropriate encapsulation method depends on several factors such as the required size of the capsules in the target product, the viability of the probiotic bacteria under the processing conditions used for the encapsulation, cost of the operation, etc. [142].

Microencapsulation has been extensively investigated to increase the viability of probiotic bacteria in fermented cow milk [164–167]. Encapsulation resulted in higher probiotics survival during both refrigerated storage and simulated gastrointestinal conditions compared to that of the free cells. Similarly, it reduced the post-acidification of cow milk yoghurts.
Therefore, it can be assumed that microencapsulation may be a successful technique to increase the viability of probiotics in buffalo milk set-yoghurts by protecting the cells from detrimental factors such as higher post-acidification compared to cow milk yoghurts during refrigerated storage. Shoji et al. [168] incorporated *Lactobacillus acidophilus* into buffalo milk yoghurts, which were microencapsulated with pectin and casein (1:1). They observed an increase in the survival of *L. acidophilus* (10⁷ CFU/g) at refrigerated conditions (4 °C). Similarly, buffalo set-yoghurts prepared with microencapsulated cultures resulted in lower post-acidification when compared to the product prepared with free culture. However, it was revealed that the encapsulation was not a successful technique to protect the *L. acidophilus* against the low pH conditions, which were similar to the human stomach.

Application of coating has been reported to enhance the protective ability of probiotic microcapsules. Therefore, the coating may be a useful technique to increase the resistance of microencapsulated probiotics under harsh gastrointestinal environment. This can be done using different materials such as alginate, chitosan, poly-l-lysine, whey proteins, etc. These coatings can form an additional layer on microcapsules, preventing the exposure of probiotics to oxygen during storage and, thus, enhancing their stability at low-pH and high-temperature conditions [169]. Several techniques have been used to apply coatings on probiotics microcapsules, such as layer-by-layer assembly (immersion of microcapsules in the polymer solution) and coacervation (forming a coacervate between microcapsules’ surface and a polymer coating) [142]. Hence, the application of an appropriate coating technique to enhance the viability of microencapsulated probiotics in buffalo milk warranted further studies.

### 5.4. Ultrasonication

Ultrasound refers to sound waves above a frequency of 20,000 Hz, which cannot be detected by humans [170]. High-intensity ultrasound (20–100 kHz) is a potential tool to accelerate the functionality and viability of probiotic bacteria through a process called “sonoporation”, which changes the cellular structure of probiotics. Sonoporation defines the progressive opening of the cell membrane due to micro-bubble cavitation upon the exposure of cells to ultrasound. This resulted in some cellular damages such as micro-cracks, micro-voids and ruptures in the cell membrane, causing enhanced permeability [120]. Consequently, sonoporation enhances mass transfer of substrates across the microbial cell membrane, which eventually improves microbial growth.

Ultrasound has been applied to numerous probiotic dairy products and results revealed shorter fermentation time, high probiotic survival and less requirement of ingredients such as prebiotics [171] and are outlined in Table 6.

| Ultrasonic Conditions | Types of Probiotic Bacteria | Major Effects Observed | References |
|-----------------------|----------------------------|------------------------|------------|
| 100 mL of inoculated milk was sonicated before fermentation at 100 W and 20 kHz for 7, 15 and 30 min, using an ice bath, energy density 420, 900 and 1800 J mL⁻¹ | *B. breve* ATCC 15700, *B. infantis*, *B. longum* (BB-46) and *B. animalis* subsp. *lactis* (BB-12) in skim milk | Reduced fermentation time for *B. breve*, *B. infantis* and BB-12, Promoted growth of bifidobacteria | [172] |
| 150 mL of inoculated milk sonicated before fermentation at 20 kHz and 450 W, 225 W and 90 W for 1, 6 and 10 min, using a 13 mm diameter probe; energy density 36–1800 J m L⁻¹ | *Bifidobacterium* and *Lb. acidophilus* in cow milk | Faster acid development Decreased fermentation time | [173] |
| Sonication of cultures before inoculation at 84 and 102 W for 75 and 150 s with a 12 mm diameter probe and frequency of 20 kHz. Sonication temperature: 37 °C. | *Lb. acidophilus* (La-5) in thermosonicated whey (480 W, 8 min, 55 °C) | Shorter time of fermentations, Increased viable cell count | [174] |
| 28 kHz, pulsed US (100 s on and 10 s off), 100 W L⁻¹ for 1 h before fermentation (=360 J mL⁻¹) and 30 min during fermentation (=180 J mL⁻¹). | *L. paracasei* CICC 20241 | Increase of 49.5% in the peptide content and 43.5% of viable cells in the fermented skim milk compared to untreated samples | [175] |
Reducing the fermentation time (interval between the time of addition of cultures and the time at which the pH of the yoghurt reaches pH 4.7) [176] and increasing the viability of probiotic bacteria using high-intensity ultrasound is one of the most promising approaches. Reduction of fermentation time resulted in shorter production cycles and, thus, lower costs. It was reported that the sonication of reconstituted skimmed milk (15%, w/v) inoculated with Bifidobacterium sp. at 20 kHz and 100 W, for 15 min, followed by the fermentation at 37 °C, reduced the fermentation time by 11–26% while increasing the cell viability [172]. Similarly, the fermentation of reconstituted sweet whey (6% of the dry matter) by the ultrasound treated culture of Lactobacillus acidophilus with 84 W for 150 s was reported to reduce fermentation time by 30 min [174]. However, studies on employing ultrasound on probiotic buffalo milk product are scarce in the literature and warranted further investigations.

Moreover, it was reported that the application of high-intensity ultrasound on cow-milk set-yoghurts promoted the gel texture and viscosity of set-yoghurts, while reducing the syneresis and whey separation [120]. A more recent study reported similar observations for buffalo-milk set-yoghurts, as the gel hardness was increased by 98% and syneresis was reduced with the ultrasonic treatment (20 kHz and with 1188 J/mL energy density) [177]. Therefore, it could be assumed that ultrasound may be a potential tool to promote the viability of probiotics in buffalo milk yoghurt, while improving the gel properties.

5.5. Use of Appropriate Packaging and Storage Conditions

The presence of viable probiotic cultures in dairy products at the time of consumption is an essential legal requirement. However, probiotic bacteria often have insufficient viability in marketable products including fermented buffalo milk and thereafter the harsh gastrointestinal conditions [168]. Therefore, the selection of proper packaging conditions and storage conditions is vital. Viability and survival of probiotic bacteria are significantly influenced by several factors such as pH, titratable acidity, oxygen level, processing conditions and starter production conditions [139,144]. The ideal pH ranges for the growth of bifidobacteria and lactobacillus species are recognized as 6.00–7.00 and 5.50–6.09, respectively [145]. Therefore, low pH conditions associated with fermented buffalo milk is the major reason for the decline of the viability of probiotic bacteria during the storage. Similarly, the presence of oxygen can cause the generation of toxic metabolites, such as hydrogen peroxide, in probiotic bacterial cells, leading to cell death. It is reported that the presence of oxygen can induce the production of toxic peroxides and free radicals, which have the potential to damage DNA in probiotic bacteria [178]. Therefore, it is important to minimize the processing steps such as agitation and mixing, which facilitate air incorporation into the product. Moreover, appropriate packaging materials containing oxygen barriers and oxygen scavengers (active and intelligent packaging), which prevent the introduction of high levels of oxygen into the final product, should be used during storage and product distribution.

