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Technological Strategies to Preserve Burrata Cheese Quality

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Abstract: Burrata cheese is a very perishable product due to microbial proliferation and undesirable sensory changes. In this work, a step-by-step optimization approach was used to design proper processing and packaging conditions for burrata in brine. In particular, four different steps were carried out to extend its shelf life. Different headspace gas compositions (MAP-1 30:70 CO_2:N_2; MAP-2 50:50 CO_2:N_2 and MAP-3 65:35 CO_2:N_2) were firstly tested. To further promote product preservation, a coating was also optimized. Then, antimicrobial compounds in the filling of the burrata cheese (lysozyme and Na_2-EDTA) and later in the coating (enzymatic complex and silver nanoparticles) were analyzed. To evaluate the quality of the samples, in each step headspace gas composition, microbial population, and pH and sensory attributes were monitored during storage at 8 ± 1 °C. The results highlight that the antimicrobial compounds in the stracciatella, coating with silver nanoparticles, and packaging under MAP-3 represent effective conditions to guarantee product preservation, moving burrata shelf life from three days (control sample) to ten days.

Keywords: burrata cheese; shelf life; antimicrobial coating; packaging design

1. Introduction

Burrata is a fresh Italian cheese, typically produced in the Apulia region, made from fiordilatte paste and a cream called stracciatella. The outer shell is solid fiordilatte paste while the inside contains both fiordilatte pieces and cream, giving it a soft texture. Burrata is traditionally stored under refrigerated conditions, like fiordilatte and mozzarella cheese, and it can be packaged with or without brine in atmospheric conditions. Due to the high moisture and fat content, this dairy product results in rapid spoilage. It is well-known that the shelf life of fresh cheese is influenced by both microbial and sensory changes [1–3]. To preserve the characteristics of fresh cheese during storage several techniques have been suggested in the literature [4–6]. Several authors demonstrated the effects of modified atmosphere conditions (MAP) on extending the shelf life of fresh cheese [2,3,7].

In particular, the headspace gas composition characterized by a low concentration or lack of oxygen and high carbon dioxide improves the microbiological stability, reduces lipid oxidation and increases sensory acceptability [1,2,8]. A proper successful gas combination for burrata cheese packaged without brine was proposed by Conte et al. [9]. The application of antimicrobial compounds, such as essential oils, organic acids, bacteriocins and nanoparticles, was also found to be a strategic solution to improve the shelf life of different fresh cheeses [6,10–13]. To retard the microbial spoilage of dairy products, the antimicrobial compounds can be directly added into the product formulation, carried by coatings or loaded into the packaging materials. Among them, a great deal of attention

has been devoted to inorganic nanoparticles (i.e., silver and copper) for their proven effects on the microbial stability of various foodstuffs [13–18]. In particular, scientific research has reported that silver nanoparticles immobilized on packaging materials or loaded in coatings improves the shelf life of mozzarella [12,17,19]. Enzymes can also play an interesting role in antimicrobial activity [6].

In particular, lysozyme, an enzyme found in many natural systems, shows antimicrobial activity against gram-positive bacteria more than gram-negative; however, the susceptibility of gram-negative bacteria can be enhanced by chelating agents such as ethylene diamine tetraacetic acid disodium salt (Na_2-EDTA). Different works have reported the antimicrobial activity of lysozyme alone or in combination with Na_2-EDTA [9,20,21]. The lactoperoxidase system—an enzymatic complex characterized by the lactoperoxidase enzyme, thiocyanate and hydrogen peroxide—is also active against gram-positive bacteria such as *Listeria monocytogenes* and *Staphylococcus aureus,* as well as gram-negative bacteria, including *Escherichia coli* [22,23]. The activity of the lactoperoxidase system has been verified on many bacterial species and pathogens in cow milk and dairy products [24,25].

