Camembert-type cheese ripening dynamics are changed by the properties of wrapping films

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ABSTRACT

Four gas-permeable wrapping films exhibiting different degrees of water permeability (ranging from 1.6 to 500 g/m² per d) were tested to study their effect on soft-mold (Camembert-type) cheese-ripening dynamics compared with unwrapped cheeses. Twenty-three-day trials were performed in 2 laboratory-size (18 L) respiratory-ripening cells under controlled temperature ($6 \pm 0.5^\circ\text{C}$), relative humidity ($75 \pm 2\%$), and carbon dioxide content (0.5 to 1%). The films allowed for a high degree of respiratory activity; no limitation in gas permeability was observed. The wide range of water permeability of the films led to considerable differences in cheese water loss (from 0.5 to 12% on d 23, compared with 15% for unwrapped cheeses), which appeared to be a key factor in controlling cheese-ripening progress. A new relationship between 2 important cheese-ripening descriptors (increase of the cheese core pH and increase of the cheese's creamy underriind thickness) was shown in relation to the water permeability of the wrapping film. High water losses (more than 10 to 12% on d 23) also were observed for unwrapped cheeses, leading to Camembert cheeses that were too dry and poorly ripened. On the other hand, low water losses (from 0.5 to 1% on d 23) led to over-ripening in the cheese underriind, which became runny as a result. Finally, water losses from around 3 to 6% on d 23 led to good ripening dynamics and the best cheese quality. This level of water loss appeared to be ideal in terms of cheese-wrapping film design.

Key words: ripening under wrapping, surface mold-ripened cheese, water vapor permeability, wrapping film

INTRODUCTION

To preserve and store surface mold-ripened soft cheeses after ripening in a chamber, the products must

be wrapped. Soft cheeses are wrapped early in the ripening process as the present trend in cheese making is to wrap cheeses as soon as *Penicillium camemberti* mycelium covers the cheese surface. Consequently, the wrapping film must make it possible to complete the cheese-ripening process to obtain the desired microbial and biochemical characteristics, as well as sensory properties, without damaging the surface flora. For economic reasons, the wrapping must also lengthen the shelf life of the cheese. To fulfill all of these requirements, scientists have studied (1) how modified-atmosphere packaging (MAP) can allow cheeses to continue ripening without damage to cheese quality in a hermetically sealed wrapping; and (2) which films allow ripening and storage without damage to the cheese.

Modified-atmosphere packaging technologies are shelf life-extension techniques introduced in recent decades in the food industry as a response to changes in market trends. The MAP technologies have been studied extensively to define the microbiological, physicochemical, biological, and sensory qualities of packaged food (Farber et al., 1990; Farber, 1991). Recently, MAP and active packaging (AP) have been used to improve the microbial stability of ricotta (Del Nobile et al., 2009), and to study their effects on cheese properties (Esmer et al., 2009) as well as on gas-exchange dynamics that occur in the MAP of soft cheeses (Rodriguez-Aguilera and Oliveira, 2009; Rodriguez-Aguilera et al., 2009). However, MAP is not used to wrap soft-surface, mold-ripened cheeses due to the brittleness of the *P. camemberti* layer (Desobry and Hardy, 1997).

To our knowledge, few studies have dealt with the effects of wrapped films on the main biological characteristics of wrapped cheeses during ripening. Most of these studies focused on respiration and the overall quality of the cheese by simulating gaseous atmospheres that could surround the cheese under its film in a small ripening cell. In this way, Desobry and Hardy (1997) showed that the wrapped film must be adapted to soft-surface, mold-ripened cheeses. To design a suitable wrapping, these authors defined the main criteria to be considered, such as *P. camemberti* respiration, cheese