Storage temperature is another important factor, which affects the probiotic survival in yoghurts [145]. It is reported that the viable counts of probiotics reduced during refrigerated storage (4 °C) [89]. Mortazavian, Ehsani, Mousavi, Sohrabvandi and Reinheimer [179] investigated the effect of cold storage temperatures (2, 5 and 8 °C) on the survival of probiotics in yoghurts. They found that the highest survival rate of L. acidophilus and Bifidobacteria was 8 and 2 °C for a 20-day period, respectively. Moreover, low storage temperature causes reduced rates of metabolic activities and less generation of harmful metabolites, which enhances the survival of probiotics. Similar results were obtained by Celik and O’Sullivan [180] during storage of freeze-dried B. animalis subsp. lactis Bb-12 up to 21 °C, which showed the optimum survival rate. However, stress-sensitive probiotic strains such as B. longum DJO10A showed the highest probiotic survival under frozen storage (−20 to 80 °C). Survival of probiotics were further promoted by immobilization techniques during refrigerated storage [165]. Loss of viability of microencapsulated L. plantarum in 3% alginate coated with chitosan in cow milk yoghurt was approximately four times higher as compared to cells kept in saline suspension during 38 days of storage (4 °C). However, it is a common practice of cottage and medium scale
industries to store and distribute buffalo set-yoghurts under ambient temperature (30–35 °C). This may be another challenge to the inclusion of probiotics into fermented buffalo milk.

6. Conclusions

Research findings of buffalo-milk-based dairy products (e.g., “Meekiri”, “Dahi” or “Dadih”), which resulted in artisanal fermentation, revealed various probiotic potentials through its microbial consortium. Buffalo milk has the potential of being a probiotics carrier food, to confer health benefits, since it is the second most-consumed type of milk after cow milk, is a potential carrier food for probiotics and confers health benefits to the consumers. A comprehensive review of such products and their challenges and strategies to overcome the limitations of incorporating probiotics into buffalo milk products was presented in this paper. It was found that the proper selection of probiotic strains that can withstand the typical high acidic conditions associated with buffalo milk helps to overcome a major challenge of manufacturing probiotic-enriched fermented buffalo milk products. However, the addition of probiotic strains with specific health benefits into buffalo milk products can be achieved through several interventions, such as applying specific stresses to the cultures (i.e., ultrasound), the addition of growth-promoting factors (i.e., prebiotics) or protecting the cells through microencapsulation and/or coating techniques. Overall, probiotic-enriched buffalo milk products play a significant role in delivering probiotics with potential health benefits to humans. Further advances in processing, packaging and storage of probiotic-enriched fermented buffalo milk-based products may provide a competitive advantage of harnessing buffalo milk’s full probiotic potentials.

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References
1. Zhang, Y.; Colli, L.; Barker, J.S.F. Asian water buffalo: Domestication, history and genetics. Anim. Genet. 2020, 51, 177–191. [CrossRef]
2. Macgregor, R. The domestic buffalo. Vet. Rec. 1941, 53, 443–450.
3. Zhang, Y.; Vankan, D.; Barker, J.S.F. Genetic differentiation of water buffalo (Bubalus bubalis) populations in China, Nepal and south-east Asia: Inferences on the region of domestication of the swamp buffalo. Anim. Genet. 2011, 42, 366–377. [CrossRef]
4. Food and Agriculture Organization of the United Nations Statistical Database (FAOSTAT). 2018. Available online: http://www.fao.org/faostat/en/#data/QA (accessed on 15 June 2020).
5. Barker, J.S.F.; Moore, S.S.; Hetzel, D.J.S.; Evans, D.; Byrne, K. Genetic diversity of Asian water buffalo (Bubalus bubalis): Microsatellite variation and a comparison with protein-coding loci. Anim. Genet. 1997, 28, 103–115. [CrossRef]
6. Cruz, L.C. Trends in buffalo production in Asia. Ital. J. Anim. Sci. 2007, 6, 9–24. [CrossRef]
7. Mane, B.G.; Chatli, M.K. Buffalo milk: Saviour of farmers and consumers for livelihood and providing nutrition. J. Agric. Rural Dev. 2015, 2, 5–11.
8. Hamid, M.; Zaman, M.; Rahman, A.; Hessain, K. Buffalo Genetic Resources and their Conservation in Bangladesh. Res. J. Vet. Sci. 2016, 10, 1–13. [CrossRef]
9. Wanapat, M.; Chanthakhoun, V. Buffalo production for emerging market as a potential animal protein source for global population. Buffalo Bull. 2015, 34, 169–180, (accessed on 02.07.2020).
10. Sindhu, J.S.; Arora, S. Buffalo Milk. In Encyclopedia of Dairy Sciences, 2nd ed.; Fuquay, J.W., Ed.; Elsevier Academic Press: Cambridge, MA, USA, 2011; pp. 503–511.
11. Guo, M.; Hendricks, G. Improving Buffalo Milk. In Improving the Safety and Quality of Milk; Griffiths, M.W., Ed.; Woodhead Publishing: Sawston, UK, 2010; pp. 402–416.
12. Jayamanne, V.S.; Adams, M. Survival of probiotic bifidobacteria in buffalo curd and their effect on sensory properties. Int. J. Food Sci. Technol. 2004, 39, 719–725. [CrossRef]
13. Jatmiko, Y.D.; Howarth, G.S.; Barton, M.D. Naturally Fermented Milk and Its Therapeutic Potential in the Treatment of Inflammatory Intestinal Disorders. In Proceedings of the AIP Conference, Malang City, Indonesia, 7–8 March 2018.

14. Sarkar, S.; Sakar, M.; Majhi, R.; Chatterjee, K.; Sikder, B.; Sur, A. Process standardization for enhancing bio functionality of Dahi. J. Nutr. Health Food Eng. 2019, 9, 1–6.

15. Collado, M.C.; Surono, I.S.; Meriluoto, J.; Salminen, S. Potential Probiotic Characteristics of Lactobacillus and Enterococcus Strains Isolated from Traditional Dadih Fermented Milk against Pathogen Intestinal Colonization. J. Food Prot. 2007, 70, 700–705. [CrossRef] [PubMed]

16. Surono, I.S.; Koestomo, F.P.; Novitasari, N.; Zakaria, F.R.; Yuliansari; Koesnanda. Novel probiotic Enterococcus faecium IS-27526 supplementation increased total salivary slgA level and body weight of pre-school children: A pilot study. Anaerobe 2011, 17, 496–500. [CrossRef] [PubMed]

17. Venema, K.; Surono, I. Microbiota composition of dadih—A traditional fermented buffalo milk of West Sumatra. Lett. Appl. Microbiol. 2019, 68, 234–240. [CrossRef] [PubMed]

18. Melia, S.; Yuherman, Y.; Jaswandi, J.; Purwati, E. Selection of Buffalo Milk Lactic Acid Bacteria with Probiotic Potential. Asian J. Pharm. Clin. Res. 2018, 11, 186–189. [CrossRef]

19. Rahmawati, I.S.; Suntornsuk, W. Effects of Fermentation and Storage on Bioactive Activities in Milks and Yoghurts. Procedia Chem. 2016, 18, 53–62. [CrossRef]

20. Kamble, K.D.; Kokate, P.S. Production and Keeping Quality of Yogurt from Buffalo and Cow Milk—A Traditional Milk Product of High Health Value; NISCAIR-CSIR: New Delhi, India, 2015; pp. 279–284. ISBN 972-5938.