To the best of our knowledge, no studies have reported on the packaging of burrata cheese with brine. The brine solution better preserves product hydration but it also concurs with the development of spoilage microorganisms. Therefore, the aim of this study was to evaluate step by step the influence of MAP, lysozyme and Na_2-EDTA in the burrata filling and the adoption of a proper active coating on burrata cheese shelf life. To assess the influence of the selected strategies, headspace gas composition, pH, spoilage microorganisms and sensory quality were monitored during the storage period.

2. Materials and Methods

2.1. Materials

Samples of burrata cheese (pieces of 150 g) were kindly provided by "Capurso Azienda Casearia SPA" (Gioia del Colle, Bari, Italy). The sodium alginic acid and the calcium chloride, as well as lysozyme, Na_2-EDTA and lactoperoxydase system (Sea-i® F75) were purchased from Perrin's Chemicals (Triggiano, Italy). Silver-montmorillonite nanoparticles were prepared by ion exchange reaction between Na^+-montmorillonite and silver nitrate solutions, as reported in detail by Incoronato et al. [12]. Polypropylene trays and multilayer film (oriented polyamide/polypropylen 75/15 µm) for tray tops were purchased from Orved (Musile di Piave, Venezia, Italy).

2.2. Sample Preparation

Table 1 briefly reports the different strategies applied to the burrata in each step. The details are reported below.

- Step 1: Two burrata samples were placed in a tray containing brine constituted by a NaCl solution (6 $g \cdot L^{-1}$). Samples were packaged under MAP conditions (MAP-1 30:70 CO_2:N_2; MAP-2 50:50 CO_2:N_2 and MAP-3 65:35 CO_2:N_2) by means of a thermo-sealing machine (Orved, Musile di Piave, Venezia, Italy).
- Step 2: In the second step, the burrata cheese was coated by immersing samples first in a sodium alginic acid solution (2% *w*/*v*), then a solution of calcium chloride (5% *w*/*v*) was used to promote the alginate-gel-forming process by dipping the product for one min. Two coated samples were packaged with brine in air (Coat-Air) and under MAP (65:35 CO_2:N_2) (Coat-MAP).
- Step 3: In this step, the antimicrobial compounds were added to the burrata filling during the production process. In particular, lysozyme (500 $mg \cdot kg^{-1}$) and Na_2-EDTA (50 mM) were dissolved in the cream and then mixed with the fiordilatte pieces. Samples of burrata with the antimicrobial compounds were packaged in air (LysEDTA-Air) and under MAP (65:35 CO_2:N_2) (LysEDTA-MAP). Moreover, burrata with the antimicrobial compounds was coated as described in Step 2 and packaged under MAP (65:35 CO_2:N_2) [Coat-LysEDTA].

- Step 4: In this step, burrata cheese with the antimicrobial compounds (lysozyme and Na_2-EDTA) was produced as described in Step 3. Subsequently, the samples were coated with alginic acid loaded with silver nanoparticles (250 mg·kg^{-1}) [NanoAg-A] or the lactoperoxidase system (10,000 mg·kg^{-1}) [LPX-A] and packaged under MAP (65:35 CO_2:N_2).

Table 1. Experimental step to improve burrata cheese shelf life.

Experimental Steps		Antimicrobial Compounds in the Burrata Filling		Coating with Antimicrobial Compound				Headspace Gas Composition			
		No. Antimicrobial	Lysozyme/ Na_2-EDTA	Absent	No. Antimicrobial	Silver Nanoparticles	Lactoperoxi_ dase system	Air	MAP-1	MAP-2	MAP-3
Step-1	Cntr-1	√		√				√			
	MAP-1	√		√					√		
	MAP-2	√		√						√	
	MAP-3	√		√							√
Step-2	Cntr-2	√		√				√			
	Coat-Air	√			√			√			
	Coat-MAP	√			√						√
Step-3	Cntr-3	√		√				√			
	LysEDTA-Air		√	√				√			
	LysEDTA-MAP		√	√							√
	Coat-Lys EDTA		√		√						√
Step-4	Cntr-4	√		√				√			
	Cntr-A		√	√				√			
	NanoAg-A		√			√					√
	LPX-A		√				√				√

Due to the variability of the raw material, a control sample without coating and antimicrobial compounds and packaged in air was also prepared in each step (Cntr-1; Cntr-2; Cntr-3; Cntr-4). All the burrata samples were stored at 8 ± 1 °C.