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rind water activity, film water and gas permeabilities, hygrometry, and storage temperature. Generally, the *P. camemberti* respiration rate during cheese cold storage is a function of environmental parameters such as partial pressures of oxygen and carbon dioxide, temperature, and wrapping stress. For example, *P. camemberti* was highly activated by an increase in temperature from 3 to 12°C, and slightly increased by an increase in CO₂ partial pressure, from 0.1 to 0.4 atm (Desobry and Hardy, 1997). According to Roger et al. (1998), to preserve *P. camemberti* and rind appearance (e.g., whiteness, silky down) in surface mold-ripened cheeses, the microflora must be kept alive, requiring appropriate oxygenation. These authors also showed that for Brie-type cheeses, the best mycelium appearance was obtained with CO₂ and O₂ concentrations of approximately 4 and 19%, respectively. To lengthen the shelf life of these cheeses, lower O₂ concentrations made it possible to slow down the enzymatic reactions of ripening without changes that could cause flaws (Champagne et al., 2003). Champagne et al. (2003), Leclercq-Perlat et al. (2006), and Picque et al. (2006) showed that a small increase in CO₂ concentration (from 2 to 5%) increased the growth and respiration of *P. camemberti*, whereas higher CO₂ concentrations (from 6 to 10%) led to major damage of the mycelium and increased mold sporulation.

Although they had not specifically studied ripening under wrapping, Leclercq-Perlat et al. (2004a, 2006) showed that after wrapping with a reference film (cellulose and paraffin paper) (1) yeast and fungi concentrations (*Kluyveromyces marxianus*, *Geotrichum candidum*, *P. camemberti* spores) remained constant; (2) the concentration of *Brevibacterium aurantiacum* increased; (3) the pH of the cheese remained constant in the rind and slowly increased in the core; and (4) the lactose was consumed on wrapping day and lactate consumption continued under wrapping for approximately 20 d.

The main objective of this work was to compare the ripening dynamics of Camembert-type cheeses wrapped with different films that had different compositions, thicknesses, and permeabilities to gas and water. Ripening respiratory cells were expressly designed to allow the measurement of cheese respiratory activity and the control of ripening relative humidity and temperature. The physical, microbial, and biochemical evolution of the cheeses, as well as changes in their appearance over time, were observed to compare the effects of the films. At the same time, unwrapped Camembert-type cheeses were ripened in the cells to compare wrapped and unwrapped cheese ripening dynamics

MATERIALS AND METHODS

Cheese Making and Ripening

The cheeses were prepared on a pilot scale under aseptic conditions, in a sterilized 3-m³ cheesemaking chamber maintained at 28 ± 1°C, in which coagulation, cutting, draining, and shaping of the curd were performed as described previously (Leclercq-Perlat et al., 1999, 2000).

For each cheesemaking trial, 50 L of milk was used to make 20 cheeses. The raw milk was obtained from the AgroParisTech experimental farm (Thiverval-Grignon, France). It was standardized at 2.9 g of fat/100 g by mixing skim and full-cream milk. It contained more than 3.5 g of protein/100 g. After mixing, the milk was pasteurized for 30 s at 77 ± 1°C, and then cooled to 34 ± 1°C. The pH of the milk varied between 6.5 and 6.6. Milk was inoculated with lactic acid starter (15 mL/L; Flora Danica, CHN11, Chr. Hansen, Saint-Germain-les-Arpajon, France) and ripening starter. The preparation of these starters was described previously by Leclercq-Perlat et al. (2004a). When the tank was full, the concentrations of *K. marxianus* (strain 44_s, GMPA), *G. candidum* (strain G, Cargill, Saint Germain en Laye, France), *P. camemberti* (strain R, Cargill), and *B. aurantiacum* (ATCC9175) were 4 × 10³ spores/mL, 80 cfu/mL, 8.1 × 10³ spores/mL, and 2.7 × 10⁴ cfu/mL, respectively. Because of lactic acid bacteria activity, the milk pH reached 6.3 after 55 to 110 min. The coagulant (rennet containing 520 mg of chymosin/L; Chr. Hansen) was then added (20 mL/100 L). The coagulation time was approximately 20 min, and the curd was cut into cubes after 40 min of hardening. Approximately 20 L of whey was drained after 30 min to obtain an average cheese DM between 40 and 42%. Curd was then shaped in polyurethane molds (diameter: 107 mm; height: 77 mm), producing cheeses that weighed approximately 300 g. The molds were inverted 3 times: after 30 min, 5 h, and 19 h. Three hours after molding, the temperature of the cheese-making chamber was reduced to 20 to 22°C; 24 h after the molding, the cheeses were plunged into sterile brine (330 g of NaCl/L, at pH 5.5, sterilized 60 min at 120°C) at 14 ± 1°C for 25 min. Eight cheeses were then transferred to each of the 2 ripening cells used for this study.