21. Joint Food and Agricultural Organization of the United Nations and World Health Organization Expert Consultation Report. Health and Nutritional Properties of Probiotics in Food Including Powder Milk with Live Lactic Acid Bacteria. Available online: http://www.who.int/foodsafety/publications/fs_management/probiotics/en/index.html (accessed on 16 August 2020).

22. Sheehan, W.J.; Phipatanakul, W. Tolerance to Water Buffalo Milk in a Child with Cow Milk Allergy. Ann. Allergy Asthma Immunol. 2009, 102, 349. [CrossRef]

23. Braun, P.G.; Preuss, S.E. Nutritional composition and chemico-physical parameters of water buffalo milk and milk products in Germany. Milchwissenschaft 2008, 63, 70–72.

24. Ahmad, S.; Zhang, T.; Lee, F.; Liu, Y.; Li, X.; Guo, M. Seasonal variations in chemical composition of buffalo milk. Buffalo Bull. 2013, 32, 1324–1329.

25. Borghese, A.; Muzzi, M. Buffalo Population and Strategies in the World. In Buffalo Production and Research; FAO: Rome, Italy, 2005.

26. McDermott, J.; Staal, S.; Freeman, H.; Herrero, M.; Van De Steeg, J. Sustaining intensification of smallholder livestock systems in the tropics. Livest. Sci. 2010, 130, 95–109. [CrossRef]

27. El Debaky, H.A.; Kutchy, N.A.; Ul-Husna, A.; Indriastuti, R.; Akhter, S.; Purwantara, B.; Memili, E. Review: Potential of water buffalo in world agriculture: Challenges and opportunities. Appl. Anim. Sci. 2019, 35, 255–268. [CrossRef]

28. Food and Agriculture Organization of the United Nations Statistical Database (FAOSTAT). 2014. Available online: http://www.fao.org/faostat/en/#data/QP (accessed on 24 June 2020).

29. Murtaza, M.A.; Pandya, A.J.; Khan, M.M.H. Buffalo Milk. In Handbook of Milk of Non-Bovine Mammals; John Wiley & Sons Ltd.: Hoboken, NJ, USA, 2017; pp. 261–283.

30. Arora, S.; Khetra, Y. Chapter 42-Buffalo Milk Yoghurt. In Handbook of Milk of Non-Bovine Mammals; John Wiley & Sons Ltd.: Hoboken, NJ, USA, 2017; pp. 284–342.

31. Patel, R.; Mistry, V. Physicochemical and Structural Properties of Ultrafiltered Buffalo Milk and Milk Powder. J. Dairy Sci. 1997, 80, 812–817. [CrossRef]

32. Melia, S.; Purwanto, H.; Purwati, E. Nutrition quality and microbial content of buffalo, cow, and goat milk from West Sumatera. J. Ilmu Ternak Vet. 2018, 23, 150–157. [CrossRef]

33. Lin, M.; Young, C. Folate levels in cultures of lactic acid bacteria. Int. Dairy J. 2000, 10, 409–413. [CrossRef]

34. El-Salam, M.H.A.; El-Shibiny, S. A comprehensive review on the composition and properties of buffalo milk. Dairy Sci. Technol. 2011, 91, 663–699. [CrossRef]
37. Ahmad, S.; Gaucher, I.; Rousseau, F.; Beaucer, E.; Piot, M.; Grongnet, J.F.; Gaucher, F. Effects of acidification on physico-chemical characteristics of buffalo milk: A comparison with cow’s milk. *Food Chem.* 2008, 106, 11–17. [CrossRef]

38. Aschaffenburg, R.; Sen, A.; Thompson, M. The caseins of buffalo milk. *Comp. Biochem. Physiol.* 1968, 27, 621–623. [CrossRef]

39. Ranjan, P.; Arora, S.; Sharma, G.S.; Sindhu, J.S.; Kansal, V.K.; Sangwan, R.B. Bioavailability of calcium and physicochemical properties of calcium-fortified buffalo milk. *Int. J. Dairy Technol.* 2005, 58, 185–189. [CrossRef]

40. Priyashantha, H.; Lundh, Å.; Höjer, A.; Hetta, M.; Johansson, M.; Langton, M. Interactive effects of casein micelle size and calcium and citrate content on rennet-induced coagulation in bovine milk. *J. Texture Stud.* 2019, 50, 508–519. [CrossRef]

41. Khedkar, C.D.; Kalyankar, S.D.; Deosarkar, S.S. Buffalo Milk. In *Encyclopedia of Food and Health*; Caballero, B., Finglas, P.M., Toldrá, F., Eds.; Academic Press: Cambridge, MA, USA, 2016; pp. 522–528.

42. Panjagari, N.R.; Singh, R.; Singh, A.K. Indian Traditional Fermented Dairy Products. In *Indian Traditional Foods*; Springer: New York, NY, USA, 2016; pp. 101–114.

43. Pandey, K.K.; Sood, S.K.; Kumar, S.; Rani, S.; Ganguli, S. Bioutilization of paneer whey for production of paneer making powder containing pediocin PA-1 as a biopreservative to enhance shelf life of paneer. *LWT* 2019, 113, 108243. [CrossRef]

44. Sserunjogi, M.L.; Abrahamsen, R.K.; Narvhus, J. Current knowledge of ghee and related products. *Int. Dairy J.* 1998, 8, 677–688. [CrossRef]

45. Cruz, A.G.; Faria, J.D.A.; Van Dender, A.G. Packaging system and probiotic dairy foods. *Food Res. Int.* 2007, 40, 951–956. [CrossRef]

46. Sanchez, P.C. *Philippine Fermented Foods: Principles and Technology*; The University of the Philippines Press: Quezon City, Philippines, 2008.

47. Syukur, S.; Aziz, H.; Fachrial, E. Probiotics and strong antimicrobial of buffalo milk fermentation (Dadih) from different places in West Sumatera Indonesia. *Res. J. Pharm. Biol. Chem. Sci.* 2016, 7, 386–392.

48. Malik, R.K.; Sheenam, G. Health Benefits of Ethnic Indian Milk Products. In *Health Benefits of Fermented Foods and Beverages*; CRC Press: Boca Raton, FL, USA, 2015; pp. 297–324.

49. Aneja, R.P.; Mathur, B.N.; Chandan, R.C.; Banerjee, A.K. Cultured/Fermented Products. In *Technology of Indian Milk Products*; A Dairy India Publication: New Delhi, India, 2002; pp. 159–182.

50. Ahmad, S. Buffalo Milk. In *Milk and Dairy Products in Human Nutrition*; John Wiley & Sons, Ltd.: Hoboken, NJ, USA, 2013; pp. 519–553.

51. Fernández, M.F.; Boris, S.; Barbès, C. Probiotic properties of human lactobacilli strains to be used in the gastrointestinal tract. *J. Appl. Microbiol.* 2003, 94, 449–455. [CrossRef] [PubMed]

52. Hallqvist, J. The Importance of Buffalo Milk in the Curd Manufacture of Sri Lanka. Bachelor’s Thesis, Department of Molecular Sciences, Swedish University of Agricultural Sciences, Uppsala, Sweden, 2019.