2.3. Microbiological Analyses and Determination of pH

The burrata cheese (20 g) was diluted in a sterile saline solution (0.9%) and homogenized in a blender (Stomacher, International PBI, Milan, Italy). Decimal dilutions of homogenate cheese were made in a saline solution and plated on selective media for the determination of lactic acid bacteria, lactococci, total bacterial count, Enterobacteriaceae and *Pseudomonas spp*. The media and the conditions were the following: de Man Rogosa and Sharpe (MRS) agar, supplemented with cycloheximide (0.17 g·L^{-1}) (Sigma, Milan, Italy) incubated under anaerobic conditions at 37 °C for 48 h for lactic acid bacteria; M17 agar, incubated at 37 °C for 48 h for lactococci; plate count agar (PCA), incubated at 30 °C for 48 h for total bacteria count; Violet Red Bile Glucose Agar (VRBGA) incubated at 37 °C for 24 h for Enterobacteriaceae; Pseudomonas Agar Base (PAB), added with SR103 selective supplement (Oxoid, Milan, Italy) and incubated at 25 °C for 48 h for *Pseudomonas spp.* All media were purchased from Oxoid (Milan, Italy). All the analyses were performed in duplicate.

At each sampling time the pH of the burrata and brine solution were also measured by a pH meter (Crison, Barcelona, Spain) with an accuracy of 0.01 pH. The instrument was calibrated with 4.01 and 7.00 pH buffer solutions. The measurements were done in duplicate on two different samples.

2.4. Headspace Gas Composition

Oxygen and carbon dioxide headspace concentrations of packaged burrata were measured using a gas meter (PBI Dansensor, Checkmate 9900, Ringsted, Denmark), previously calibrated by the company at 23 ± 2 °C and a pressure of 1013 ± 50 hPa. The volume taken from the package headspace for gas analysis was about 10 cm^3. To avoid modifications in the headspace gas composition each package was used only for a single measurement of gas composition. Two packages were used at each sampling time.

2.5. Sensory Analysis

Sensory evaluation was carried out by seven trained panelists, members belonging to the food packaging laboratory. The selection of the panelists was made considering various aspects: interest and motivation, eating habits (consumption of fresh dairy products), ability to communicate sensations, time available for analysis sessions, ability to concentrate, and performance training. Eight sessions of 1 h each were required to define the sensory profile, with a frequency of three meetings a week. The sessions were used to familiarize the testers with the characteristics of burrata cheese samples in terms of odor, color, texture and overall quality [26,27]. The samples coated with alginic acid were presented with and without coating to the panelists in a random order [27]. The quality of the attributes (firmness, color, odor and overall quality) of the cheese samples were evaluated. The intensity of each attribute was quantified on a 7-point scale where 1 corresponded to fully poor quality, 2 to poor quality, 3 inadequate quality, 4 represented the threshold for product acceptability, 5 good quality, 6 very good quality, 7 excellent quality [2].

2.6. Shelf Life Calculation

For each step, to calculate the shelf life values of the burrata cheese, the microbial acceptability limit (*MAL*) and the sensory acceptability limit (*SAL*) were assessed with a re-parameterized Gompertz equation [2,26]. Shelf life was assumed to be the lowest value between *MAL* and *SAL*. In particular, the following equation was used to calculate the *MAL*:

$$\mathrm{Log}(N(t)) = \log(N_{max}) - A \times e^{-e^{[\{[u_{max} \times 2.71 \frac{\lambda - MAL}{A}]+1\}]}} + A \times e^{-e^{[\{[u_{max} \times 2.71 \frac{\lambda - t}{A}]+1\}]}} \quad (1)$$

where $N(t)$ is the viable cell concentration (CFU/g) at storage time t; A is related to the difference between the decimal logarithm of maximum bacterial growth attained at the stationary phase and the decimal logarithm of the initial cell load concentration (CFU/g); μ_{max} is the maximal specific growth rate (Δlog[CFU/g]/day); λ is the lag time (day); t is the time (day); N_{max} is the cell load concentration threshold value (CFU/g); and *MAL* is the microbial acceptability limit (day) (i.e., the storage time at which the $N(t)$ equals N_{max}). The microbial threshold (N_{max}) was set to 10^6 CFU/g for total *Pseudomonas spp.*

