Sustainable Preservation Approaches of Whey cheeses

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Whey cheeses have been produced from the very early steps of cheesemaking practices as a sustainable way to utilize whey, which is the main by-product of cheesemaking.

whey cheese | sustainable preservation | bio-preservation | functional whey cheeses

1. Modified Atmosphere Packaging

The use of effective and sustainable methods for the preservation and safety of whey cheeses is necessary to control cross-contamination of fresh whey cheeses throughout their storage. The increased consumer demand for fresh, preservative-free foods has led to extended research on advances in cheese preservation focusing on 'clean labels' [1]. The use of modified atmosphere packaging (MAP) as a technique to improve product' safety and extend the shelf life satisfies the chemical preservative-free strategies for various foods [2]; MAP is widely used as a storage method, extending the shelf life and improving the appearance of several foods. The potential of MAP and active packaging for extending shelf life of dairy products, including cheese, has been demonstrated [3][4][5].

Several MAP conditions were used to assess the effect of MAP on the characteristics, that is, free fatty acids, lactose, lactic acid, moisture, pH, and texture of whey cheeses [6][7][8][9][10][11][12][13][14][15][16]. The MAP conditions and the best practice and/or effect on whey cheeses is presented in **Table 1**. Different mixtures have been applied in different whey cheeses; in most studies, a specific mixture of gases provided an extension in the shelf life.

Table 1. Modified atmosphere packaging (MAP) conditions and the best practice and/or effect on whey cheeses.

Cheese	MAP Conditions Used	Best Practice/Effect	Reference
Anthotyros	40% CO_2/55% N_2/5% O_2, 60% CO_2/40% N_2 and 50% CO_2/50% N_2	60% CO_2/40% N_2 and 50% CO_2/50% N_2 mixtures proved to be most effective for inhibiting total mesophilic microorganisms and *E. coli*	[10]
Anthotyros	30% CO_2/70% N_2 and 70% CO_2/30% N_2	The use of MAP conditions 70% CO_2/30% N_2 extended the shelf-life of fresh cheese for 20 days	[11]
Anthotyros	40% CO_2/60% N_2 and basil essential oil (0.4% *v*/*w*)	Extend the shelf life by approximately 10–12 days compared to aerobic packaging	[12]

Cheese	MAP Conditions Used	Best Practice/Effect	Reference
Lor	40% CO_2/60% N_2, 60% CO_2/40% N_2 and 70% CO_2/30% N_2	60% and 70% CO_2 were the most effective mixture for inhibition of growth of micro-organisms	[13]
Lor	80% CO_2/20% N_2 and 60% CO_2/40% N_2	80% CO_2/20% N_2 was the most effective for inhibiting growth of micro-organisms	[14]
Myzithra Kalathaki	20% CO_2/80% N_2, 40% CO_2/60% N_2 and 60% CO_2/40% N_2	40% CO_2/60% N_2 was the most effective treatment for the inhibition of psychrotrophs in Myzithra cheese until days 40; control samples were sensorily unacceptable after 10–12 days of storage	[17]
Requeijao	100% CO_2, 100% N_2 and 50% CO_2/50% N_2	CO_2 alone ensured more consistent cheese composition until 15 days of storage and provided protection against lipolysis	[15]
Ricotta fresca	30% CO_2/70% N_2 and 100% N_2	No evidence that MAP conditions used in Sardinian dairies allowed to extend the shelf life to 21 days	[6]

[16] ... giotensin-converting-enzyme (ACE)-inhibitory activities in Requeson. Di Pierro et al. [18] studied the application of chitosan/whey protein film as active coating in combination with 40% CO_2/60% N_2 MAP conditions to extend the shelf life of Ricotta cheese; the treatment reduced the viable numbers of mesophilic and psychrotrophic bacteria and delayed the development of undesirable acidity, better maintained the texture, and did not modify the sensory characteristics.

2. Addition of Herbs and/or Plant Extracts

There are a number of studies in the literature on the addition of various herbs and/or plant extracts and their potential use in combination with different packaging materials to extend the shelf life of whey cheeses [16][18][19][20][21][22][23][24]. Black cumin, thyme, and rosemary are frequently added to cheeses because of their sensory and antioxidant properties [19][20]. Akpinar et al. [19] studied whey cheeses packaged in goat-skin bags used for the storage of traditional cheeses with a long shelf life (semi-hard and hard cheeses) and alternatively studied cheeses in artificial casings. In addition to different packaging materials, the potential usage of different plants (black cumin, thyme, and rosemary) in Lor cheese production was evaluated.

Christaki et al. [24] studied the effect of oregano essential oil and extracts on two Greek whey cheeses. The authors evaluated the feasibility of employing oregano essential oil and extracts in whey cheese to control fungal contamination that causes cheese spoilage and important economic losses and reported that the combination of oregano essential oil and extracts produced nanoemulsions with potent antioxidant and antifungal activity against *Penicillium expansum* in vitro.