53. Priyashantha, H.; Quintán, A.P.; Baixauli, R.; Vidanarachchi, J.K. Type of starter culture influences on structural and sensorial properties of low protein fermented gels. *J. Texture Stud.* 2019, 50, 482–492. [CrossRef] [PubMed]

54. Adikari, A.M.M.U.; Jayathilake, J.A.M.S.; Parahitityawa, N.B.; Vidanarachchi, J.K.; Kodithuwakkhu, K.K.S.P. Biochemical and physiological characterization of *Lactobacillus* spp. isolated from curd (‘Meekiri’ and ‘Deekiri’). *Proc. Peradeniya Univ.* 2014, 18, 214.

55. Dekumpitiya, N.; Gamalakse, D.; Abeygunawardena, S.I.; Jayaratne, D. Identification of the Microbial Consortium in Sri Lankan Buffalo Milk Curd and their growth in the Presence of Prebiotics. *J. Food Sci. Technol. Nepal* 2016, 9, 20–30. [CrossRef]

56. Shuhadha, M.F.F.; Panagoda, G.J.; Madhujith, T.; Jayawardana, N.W.I.A. Evaluation of probiotic attributes of *Lactobacillus* sp. isolated from cow and buffalo curd samples collected from Kandy. *Ceylon Med. J.* 2017, 62, 159. [CrossRef]

57. Disanayaka, J.N.K.; Vidanarachchi, J.K.; Kodithuwakkhu, S.; Jayathilake, J.A.M.S.; Prasanna, P.H.P. Antifungal Property of *Lactobacillus fermentum* Isolated from Sri Lankan Homemade Curd on Candida Species: *Candida albicans*, *Candida glabrata*, *Candida krusei*, *Candida parapsilosis* and *Candida tropicalis*. In Proceedings of the Faculty of Agriculture Undergraduate Research Symposium 2018, University of Peradeniya, Peradeniya, Sri Lanka, 21 February 2019; p. 74.
Fermentation 2020, 6, 121

58. Borková, M.; Snášelová, J. Possibilities of different animal milk detection in milk and dairy products—A review. Czech J. Food Sci. 2011, 23, 41–50. [CrossRef]

59. Randiwela, R.; Mangalika, U.; Adikari, A.; Pathirana, A.; Weeragalla, W. PCR Based Assay for the Detection of Cow’s Milk Adulteration in Buffalo Curd. Int. J. Livest. Res. 2018, 8, 67. [CrossRef]

60. Sri Lanka Standard Institution (SLSI). Specification for Fermented Milk Products-Curd; Sri Lanka Standard Institution: Colombo, Sri Lanka, 1988; Volume I, p. 824.

61. Zachar, P.; Šolteš, M.; Kasarda, R.; Novotný, J.; Novíkkemcová, M.; Marcinčáková, D. Analytical methods for the species identification of milk and milk products. Mljekarstvo 2011, 61, 199–207. [CrossRef]

62. Jayamanne, V.; Samarajeewa, U. Evaluation of the effects of fermentation of buffalo curd and acidity on survival kinetics of Listeria monocytogenes. Trop. Agric. Res. Ext. 2011, 13, 94. [CrossRef]

63. Naalir, M. Good Times for Kantale Curd Industry. Features, Sunday Observer. 2011. Available online: http://archives.sundayobserver.lk/2011/06/19/fea09.asp (accessed on 14 July 2020).

64. Wickramaratne, D.; Gunasena, D. In vitro Antibacterial Activity of Lactobacillus Strains in Spontaneously Fermented Curd from Kanthale, Sri Lanka. In Proceedings of the Sixth AAAF, Colombo, Sri Lanka, 28–29 December 2016; ISBN 978-955-4534-34-8.

65. Rajapakse, N.; Jeganathan, B.; Wijesinghe, D.G.N.G.; Chandrasekara, A. Assessing the Probiotic Effect of Buffalo Milk Curd. In Proceedings of the Faculty of Agriculture Undergraduate Research Symposium, Peradeniya, Sri Lanka, 23 December 2014; p. 76. Available online: http://researcharchive.wintec.ac.nz/5434/1/Full_Proceedings.pdf (accessed on 23 June 2020).

66. Shafakatullah, N.; Chandra, M. Screening of raw buffalo’s milk from Karnataka for potential probiotic strains. Res. J. Recent Sci. 2014, 3, 73–78.

67. Forhad, M.H.; Rahman, S.M.K.; Rahman, M.S.; Saikot, F.K.; Biswas, K.C. Probiotic properties analysis of isolated lactic acid bacteria from buffalo milk. Arch. Clin. Microbiol. 2015, 7, 5–10.

68. Kumar, A.; Hussain, S.A.; Raja, P.N.; Singh, A.K.; Singh, R.R.B. Packaging material type affects the quality characteristics of Aloe-probiotic lassi during storage. Food Biosci. 2017, 19, 34–41. [CrossRef]

69. Shimamura, S.; Abe, F.; Ishibashi, N.; Miyakawa, H.; Yaeshima, T.; Araya, T.; Tomita, M. Relationship Between Oxygen Sensitivity and Oxygen Metabolism of Bifidobacterium Species. J. Dairy Sci. 1992, 75, 3296–3306. [CrossRef]

70. Yadav, H.; Jain, S.; Sinha, P.R. Effect of Dahi Containing Lactococcus lactis on the Progression of Diabetes Induced by a High-Fructose Diet in Rats. Biosci. Biotechnol. Biochem. 2006, 70, 1255–1258. [CrossRef] [PubMed]

71. Singh, R.; Kansal, V.K. Augmentation of immune response in mice fed with Dahi: A fermented milk containing Leuconostoc citrovorum and Lactococcus lactis. Milchwissenschaft 2003, 58, 480–482.

72. Vijayendra, S.; Gupta, R.C. Associative growth behavior of dahi and yoghurt starter cultures with Bifidobacterium bifidum and Lactobacillus acidophilus in buffalo skim milk. Ann. Microbiol. 2012, 63, 461–469. [CrossRef]

73. Melia, S.; Purwati, E.; Aritonang, S.N.; Silaen, M.; Yuherman; Jaswandi. Characterization of the Antimicrobial Activity of Lactic Acid Bacteria Isolated from Buffalo Milk in West Sumatera (Indonesia) Against Listeria monocytogenes. Pak. J. Nutr. 2017, 16, 645–650. [CrossRef]

74. Harun, H.; Wirasti, Y.; Purwanto, B.; Purwati, E. Characterization of lactic acid bacteria and determination of antimicrobial activity in Dadih from Dingin Alahan Panjang District, Solok regency—West Sumatera. Syst. Rev. Pharm. 2010, 20, 583–586. [CrossRef]

75. Syukur, S.; Fachrial, E.; Jamsari. Isolation, antimicrobial activity and protein bacteriocin characterization of lactic acid bacteria isolated from Dadih in Solok, West Sumatera, Indonesia. Res. J. Pharm. Biol. Chem. Sci. 2014, 5, 1096.

76. Metchnikoff, E. Lactic acid as Inhibiting Intestinal Putrefaction. In The Prolongation of Life: Optimistic Studies; W. Heinemann: London, UK, 1907; pp. 161–183.