A similar approach was used to quantitatively determine the efficacy of the tested variables (i.e., antimicrobial compounds, gas composition and coating) on sensory quality. To this aim, the re-parameterized [2,26] Gompertz equation was also fitted to the sensory data:

$$QSQ(t) = OSQ_{\min} - A^Q \times e^{[-e^{\{[u^Q_{max} \times 2.71 \frac{\lambda^Q - SAL}{A^Q}] + 1\}}] + A^Q \times e^{[-e^{[\{[u^Q_{max} \times 2.71 \frac{\lambda^Q - t}{A^Q}]+1\}]}}} \quad (2)$$

where $OSQ(t)$ is the burrata cheese overall quality at time t; A^Q is related to the difference between the overall quality attained at the stationary phase and the initial value; u^Q_{max} is the maximal rate at which $OSQ(t)$ decreases; λ^Q is the lag time; $OSQ_{\min}$ is the threshold value; *SAL* is the sensory acceptability limit (i.e., the storage time at which the $OSQ(t)$ equals $OSQ_{\min}$); and t is the storage time. The value of $OSQ_{\min}$ was set equal to 4.

2.7. Statistical Analysis

The *MAL*, *SAL* and shelf life values of all the investigated samples were compared respectively by one-way Anova analysis. A Duncan multiple range test, with the option of homogeneous groups ($p < 0.05$), was used to determine significance among differences. To this aim, Statistica 7.1 for Windows (StatSoft Inc., Tulsa, OK, USA) was used.

3. Results and Discussion

The first experimental step was aimed at assessing the optimal MAP composition to improve the microbial and sensory quality of burrata cheese packaged with brine. In particular, three different headspace gas compositions with increasing concentrations of carbon dioxide were tested (30:70; 50:50 and 65:35 CO_2:N_2). The data are reported in Figure 1, where a rapid reduction of carbon dioxide in all tested packages was detected due to the solubility and diffusivity of gas in brine and in burrata cheese [28]. After one week of storage, an increase of headspace carbon dioxide was observed above all for the Cntr-1 sample packaged in air, principally due to the metabolic reaction of microbial proliferation [29]. For the same reason, a gradual decrease of oxygen concentration (up to 0%) was found in Cntr-1. For all samples packaged under MAP conditions, a gradual oxygen increase (up to 3 ± 0.5%) was detected during the storage time, mainly attributable to film permeability.

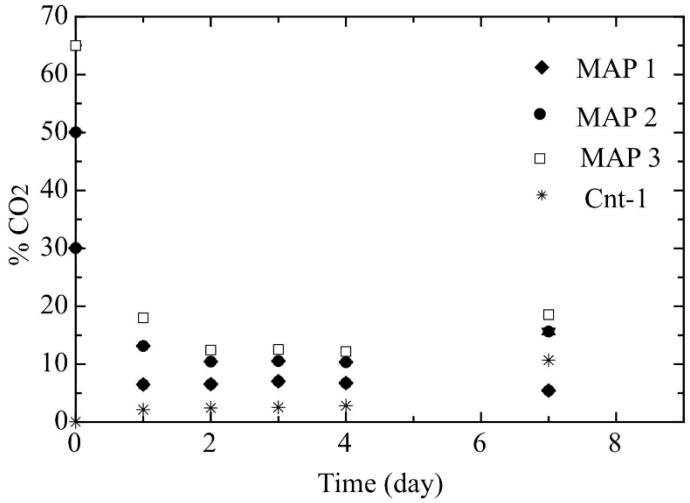

Figure 1. Carbon dioxide concentration in burrata samples packaged in air and under MAP.