Ripening Respiratory Cell Description. A schematic presentation of the 18-L cell used to ripen 8 Camembert-type cheeses is shown in Figure 1, with the sensors and the loops controlling the relative humidity (RH) and the CO₂ concentration (Hélias et al., 2007).

Figure 1. Schematic presentation of the ripening respiratory cell. T = temperature; RH = relative humidity. The CO₂ and O₂ contents are measured and RH and CO₂ are automatically controlled. Temperature control is carried out by placing the cell in a cold room (4 to 15°C).

The 3 sensors used to make the online measurements were as follows: (1) a Hygroclip S sensor (RH: accuracy $\pm 1.5\%$; T: accuracy $\pm 0.3^\circ\text{K}$ at 23°C ; Rotronic, Croissy Beaubourg, France) for temperature and RH measurements; (2) an infrared analyzer (BlueSens model AN-AO2, 0 to $25 \pm 0.2\%$; Infors, Massy, France) for CO₂ concentration measurements; and (3) an electrochemical sensor (Figaro KE50; accuracy $\pm 1\%$; Diltronic SA, Saint-Germain-en-Laye, France) for O₂ concentration measurements. These sensors were located at the upper part of the respiratory cell (Figure 1). An external circuit involving an air dryer filled with silica gel was created to allow for control of the air RH in the cell. The temperature control was obtained by placing the cell in a cold room where the temperature could be programmed at a set point ranging from 4 to 15°C , with an accuracy of $\pm 0.5^\circ\text{C}$. The control of the CO₂ content in the cell was performed between 2 thresholds, 0.5 and 1% as the low and high set points, respectively, by the injection of new filtered air (Figure 1). In this way, the increase of CO₂ between the 2 set points was in direct relationship with the CO₂ production rate. A propeller (diameter: 120 mm; speed: 30 rpm) in the upper part of the cell, and the periodic gas circulation carried out to control the cell relative humidity (mean flow rate:

$0.24 \text{ m}^3/\text{h}$; mean renewal time: 0.075 h), favored cell homogeneity.

Software developed expressly for the purpose (RE-CEL, IDDN.FR. 001.080017.000. R.P. 2009.000.30600) was used to monitor the ripening respiratory cells and to determine the rates of O₂ consumption and CO₂ production that correspond to cheese respiratory activity. The respiratory activity was calculated according to Roger et al. (1998).

Ripening Conditions in the Respiratory Cells.

After the transfer of 8 cheeses to each ripening cell, the temperature and RH were controlled at $12 \pm 1^\circ\text{C}$ and $95 \pm 2\%$, respectively, and the atmosphere was partially renewed (CO₂ concentrations remained from 0.5 to 1.0%). The cheeses were ripened under these conditions for 12 d and then wrapped. Under wrapping, the temperature and the RH in the cells were controlled at $6 \pm 0.5^\circ\text{C}$ and $75 \pm 2\%$, respectively. The length of this second ripening step was 23 d, from d 0 (wrapping day) to d 23. At the end of the experiments, the cheeses had been ripened for a total of 35 d, which corresponds to the optimal age for cheese tasting. The 8 unwrapped cheeses could not be ripened at 75% RH without a very high water mass loss and surface drying. Consequently, the cheeses were ripened at $95 \pm 2\%$ RH and $6 \pm 0.5^\circ\text{C}$.