77. Lilly, D.M.; Stillwell, R.H. Probiotics: Growth-Promoting Factors Produced by Microorganisms. Science 1965, 147, 747–748. [CrossRef] [PubMed]

78. Afr, R.F. Probiotics in man and animals. J. Appl. Bacteriol. 1989, 66, 365–378. [CrossRef]

79. Goldin, B.R.; Gorbach, S.L.; Fuller, R. Probiotics for Humans. In Probiotics: The Scientific Basis; Fuller, R., Ed.; Chapman & Hall: London, UK, 1992; pp. 355–386.
80. Salminen, S.; Ouwehand, A.; Benno, Y.; Lee, Y.K. Probiotics: How should they be defined? Trends Food Sci. Technol. 1999, 10, 107–110. [CrossRef]
81. Tannock, G.W.; Munro, K.; Harmsen, H.J.M.; Welling, G.W.; Smart, J.; Gopal, P.K. Analysis of the Fecal Microflora of Human Subjects Consuming a Probiotic Product Containing Lactobacillus rhamnosus DR20. Appl. Environ. Microbiol. 2000, 66, 2578–2588. [CrossRef]
82. Hill, C.; Guarner, F.; Reid, G.; Gibson, G.R.; Merenstein, D.J.; Pot, B.; Salminen, S. Expert consensus document: The international scientific association for probiotics and prebiotics consensus statement on the scope and appropriate use of the term probiotic. Nat. Rev. Gastroenterol. Hepatol. 2014, 11, 506. [CrossRef]
83. Boylston, T.D.; Vinderola, C.G.; Ghodusi, H.B.; Reinheimer, J.A. Incorporation of bifidobacteria into cheeses: Challenges and rewards. Int. Dairy J. 2004, 14, 375–387. [CrossRef]
84. Dagmar, Š.; Španova, A.; Špano, M.; Dráb, V.; Schwarzer, M.; Kozaková, H.; Rittich, B. Efficiency of PCR-based methods in discriminating Bifidobacterium longum ssp. longum and Bifidobacterium longum ssp. infantis strains of human origin. J. Microbiol. Methods 2011, 87, 10–16.
85. Douglas, L.C.; Sanders, M.E. Probiotics and Prebiotics in Dietetics Practice. J. Am. Diet. Assoc. 2008, 108, 510–521. [CrossRef]
86. Gorbach, S. Probiotics in the third millennium. Dig. Liver Dis. 2002, 34, S2–S7. [CrossRef]
87. Senok, A.C.; Ismaeel, A.Y.; Botta, G.A. Probiotics: Facts and myths. J. Dairy Sci. 2004, 87, 3250–3255. [CrossRef] [PubMed]
88. Ranadheera, C.S.; Evans, C.A.; Adams, M.C.; Baines, S.K. Probiotic viability and physico-chemical and sensory properties of plain and stirred fruit yogurts made from goat’s milk. Food Chem. 2012, 135, 1411–1418. [CrossRef]
89. Caplan, M.S.; Frost, B. Myth: Necrotizing enterocolitis: Probiotics will end the disease, and surgical intervention improves the outcome. Semin. Fetal Neonatal Med. 2011, 16, 264–268. [CrossRef]
90. Coeuret, V.; Gueguen, M.; Vernoux, J.P. In vitro screening of potential probiotic activities of selected lactobacilli isolated from unpasteurized milk products for incorporation into soft cheese. J. Dairy Res. 2004, 71, 451–460. [CrossRef]
91. Herbel, S.; Vahjen, W.; Wieler, L.H.; Guenther, S. Timely approaches to identify probiotic species of the genus Lactobacillus. Gut Pathog. 2013, 5, 27. [CrossRef] [PubMed]
92. Da Silva, T.M.S.; Piazentin, A.C.M.; Mendonça, C.M.N.; Converti, A.; Bogsan, C.S.B.; Mora, D.; Oliveira, R.P.D.S. Buffalo milk increases viability and resistance of probiotic bacteria in dairy beverages under in vitro simulated gastrointestinal conditions. J. Dairy Sci. 2020, 103, 7890–7897. [CrossRef]
93. Coeuret, V.; Gueguen, M.; Vernoux, J.P. In vitro screening of potential probiotic activities of selected lactobacilli isolated from unpasteurized milk products for incorporation into soft cheese. J. Dairy Sci. 2004, 71, 451–460. [CrossRef]
94. Songisepp, E.; Kullisaar, T.; Hütt, P.; Elias, P.; Brilene, T.; Mikelsaar, M. A New Probiotic Cheese with Antioxidative and Antimicrobial Activity. J. Dairy Sci. 2004, 87, 2017–2023. [CrossRef]
95. Minervini, F.; Siragusa, S.; Faccia, M.; Bello, F.D.; Gobberti, M.; De Angelis, M. Manufacture of Fior di Latte cheese by incorporation of probiotic lactobacilli. J. Dairy Sci. 2012, 95, 508–520. [CrossRef]
96. Junaid, M.; Javed, I.; Gulzar, M.; Ayaz, M.; Abdullah, M.; Younas, U.; Nasir, J. Flavored probiotic (Acidophilus) buffalo milk: Development and quality assessment. Buffalo Bull. 2013, 32, 1300–1304.
97. Macedo, R.F.; Freitas, R.J.S.; Pandey, A.; Soccol, C.R. Production and shelf-life studies of low cost beverage with soymilk, buffalo cheese whey and cow milk fermented by mixed cultures of Lactobacillus casei ssp. shirota and Bifidobacterium adolescentis. J. Basic Microbiol. 1999, 39, 243–251. [CrossRef]
98. Gul, O.; Mortas, M.; Atalar, I.; Dervisoglu, M.; Kahyaoglu, T. Manufacture and characterization of kefir made from cow and buffalo milk, using kefir grain and starter culture. J. Dairy Sci. 2015, 98, 1517–1525. [CrossRef] [PubMed]
99. Addeo, F.; Alloisio, V.; Chianese, L. Tradition and innovation in the water buffalo dairy products. Ital. J. Anim. Sci. 2007, 6, 51–57. [CrossRef]
100. Farnworth, E.R.; Mainville, I. Kefir: A Fermented Milk Product. In Handbook of Fermented Functional Foods; CRC Press: Boca Raton, FL, USA, 2003; Volume 2, pp. 89–127.
101. Ismail, A.A.; El-Nockrashy, S.A.; Khorshid, M.A. A beverage from separated buffalo milk fermented with kefir grains. Int. J. Dairy Technol. 1983, 36, 117–118. [CrossRef]
102. Ozcan, T.; Sahin, S.; Akpinar-Bayizit, A.; Yilmaz-Ersan, L. Assessment of antioxidant capacity by method comparison and amino acid characterisation in buffalo milk kefir. *Int. J. Dairy Technol.* 2019, 72, 65–73. [CrossRef]

103. Tomar, O.; Akarca, G.; Çağlar, A.; Beykaya, M.; Gök, V. The effects of kefir grain and starter culture on kefir produced from cow and buffalo milk during storage periods. *Food Sci. Technol.* 2020, 40, 238–244. [CrossRef]

104. Gul, O.; Atalar, I.; Mortas, M.; Dervisoglu, M. Rheological, textural, colour and sensorial properties of kefir produced with buffalo milk using keif grains and starter culture: A comparison with cows’ milk kefir. *Int. J. Dairy Technol.* 2018, 71, 73–80. [CrossRef]

105. Ranadheera, R.; Baines, S.; Adams, M. Importance of food in probiotic efficacy. *Food Res. Int.* 2010, 43, 1–7. [CrossRef]

106. Donkor, O.N.; Tsangalis, D.; Shah, N.P. Viability of probiotic bacteria and concentrations of organic acids in commercial yoghurts during refrigerated storage. *Food Aust.* 2007, 59, 121–126.