Figure 2 shows the pH value of brine for samples packaged in air and under MAP. As expected, lower pH values were detected for samples packaged under MAPs compared to the control [28].

In particular, dissolved carbon dioxide is hydrated into carbonic acid, bicarbonate ion and carbonate ion, with the liberation of protons that cause pH change [28]. However, the pH of all the burrata samples remained constant for the entire storage period (6.50 ± 0.05) (data not shown).

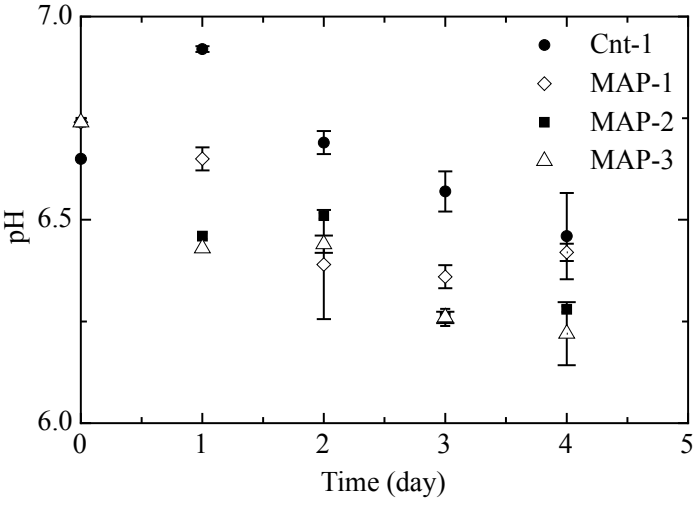

Figure 2. pH value of brine for samples packaged in air and under MAP.

From a microbiological point of view, spoilage microorganisms (Enterobacteriaceae and *Pseudomonas spp.*) were progressively delayed as carbon dioxide increased (data not shown). The increase in carbon dioxide also delayed sensory decay; therefore, among the MAP analyzed, MAP-3 (65:35 CO_2:N_2) was the headspace selected for the following steps due to its ability to prolong shelf life compared to the control sample in air (Table 2).

Table 2. Shelf life values (means ± sd) for each step calculated as the lowest value between *MAL* and *SAL*. The shelf life increase (%) compared to the control was also reported.

Experimental Steps		*MAL* (Day)	*SAL* (Day)	Shelf Life (Day)	Shelf Life Increase (%)
Step-1	Cntr-1	1.87 ± 0.11 ^{a}	2.11 ± 0.04 ^{a}	1.87 ± 0.11 ^{a}	–
	MAP-1	1.98 ± 0.05 ^{a}	3.81 ± 0.66 ^{b}	1.98 ± 0.05 ^{a}	5.88
	MAP-2	2.34 ± 0.04 ^{b}	3.84 ± 0.01 ^{b}	2.34 ± 0.04 ^{b}	25.13
	MAP-3	2.53 ± 0.09 ^{c}	5.04 ± 0.51 ^{c}	2.53 ± 0.09 ^{c}	35.29
Step-2	Cntr-2	1.68 ± 0.02 ^{a}	3.69 ± 0.01 ^{a}	1.68 ± 0.02 ^{a}	–
	Coat-Air	1.80 ± 0.18 ^{a}	4.19 ± 0.01 ^{b}	1.80 ± 0.18 ^{a}	7.15
	Coat-MAP	2.61 ± 0.06 ^{b}	5.76 ± 0.27 ^{c}	2.61 ± 0.06 ^{b}	55.35
Step-3	Cntr-3	1.67 ± 0.10 ^{a}	3.81 ± 0.02 ^{a}	1.67 ± 0.10 ^{a}	–
	LysEDTA-Air	2.10 ± 0.16 ^{a}	3.39 ± 0.18 ^{b}	2.10 ± 0.16 ^{a}	25.74
	LysEDTA-MAP	3.85 ± 0.05 ^{b}	4.36 ± 0.01 ^{c}	3.85 ± 0.05 ^{b}	130.53
	Coat-Lys EDTA	4.55 ± 0.76 ^{b}	5.34 ± 0.02 ^{d}	4.55 ± 0.76 ^{b}	172.45
Step-4	Cntr-4	3.00 ± 1.00 ^{a}	6.47 ± 0.14 ^{a}	3.00 ± 1.00 ^{a}	–
	Cntr-A	4.19 ± 0.13 ^{a}	5.62 ± 0.52 ^{a}	4.19 ± 0.13 ^{a}	39.66
	NanoAg-A	10 < day < 12	10.01 ± 0.64 ^{b}	10.01 ± 0.64 ^{b}	233.66
	LPX-A	9 < day < 10	8.21 ± 0.63 ^{c}	8.21 ± 0.63 ^{c}	173.66