Table 1. Main characteristics of films used to wrap Camembert-type cheeses and cheese mass losses observed for wrapped and unwrapped cheeses on d 23 of ripening (after wrapping)

Trial ¹	Film characteristic			Cheese mass loss		Water mass loss rate (g/m ² per d)	Absorbed water in the film (%)
	Composition ²	Thickness (μm)	WVP ³ (g/m ² per d)	g	%		
Unwrapped cheese		—	—	40	13.6	64.2	—
VFC	CP/PP	82	300	9.3	3.1	14.4	33 ± 2
VBF1	CP/PP	88	470	37.0	12.0	57.2	31 ± 2
VBF2	PLA/PE	68	100	16.5	5.5	27.2	10 ± 2
INVOS	PA/PE	67	1.6	1.7	0.6	2.6	1.0 ± 0.1

¹VFC film (CdL, Amcor Flexibles, Barbézieux, France) was considered as a reference for Camembert wrapping. The INVOS film (Invos II, INVOS a.s., Svarov, Czech Republic) was characterized by its very low water permeability, in contrast to VFB1 (270874, Amcor Flexibles), which allowed for very high water transfer. Film VFB2 (269422, Amcor Flexibles) was made from biodegradable material, polylactic acid, and paraffin of plant origin, in contrast to VFC, which was made with paraffin of fossil origin.

²CP = cellulose pellicle; PP = paraffin paper; PLA = polylactic acid; PA = polyamide; PE = polyethylene.

³Water vapor permeability (measurements performed at 38°C and 90% relative humidity; ASTM, 1990).

This RH corresponded to the usual ripening condition for unwrapped Camembert ripening.

Properties and Performances of Films Used for Wrapping

The 4 films tested differed by their composition, thickness, and water permeability, as shown in Table 1. A VFC film (CdL, Amcor Flexibles, Barbézieux, France) was considered as a reference for Camembert wrapping. The INVOS film (Invos II, INVOS a.s., Svarov, Czech Republic) was characterized by its very low water permeability, in contrast to VFB1 (270874, Amcor Flexibles), which allowed for very high water transfer. Finally, the permeability properties of VFB2 (269422, Amcor Flexibles) were 3 times lower than those of VFC. The VFB2 was made from biodegradable material, polylactic acid, and paraffin of plant origin, in contrast to VFC, which was made with paraffin of fossil origin. The effect of wrapping films on Camembert-type cheese ripening also was compared with a ripening trial performed without cheese wrapping.

The water absorbed by the films during ripening was measured using the Karl Fisher method with a 756 KF coulometer and an 832 KF Thermoprep oven (Metrohm, Villebon Courtabeouf, France). The method used was adapted from Kestens et al. (2008). Briefly, a slice (diameter: 0.8 cm; weight: approximately 50 mg) of film was put into a 5-mL flask sealed with a septum top. The flow of dry air proceeded into the sample flask and the water contained in the sample was vaporized by heating (between 110 to 150°C, depending on the film tested). This airflow was directly injected into the KF coulometer.

Forty-eight hours before cheeses were wrapped, the films were stored in a controlled atmosphere at 6°C and

75% RH. Thus, at the beginning of the trials, the water absorbed by the films was 4% for INVOS and VFB1 and 12% for VFC and VFB2.

Cheese Analysis

The rind (1-mm-thick over the cheese surface) and core of each cheese (inner layer) were separated using the method of Le Graët and Brûlé (1988). Half of the cheese was used to prepare the suspensions used for microbial counts as described previously by Leclercq-Perlat et al. (2004a). The rest was used to determine pH, lactose, and lactate contents, as well as nitrogen fractions [total nitrogen, acid-soluble nitrogen (ASN), NPN, and ammonium (NH₄⁺) concentrations], as described previously (Leclercq-Perlat et al., 2004a).