107. Nguyen, H.T.; Ong, L.; Kentish, S.E.; Gras, S.L. Homogenisation improves the microstructure, syneresis and rheological properties of buffalo yoghurt. *Int. Dairy J.* 2015, 46, 78–87. [CrossRef]

108. Nguyen, H.T.; Ong, L.; Lefèvre, C.; Kentish, S.E.; Gras, S. The Microstructure and Physicochemical Properties of Probiotic Buffalo Yoghurt During Fermentation and Storage: A Comparison with Bovine Yoghurt. *Food Bioprocess Technol.* 2013, 7, 937–953. [CrossRef]

109. Han, X. Survivability of probiotics in symbiotic low fat buffalo milk yoghurt. *Afr. J. Biotechnol.* 2012, 11, 12331–12338. [CrossRef]

110. Ehsani, A.; Banihabib, E.K.; Hashemi, M.; Saravani, M.; Yarahmadi, E. Evaluation of Various Properties of Symbiotic Yoghurt of Buffalo Milk. *J. Food Process. Preserv.* 2016, 40, 1466–1473. [CrossRef]

111. Santo, A.P.E.D.; Perego, P.; Converti, A.; Oliveira, M.N. Influence of milk type and addition of passion fruit peel powder on fermentation kinetics, texture profile and bacterial viability in probiotic yoghurts. *LWT* 2012, 47, 393–399. [CrossRef]

112. Kaushal, D.; Kansal, V.K. Probiotic Dahi containing *Lactobacillus acidophilus* and *Bifidobacterium bifidum* alleviates age-inflicted oxidative stress and improves expression of biomarkers of ageing in mice. *Mol. Biol. Rep.* 2011, 39, 1791–1799. [CrossRef]

113. Jain, S.; Yadav, H.; Sinha, P.R.; Kapila, S.; Naito, Y.; Marotta, F. Anti-allergic effects of probiotic Dahi through modulation of the gut immune system. *Turk. J. Gastroenterol.* 2010, 21, 244–250. [CrossRef]

114. Mohania, D.; Kansal, W.K.; Nagpal, R.; Yamashiro, Y.; Marotta, F. Suppression of diet-induced hypercholesterolemia by probiotic Dahi containing *Lactobacillus acidophilus* and *Lactobacillus plantarum*. *Int. J. Probiotics Prebiotics* 2013, 8, 75–84.

115. Shandilya, U.K.; Sharma, A.; Kapila, R.; Kansal, V.K. Probiotic Dahi containing *Lactobacillus acidophilus* and *Bifidobacterium bifidum* modulates immunoglobulin levels and cytokines expression in whey proteins sensitised mice. *J. Sci. Food Agric.* 2015, 96, 3180–3187. [CrossRef]

116. Gomes, A.; Braga, S.; Cruz, A.G.; Cadena, R.; Lollo, P.; Carvalho, C.; Amaya-Farfan, J.; Faria, J.; Bolini, H.M.A. Effect of the inoculation level of *Lactobacillus acidophilus* in probiotic cheese on the physicochemical features and sensory performance compared with commercial cheeses. *J. Dairy Sci.* 2011, 94, 4777–4786. [CrossRef]

117. Rolim, F.R.; Neto, O.C.F.; Oliveira, M.E.G.; Oliveira, C.J.; Queiroga, R.C. Cheeses as food matrices for probiotics: In vitro and in vivo tests. *Trends Food Sci. Technol.* 2020, 100, 138–154. [CrossRef]

118. Mushfaq, M.; Gani, A.; Masoodi, F.; Ahmad, M. Himalayan cheese (Kalari/Kradi)—Effect of different probiotic strains on oxidative stability, microbiological, sensory and nutraceutical properties during storage. *LWT* 2016, 67, 74–81. [CrossRef]

119. Murtaza, M.A.; Huma, N.; Shabbir, M.A.; Anees-Ur-Rehman, M. Survival of micro-organisms and organic acid profile of probiotic Cheddar cheese from buffalo milk during accelerated ripening. *Int. J. Dairy Technol.* 2017, 70, 562–571. [CrossRef]

120. Abesinghe, A.; Islam, N.; Vidanarachchi, J.; Prakash, S.; Silva, K.; Karim, M.A. Effects of ultrasound on the fermentation profile of fermented milk products incorporated with lactic acid bacteria. *Int. Dairy J.* 2019, 90, 1–14. [CrossRef]