Notes: For each step, data in the same column with different letters (a–d) are significantly different ($p < 0.05$). Step 1 (Cntr-1: burrata packaged in air; MAP-1: burrata packaged under 30:70 CO_2:N_2; MAP-2: burrata packaged under 50:50 CO_2:N_2; MAP-3 burrata packaged under 65:35 CO_2:N_2). Step 2 (Cntr-2: burrata packaged in air; Coat-Air: burrata coated with aginic acid and packaged in air; Coat-MAP: burrata coated with aginic acid and packaged under 65:35 CO_2:N_2). Step 3 (Cntr-3: burrata packaged in air; LysEDTA-Air: burrata with lysozyme and Na_2-EDTA dissolved in cream and packaged in air; LysEDTA-MAP: burrata with lysozyme and Na_2-EDTA dissolved in cream and packaged under 65:35 CO_2:N_2; Coat-LysEDTA: burrata with lysozyme and Na_2-EDTA dissolved in cream, coated and packaged under 65:35 CO_2:N_2). Step 4 (Cntr-4: burrata packaged in air; Cntr-A: burrata with lysozyme and Na_2-EDTA dissolved in cream, coated and packaged in air; NanoAg-A: burrata with lysozyme and Na_2-EDTA dissolved in cream, with active coating with nanoparticles and packaged under 65:35 CO_2:N_2; LPX-A: burrata with lysozyme and Na_2-EDTA dissolved in cream, with active coating with lactoperoxidase and packaged under 65:35 CO_2:N_2).

To further improve product quality, a coating was optimized prior to packaging the fresh cheese. The coating application combined with MAP retarded the spoilage, thus prolonging the microbial acceptability limit and consequently the shelf life (1.68 and 2.61 days for Cntr-2 and Coat-MAP, respectively—Table 2, Step 2). In particular, among spoilage microorganisms a rapid development of Enterobacteriaceae and *Pseudomonas spp.* was observed (Table 3); however, the development was better controlled by the application of combined strategies. As also confirmed by other scientific studies, the natural microflora (lactococci and lactobacilli) increased from 6 log CFU/g to about 8 log CFU/g during the storage period (data not shown) without being compromised by the coating application or the MAP conditions [11,17].

As regards sensory quality, Figure 3 reports the evolution of overall quality for the Step 2 burrata samples. The overall quality reflects the firmness, color, and odor of burrata. As can be seen, a rapid quality of decay was recorded for samples packaged in air (Cntr-2 and Coat-Air), even though the coating improved product acceptability, principally preserving cheese firmness [26,30,31]. The best results from the sensory point of view were obtained for samples coated and packaged under MAP.

Table 3. Log CFU/g ± sd of Enterobacteriaceae and *Pseudomonas spp.* for Step 2 burrata samples. (Cntr-2: burrata packaged in air; Coat-Air: burrata coated with aginic acid and packaged in air; Coat-MAP: burrata coated with aginic acid and packaged under 65:35 CO_2:N_2).