3. Bio-Preservation

The use of natural antimicrobial compounds from a wide variety of natural sources, or protective LAB cultures, i.e., bio-preservation, has been studied extensively [25][26][27][28][29][30][31][32][33][34][35][36][37][38][39][40][41][42][43][44][45]. Bio-preservation is of high interest due to its ecological sustainability and consumer friendly nature [32]. Unlike artificially synthesized chemical preservatives that have toxic effects over long-term usage, bio-preservatives offer little or no harmful health effects [37][38][39][40][41][42]. Nisin, a bacteriocin produced by strains of *Lactococcus lactis* subsp. *lactis* has been used as a natural preservative to extend the self-life of certain dairy products [24][33]. Nisin inhibits Gram-positive bacteria, including *L. monocytogenes* and *B. cereus* and outgrows the spores of members of the genus *Bacillus* and *Clostridium* [26][33]. Wu et al. [43] concluded that the combined use of nisin with other antibacterial methods showed more advantageous activities against *L. monocytogenes* than single use.

Samelis et al. [34] investigated the use of nisin as a bio-preservative to control *L. monocytogenes* introduced post-processing on Anthotyros stored in refrigerated storage in vacuum packages for up to 45 days; they reported that this treatment suppressed *L. monocytogenes* growth below the inoculation level for 30 and 45 days [34]. Interestingly, nisin resulted in a switch in the natural spoilage flora of Anthotyros from Gram-positive to Gram-negative [34]. Aspri et al. [35] applied a bacteriocin-producing *Enterococcus faecium* isolated from donkey milk in the bio-control of *L. monocytogenes* in fresh whey cheese. Spanu et al. [36] investigated bio-preservatives to control the growth of spoilage microorganism, that is *Pseudomonas* spp., on the surface of MAP-packed Ricotta fresca during refrigerated storage and *Carnobacterium* spp. inoculated on the surface of the finished product; they reported promising results in controlling contamination of Ricotta fresca with certain spoilage microorganisms. In another study, *Carnobacterium* spp. significantly reduced the growth of *Pseudomonas* spp. at 1.28 log and 0.83 log after 14 and 21 days of refrigerated storage, respectively [37]. Fernández et al. [42] studied the effect of nisin alone and in combination with Microgard, that is bacteriocin-like inhibitory products, on the microbial flora of Ricotta cheese.

Bacteriocin production in situ from several LAB and its impact on food preservation have been examined; thermophilin T, a bacteriocin produced by *Streptococcus thermophilus* ACA-DC 0040, had an inhibitory activity against a large number of related LAB as well as *Clostridium* spp. [44]. Kaminarides et al. [45] evaluated the effect of thermophilin T, previously produced in fermented milk, on the microbiological and physicochemical characteristics of Myzithra cheese.

More recently, Sameli et al. [40] studied the effect of an enterocin A-B-P crude extract on the spoilage microbiota in fresh Anthotyros whey cheeses stored at refrigeration temperatures in vacuum for 40 days; *Pseudomonas* spp., *Aeromonas* spp., *Hafnia* spp., and *Serratia* spp. grew faster than LAB during early storage. Later, LAB outgrew the Gram-negative bacteria and prevailed by mid- to late storage in all cheese batches, causing an acidification effect [40]. Sameli and Samelis [25] assessed the growth and bio-control of inoculated *L. monocytogenes* in Anthotyros whey cheeses, without or with 5% of a crude enterocin A-B-P extract during storage at 4° C. From day 15 to the sell-by date (days 35–40), *L. monocytogenes* growth ceased, and progressively, the populations of the pathogen declined in most cheeses; this was due to an unmonitored, batch-dependent natural acidification by spoilage lactic acid bacteria, predominantly *Leuconostoc mesenteroides*, which reduced the cheese pH to 5.5 and finally to a value of 5.0 [25].

4. Novel Treatments for Extending the Shelf Life

During the last 10 years, a number of novel treatments have been applied to whey cheeses in order to extend the shelf life and to enhance their functional and sensory characteristics. Duarte et al. [46] proposed an alternative to refrigerated storage technology for Requeijão; they stored the cheese under 100 MPa hyperbaric storage at variable room temperature, and total aerobic mesophiles and *Enterobacteriaceae* growth was inhibited. For LAB, yeasts, and molds, hyperbaric storage showed an additional microbial inactivation effect. This technology is an environmentally friendlier technology, with a carbon footprint estimated to be about 26-fold lower compared to refrigerated storage [46]. The possibilities of using the continuous type of UV-C light on the surface of Lor cheese was studied, and it was found that the application of UV-C light (1.617, 4.018, and 36.832 kJ/m^2) to the cheese surface allowed delaying mold growth during storage; however, extreme doses could induce lipid and protein oxidation reactions, leading to quality deterioration [47].

Two novel food preservation technologies were applied to Ricotta, that is pulsed light [48] and plasma treatment [49]. The authors concluded that both methods could be used to extend the shelf life of Ricotta cheese. To extend the shelf life of buffalo Ricotta cheese, a process was assessed that included a second heat treatment followed by homogenization and hot packaging. In another study, Tripaldi et al. [50] reported that homogenized buffalo Ricotta cheese had a longer shelf life than traditional Ricotta cheese, although the process could be optimized to reduce the total bacterial load during storage.

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