121. Van Nieuwenhove, C.P.; Oliszewski, R.; Gonzalez, S.N.; Chaia, A.P. Influence of bacteria used as adjunct culture and sunflower oil addition on conjugated linoleic acid content in buffalo cheese. *Food Res. Int.* 2007, 40, 559–564. [CrossRef]
122. Sameer, B.; Ganguly, S.; Khetra, Y.; Sabikhi, L. Development and Characterization of Probiotic Buffalo Milk Ricotta Cheese. *LWT* **2020**, *121*, 108944. [CrossRef]
123. Diana, A.B.M.; Janer, C.; Peala, C.; Requena, T. Development of a fermented goat’s milk containing probiotic bacteria. *Int. Dairy J.* **2003**, *13*, 827–833. [CrossRef]
124. Prasanna, P.; Grandison, A.; Charalampopoulos, D. Screening human intestinal Bifidobacterium strains for growth, acidification, EPS production and viscosity potential in low-fat milk. *Int. Dairy J.* **2012**, *23*, 36–44. [CrossRef]
125. Akalin, A.; Unal, G.; Dinkci, N.; Hayaloglu, A. Microstructural, textural, and sensory characteristics of probiotic yogurts fortified with sodium calcium caseinate or whey protein concentrate. *J. Dairy Sci.* **2012**, *95*, 3617–3628. [CrossRef]
126. García-Ceja, A.; Mani-López, E.; Palou, E.; López-Malo, A. Viability during refrigerated storage in selected food products and during simulated gastrointestinal conditions of individual and combined lactobacilli encapsulated in alginate or alginate-chitosan. *LWT* **2015**, *63*, 482–489. [CrossRef]
127. Silva, K.C.G.; Cezarino, E.C.; Michelon, M.; Sato, A.C.K. Symbiotic microencapsulation to enhance *Lactobacillus acidophilus* survival. *LWT* **2018**, *89*, 503–509. [CrossRef]
128. Lacroix, C.; Yildirim, S. Fermentation technologies for the production of probiotics with high viability and functionality. *Curr. Opin. Biotechnol.* **2007**, *18*, 176–183. [CrossRef] [PubMed]
129. Nuraida, L. A review: Health promoting lactic acid bacteria in traditional Indonesian fermented foods. *Food Sci. Hum. Wellness* **2015**, *4*, 47–55. [CrossRef]
130. Collado, M.C.; Surono, I.; Meriluoto, J.; Salminen, S. Indigenous Dadih Lactic Acid Bacteria: Cell-Surface Properties and Interactions with Pathogens. *J. Food Sci.* **2007**, *72*, M89–M93. [CrossRef] [PubMed]
131. Surono, I.S. In Vitro Probiotic Properties of Indigenous Dadih Lactic Acid Bacteria. *Asian Australas. J. Anim. Sci.* **2003**, *16*, 726–731. [CrossRef]
132. Pato, U.; Johan, V.; Khairenisa, F.; Hasibuan, R.D.H. Antibiotic resistance and antibacterial activity of Dadih originated *Lactobacillus casei subsp.* casei R-68 against food borne pathogens. *Asian J. Microbiol. Biotech. Environ. Sci.* **2017**, *19*, 577–587.
133. Rashid, H.-U.; Togo, K.; Ueda, M.; Miyamoto, T. Probiotic Characteristics of Lactic Acid Bacteria Isolated from Traditional Fermented Milk ‘Dahi’ in Bangladesh. *Pak. J. Nutr.* **2007**, *6*, 645–652. [CrossRef]
134. Jatmiko, Y.D.; Howarth, G.S.; Barton, M. Assessment of Probiotic Properties of Lactic Acid Bacteria Isolated from *Indonesia Naturally Fermented Milk*; AIP Publishing: Melville, NY, USA, 2017.
135. Pato, U.; Ali, M.; Parhindungan, A.K. Taurocholate Deconjugation and Cholesterol Binding by Indigenous Dadih Lactic Acid Bacteria. *HAYATI J. Biosci.* **2005**, *12*, 103–107. [CrossRef]
136. Yuliawati, Y.; Jurnalis, Y.D.; Purwati, E.; Lubis, G. The Effect of *Pediococcus pentosaceus* on stool frequency, TNF-α level, gut microflora balance in diarrhea-induced mice. *Indones. J. Gastroenterol. Hepatol. Dig. Endosc.* **2012**, *13*, 97–102.
137. Aslinar, A.; Jurnalis, Y.D.; Purwati, E.; Sayoeti, Y. Probiotic Weisella paramesenteroides on enteropathogenic *E. coli*-induced diarrhea. *Paediatr. Indones.* **2014**, *54*, 1–8. [CrossRef]
138. Dharmawan, J.; Surono, I.S.; Kun, L.Y. Adhesion Properties of Indigenous Dadih Lactic Acid Bacteria on Human Intestinal Mucosal Surface. *Asian Australas. J. Anim. Sci.* **2006**, *19*, 751–755. [CrossRef]
139. Champagne, C.P.; Gardner, N.J.; Roy, D. Challenges in the Addition of Probiotic Cultures to Foods. *Crit. Rev. Food Sci. Nutr.* **2005**, *45*, 61–84. [CrossRef] [PubMed]
140. Khurana, H.; Kanawjia, S. Recent Trends in Development of Fermented Milks. *Curr. Nutr. Food Sci.* **2007**, *3*, 91–108. [CrossRef]
141. Al-Manhel, A.; Niamah, A. Mannan extract from *Saccharomyces cerevisiae* used as prebiotic in biyogurt production from buffalo milk. *Int. Food Res. J.* **2017**, *24*, 2259–2264.
142. Ramos, P.E.; Cerqueira, M.A.; Teixeira, J.A.; Vicente, A.A. Physiological protection of probiotic microcapsules by coatings. *Crit. Rev. Food Sci. Nutr.* **2018**, *58*, 1864–1877. [CrossRef] [PubMed]
143. Karki, T.; Shrestha, S.; Bohara, B.; Jyakhwa, U. Characterization and Comparison of Soy Milk and Buffalo Milk Based Synbiotic Product. *J. Food Sci. Technol. Nepal* **2014**, *8*, 23–29. [CrossRef]
144. Meybodi, N.M.; Mortazavian, A.M.; Arab, M.; Nematollahi, A. Probiotic viability in yoghurt: A review of influential factors. *Int. Dairy J.* **2020**, *109*, 104793. [CrossRef]
145. Tripathi, M.; Giri, S. Probiotic functional foods: Survival of probiotics during processing and storage. *J. Funct. Foods* **2014**, *9*, 225–241. [CrossRef]
146. De Araújo, E.M.; Raddatz, G.C.; Cichoski, A.J.; Flores, É.M.M.; Barin, J.S.; Zeppa, L.Q.; De Menezes, C.R. Effect of resistant starch (Hi-maize) on the survival of Lactobacillus acidophilus microencapsulated with sodium alginate. J. Funct. Foods 2016, 21, 321–29. [CrossRef]

147. Holkem, A.T.; Raddatz, G.C.; Barin, J.S.; Flores, É.M.M.; Muller, E.I.; Codevilla, C.F.; Jacob-Lopes, E.; Grosso, C.R.F.; De Menezes, C.R. Production of microcapsules containing Bifidobacterium BB-12 by emulsification/internal gelation. LWT 2017, 76, 216–221. [CrossRef]

148. Mokarram, R.; Mortazavi, S.A.; Najafi, M.B.H.; Shahidi, F. The influence of multi stage alginate coating on survivability of potential probiotic bacteria in simulated gastric and intestinal juice. Food Res. Int. 2009, 42, 1040–1045. [CrossRef]

149. Shah, N.; Ravula, R. Microencapsulation of probiotic bacteria and their survival in frozen fermented dairy desserts. Aust. J. Dairy Technol. 2000, 55, 139.

150. Jiménez-Pranteda, M.L.; Poncelet, D.; Nader-Macías, M.E.; Arcos, A.; Aguiler, M.; Montesoliva-Sánchez, M.; Ramos-Cormenzana, A. Stability of lactobacilli encapsulated in various microbial polymers. J. Biosci. Bioeng. 2012, 113, 179–184. [CrossRef]

151. Peniche, C.; Argüelles-Monal, W.; Peniche, H.; Acosta, N. Chitosan: An Attractive Biocompatible Polymer for Microencapsulation. Macromol. Biosci. 2003, 3, 511–520. [CrossRef]

152. Adhikari, K.; Mustapha, A.; Grün, I.; Fernando, L. Viability of Microencapsulated Bifidobacteria in Set Yogurt During Refrigerated Storage. J. Dairy Sci. 2000, 83, 1946–1951. [CrossRef]

153. Tsen, J.-H.; Lin, Y.-P.; Huang, H.-Y.; King, V.A.-E. Studies on the Fermentation of Tomato Juice by Using K-Carrageenan Immobilized Lactobacillus acidophilus. J. Food Process. Preserv. 2008, 32, 178–189. [CrossRef]

154. Borza, A.D.; Annan, N.T.; Moreau, D.L.; Allan-Wojtas, P.M.; Ghanem, A.; Rousseau, D.; Hansen, L.T. Microencapsulation in genipin cross-linked gelatine-maltodextrin improves survival of Bifidobacterium adolescentis during exposure to in vitro gastrointestinal conditions. J. Microencapsul. 2010, 27, 387–399. [CrossRef]

155. Hyndman, C.L.; Groboillot, A.F.; Poncelet, D.; Champagne, C.P.; Neufeld, R.J. Microencapsulation of Lactococcus lactis within cross-linked gelatin membranes. J. Chem. Technol. Biotechnol. 2007, 56, 259–263. [CrossRef]

156. Kia, E.M.; Ghasempour, Z.; Ghanbari, S.; Ehsani, A. Development of probiotic yogurt by incorporation of milk protein concentrate (MPC) and microencapsulated Lactobacillus paracasei in gellan-caseinate mixture. Br. Food J. 2018, 120, 1516–1528. [CrossRef]