Microorganisms	Sampling Time (day)	Cntr-2 (log CFU/g)	Coat-Air (log CFU/g)	Coat-MAP (log CFU/g)
Enterobacteriaceae	0	1.78 ± 0.24	1.78 ± 0.24	1.78 ± 0.25
	3	5.55 ± 0.06	5.56 ± 0.08	5.84 ± 0.34
	4	7.44 ± 0.19	7.29 ± 0.30	6.62 ± 0.73
	6	–	–	7.43 ± 0.80
Pseudomonas spp.	0	3.41 ± 0.10	3.41 ± 0.10	3.41 ± 0.10
	3	6.54 ± 0.11	6.60 ± 0.01	6.29 ± 0.29
	4	6.57 ± 0.30	6.32 ± 0.16	5.93 ± 0.21
	6	–	–	6.73 ± 0.21

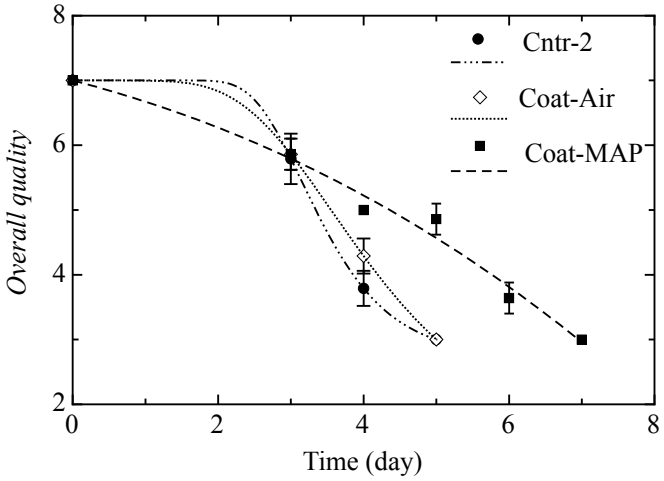

Figure 3. Overall Quality for Step 2 burrata samples (● Cntr-2: burrata packaged in air; ◇ Coat-Air: burrata coated with aginic acid and packaged in air; ■ Coat-MAP: burrata coated with aginic acid and packaged under 65:35 CO_2:N_2). The curves are the best fit of the re-parametrized Gompertz equation to the experimental data.

In Step 3, the antimicrobial activity of the lysozyme and the Na_2-EDTA added to the burrata filling and combined with coating and MAP were tested. The concentration of active compounds was taken from previously published data also dealing with burrata cheese [9]. As can be seen in Table 2, for Step 3 the shelf life was improved by the combination of these selected mild strategies. In fact, the active compounds exerted good effects in terms of both microbial and sensory quality, as is also confirmed in the literature [9,20], but their effect were more relevant when combined to coating or to MAP or to both. It is worth considering that the selected strategies did not influence the natural microflora of the burrata, as also confirmed by Conte et al. [9].

In the final experimental step (Step 4), the addition of lysozyme and Na_2-EDTA in the filling of the burrata was combined with the active coating containing the lactoperoxidase system or the silver nanoparticles and to MAP conditions during packaging. In Figure 4 the evolution of *Pseudomonas spp.* in samples from the last step can be observed. The control samples rapidly overlapped with the threshold within the first four days, whereas the burrata with the active coating maintained low microbial concentrations for much more than one week, above all when the silver nanoparticles were incorporated in the coating. The antimicrobial activity of the silver nanoparticles applied to dairy products is well documented in the literature [12,17,19], thus justifying the results also recorded in the current work.