157. Loyeau, P.; Spotti, M.; Braber, N.V.; Rossi, Y.; Montenegro, M.; Vinderola, G.; Carrara, C. Microencapsulation of Bifidobacterium animalis subsp. lactis IN1 using whey proteins and dextran conjugates as wall materials. Food Hydrocoll. 2018, 85, 129–135. [CrossRef]

158. Shi, L.-E.; Li, Z.-H.; Li, D.-T.; Xu, M.; Chen, H.-Y.; Zhang, Z.-L.; Tang, Z.-X. Encapsulation of probiotic Lactobacillus bulgaricus in alginate-milk microspheres and evaluation of the survival in simulated gastrointestinal conditions. J. Food Eng. 2013, 117, 99–104. [CrossRef]

159. Ji, R.; Wu, J.; Zhang, J.; Wang, T.; Zhang, X.; Shao, L.; Chen, D.; Wang, J. Extending Viability of Bifidobacterium longum in Chitosan-Coated Alginate Microcapsules Using Emulsification and Internal Gelation Encapsulation Technology. Front. Microbiol. 2019, 10, 1389. [CrossRef] [PubMed]

160. Lee, Y.; Ji, Y.R.; Lee, S.; Choi, M.-J.; Cho, Y. Microencapsulation of Probiotic Lactobacillus acidophilus KBL409 by Extrusion Technology to Enhance Survival under Simulated Intestinal and Freeze-Drying Conditions. J. Microbiol. Biotechnol. 2019, 29, 721–730. [CrossRef] [PubMed]

161. Silva, P.T.D.; Fries, L.L.M.; Menezes, C.R.D.; Silva, C.D.B.D.; Soriani, H.H.; Bastos, J.D.O.; Motta, M.H.; Ribeiro, R.F. Microencapsulation of probiotics by spray drying: Evaluation of survival in simulated gastrointestinal conditions and availability under different storage temperatures. Ciência Rural 2015, 45, 1342–1347. [CrossRef]

162. Schell, D.; Beermann, C. Fluidized bed microencapsulation of Lactobacillus reuteri with sweet whey and shellac for improved acid resistance and in-vitro gastro-intestinal survival. Food Res. Int. 2014, 62, 308–314. [CrossRef]

163. Martín, M.J.; Lara-Villolosla, F.; Ruiz, M.A.; Morales, M.E. Microencapsulation of bacteria: A review of different technologies and their impact on the probiotic effects. Innov. Food Sci. Emerg. Technol. 2015, 27, 15–25. [CrossRef]
164. Ribeiro, M.C.E.; Chaves, K.S.; Gebara, C.; Infante, F.N.; Grosso, C.R.F.; Gigante, M.L. Effect of microencapsulation of *Lactobacillus acidophilus* LA-5 on physicochemical, sensory and microbiological characteristics of stirred probiotic yoghurt. *Food Res. Int.* 2014, 66, 424–431. [CrossRef]

165. Brinques, G.B.; Ayub, M.A.Z. Effect of microencapsulation on survival of *Lactobacillus plantarum* in simulated gastrointestinal conditions, refrigeration, and yogurt. *J. Food Eng.* 2011, 103, 123–128. [CrossRef]

166. Pavunc, A.L.; Beganović, J.; Kos, B.; Buneta, A.; Beluhan, S.; Šušković, J. Influence of microencapsulation and transglutaminase on viability of probiotic strain *Lactobacillus helveticus* M92 and consistency of set yoghurt. *Int. J. Dairy Technol.* 2010, 64, 254–261. [CrossRef]

167. Ortakci, F.; Sert, S. Stability of free and encapsulated *Lactobacillus acidophilus* ATCC 4356 in yoghurt and in an artificial human gastric digestion system. *J. Dairy Sci.* 2012, 95, 6918–6925. [CrossRef]

168. Shoji, A.; Oliveira, A.; Balieiro, J.; Freitas, O.; Thomazini, M.; Heinemann, R.; Okuro, P.; Favaro-Trindade, C. Viability of *L. acidophilus* microcapsules and their application to buffalo milk yoghurt. *Food Bioprod. Process.* 2013, 91, 83–88. [CrossRef]

169. Chávarri, M.; Marañón, I.; Ares, R.; Ibáñez, F.C.; Marzo, F.; Villarán, M.D.C. Microencapsulation of a probiotic and prebiotic in alginate-chitosan capsules improves survival in simulated gastro-intestinal conditions. *Int. J. Food Microbiol.* 2010, 142, 185–189. [CrossRef] [PubMed]

170. Awad, T.; Moharram, H.; Shaltout, O.E.; Asker, D.; Youssef, M. Applications of ultrasound in analysis, processing and quality control of food: A review. *Food Res. Int.* 2012, 48, 410–427. [CrossRef]

171. Guimarães, J.T.; Balthazar, C.F.; Scudino, H.; Pimentel, T.C.; Esmerino, E.A.; Kumar, M.A.; Freitas, M.Q.; Cruz, A.G. High-intensity ultrasound: A novel technology for the development of probiotic and prebiotic dairy products. *Ultrason. Sonochem.* 2019, 57, 12–21. [CrossRef] [PubMed]

172. Nguyen, T.M.P.; Lee, Y.K.; Zhou, W. Stimulating fermentative activities of bifidobacteria in milk by highintensity ultrasound. *Int. Dairy J.* 2009, 19, 410–416. [CrossRef]

173. Wu, H.; Hulbert, G.J.; Mount, J.R. Effects of ultrasound on milk homogenization and fermentation with yogurt starter. *Innov. Food Sci. Emerg. Technol.* 2000, 1, 211–218. [CrossRef]

174. Barukčić, I.; Jakopović, K.L.; Herceg, Z.; Karlović, S.; Božanić, R. Influence of high intensity ultrasound on microbial reduction, physico-chemical characteristics and fermentation of sweet whey. *Innov. Food Sci. Emerg. Technol.* 2015, 27, 94–101. [CrossRef]

175. Huang, G.; Chen, S.; Tang, Y.; Dai, C.; Sun, L.; Ma, H.; He, R. Stimulation of low intensity ultrasound on fermentation of skim milk medium for yield of yoghurt peptides by *Lactobacillus paracasei* Ultrason. *Sonochem.* 2019, 51, 315–324. [CrossRef]

176. Puvanenthiran, A.; Williams, R.P.; Augustin, M. Structure and visco-elastic properties of set yoghurt with altered casein to whey protein ratios. *Int. Dairy J.* 2002, 12, 383–391. [CrossRef]

177. Abesinghe, A.; Vidanarachchi, J.; Islam, N.; Prakash, S.; Silva, K.; Bhandari, B.; Karim, M. Effects of ultrasonication on the physicochemical properties of milk fat globules of *Bubalis bubalis* (water buffalo) under processing conditions: A comparison with shear-homogenization. *Innov. Food Sci. Emerg. Technol.* 2020, 59, 102237. [CrossRef]

178. Lin, M.-Y.; Yen, C.-L. Antioxidative Ability of Lactic Acid Bacteria. *J. Agric. Food Chem.* 1999, 47, 1460–1466. [CrossRef] [PubMed]

179. Mortazavian, A.; Ehsani, M.; Mousavi, S.; Sohrabvandi, S.; Reinheimer, J. Combined effects of temperature-related variables on the viability of probiotic microorganisms in yoghurt. *Aust. J. Dairy Technol.* 2006, 61, 248.

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