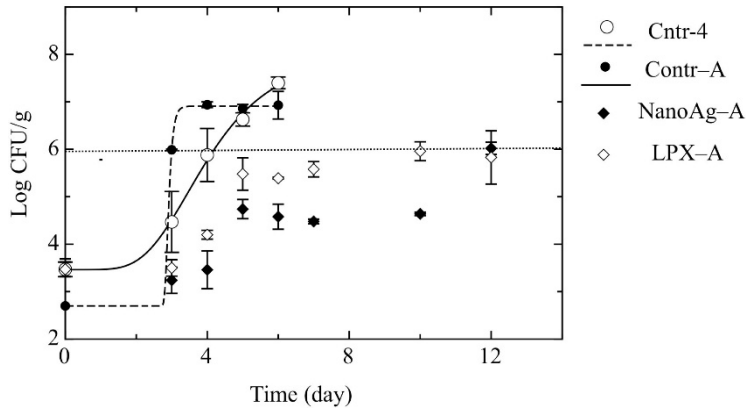

Figure 4. Evolution of *Pseudomonas spp.* for burrata samples of Step 4 (○ Cntr-4: Burrata packaged in air; ● Cntr-A: Burrata with lysozyme and Na_2-EDTA dissolved in cream, coated and packaged in air; ◆ NanoAg-A: Burrata with lysozyme and Na_2-EDTA dissolved in cream, with active coating with nanoparticles and packaged under 65:35 CO_2:N_2; ◇ LPX-A: burrata with lysozyme and Na_2-EDTA dissolved in cream, with active coating with lactoperoxidase and packaged under 65:35 CO_2:N_2). The curves are the best fit of the re-parametrized Gompertz equation to the experimental data. The solid horizontal line represents the microbial threshold for *Pseudomonas spp.*

The LPX system greatly controlled the *Pseudomonas spp.* growth compared to the control samples, but it was less effective than nanoparticles. It is interesting to see from the data in Table 4 that the natural microflora proliferated without stress in the samples.

Table 4. Initial and final cell loads (log CFU/g ± sd) of lactic bacteria in Step 4.

Samples	Lactic Acid Bacteria		Mesophylic Lactococci	
	$\log_{(i)}$ CFU/g	$\log_{(f)}$ CFU/g	$\log_{(i)}$ CFU/g	$\log_{(f)}$ CFU/g
Cntr-4	5.11 ± 0.37	7.36 ± 0.35	6.08 ± 0.07	7.42 ± 0.11
Cntr-A	4.88 ± 0.03	6.99 ± 0.04	6.15 ± 0.09	7.34 ± 0.02
NanoAg-A	4.88 ± 0.03	7.12 ± 0.02	6.05 ± 0.03	7.49 ± 0.13
LPX-A	4.71 ± 0.05	7.27 ± 0.21	6.14 ± 0.17	7.62 ± 0.22

The active coating also preserved the sensory properties of the cheese, with slightly better effects for nanoparticles. The shelf life values reported in Table 2 highlight that a significant increase of more than 200% was recorded when the active compounds were used during burrata processing and an active coating with silver nanoparticles was applied prior to packaging the cheese under specific MAP conditions.

4. Conclusions

In this study, a step-by-step approach was used to optimize process and packaging for burrata cheese with brine. In particular, the shelf life was improved by combining the antimicrobial compounds to be applied during the processes of burrata filling, active coating and MAP. The results obtained in each step allowed the identification of the most appropriate conditions: the headspace gas composition, the coating application and the antimicrobial compounds in the burrata and in the coating. The results showed a significant increase in shelf life for samples under MAP compared to cheese packaged in air. The coating application above all improved the sensory quality. A relevant antimicrobial effect was recorded by applying active agents during the process and in the coating. Therefore, the combination of various mild strategies allowed us to reach a very significant extension of shelf life that accounted for a more than 200% increase, when compared to the control sample.

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Author Contributions: For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used Matteo Alessandro Del Nobile, Amalia Conte and Angelo Vittorio Zambrini conceived and designed the experiments; Cristina Costa and Annalisa Lucera performed the experiments; Matteo Alessandro Del Nobile and Amalia Conte analyzed the data; Angelo Vittorio Zambrini contributed reagents and materials; Cristina Costa and Amalia Conte wrote the paper. Authorship must be limited to those who have contributed substantially to the work reported.

Conflicts of Interest: The authors declare no conflict of interest.

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