Microbial Counts and Chemical Analysis. On the surface, viable cell counts of *K. marxianus* and *G. candidum* were measured by counting on yeast extract glucose chloramphenicol agar after incubation at 30°C for 2 d to ensure immediate differentiation of the colonies based on their size and appearance, and to detect any microbial contamination. Spore counts of *P. camemberti* were determined by culturing on yeast extract glucose chloramphenicol agar containing 60 g of NaCl/L to limit *G. candidum* growth (incubation: 20°C, 6 to 8 d). Viable cells of *B. aurantiacum* were determined on amphotericin-containing lactate agar (incubation: 25°C, 7 d).

Nitrogen fractions, pH, and lactose and lactate concentrations in both the cheese rind and core were measured on d 23 as described previously (Leclercq-Perlat et al., 2004a).

Assessment of Cheese Appearance. The thickness of the cheese creamy underind that represents the progress in cheese ripening was measured at 6 points on

Table 2. Definition and score of the descriptors used to evaluate the cheese appearance evolution during ripening

Descriptor	Scale and reference				
	1	2	3	4	5
<i>Penicillium camemberti</i> appearance	<10%	25%	50%	75%	>90%
Overall odor	Musty-mushroom	Wet moldy	Camembert	Camembert-ammoniac	Ammoniac
Rind color	White	Cream	Dark cream	Light brown	Dark brown
Core hardness	Very soft	Soft	Medium	Hard	Very hard
Underrind consistency	Very dried	Dried	Soft	Soft with runny edge	Runny

each side. The arithmetic average of these 12 measurements was then calculated. Six or seven cheese samples were studied from d 0 to the end of ripening (d 23).

Cheese appearance was assessed as proposed by Agioux (2003) and Bonaïti et al. (2004). Five operators assessed each cheese on d 23, taking into account 5 descriptors generally used by the cheese-makers. Each cheese was rated on a scale from 1 to 5 as described in Table 2. The methodology was described by Sicard et al. (2011). Six sessions were devoted to training and evaluation before validation of the panel's performance. The appearance of *P. camemberti* was assessed in terms of mycelium density and uniformity. Overall cheese odor varied from musty-mushroom (score of 1) to ammoniac (score of 5). The cheese color under the *P. camemberti* covering varied from white (score of 1) to dark brown (score of 5). The cheese core hardness was estimated by the ease with which the cheese could be ground with a mortar and pestle. The underrind consistency varied from a dried (score of 1) to a very runny underrind (score of 5).

RESULTS AND DISCUSSION

Initial Cheese Composition

On d 0, the average decimal logarithm of viable cells concentration calculated from all the trials were 7.3 ± 0.2 , 7.4 ± 0.3 , 4.4 ± 0.4 and 5.4 ± 0.8 for *Kluyveromyces marxianus*, *Geotrichum candidum*, *Penicillium camemberti*, and *Brevibacterium aurantiacum*, respectively. The average physicochemical composition of the rind of the initial cheeses was as follows: DM, $43.9 \pm 0.7\%$; pH, 7.5 ± 0.4 ; lactic acid, 7 ± 3 g/kg of wet cheese; ASN, $55 \pm 6\%$; NPN, $32 \pm 4\%$; NH_4^+ , 6 ± 1 g/kg of DM. The core composition of initial cheeses was as follows: DM, $43.1 \pm 0.8\%$; pH, 4.7 ± 0.4 ; lactic acid, 9 ± 2 g/kg of wet cheese; ASN, $15 \pm 1\%$; NPN, $8.1 \pm 0.9\%$; and NH_4^+ , 3.3 ± 0.5 g/kg of DM. The standard deviations are very good for the ripening flora, and reasonably good for all of the components except for lactic acid. The effect of the difference of the initial lactic acid

concentration is minimal because, as a substrate, this compound was not limiting for ripening microorganism growth and activity. Amrane and Prigent (1997) have shown that in solid cultures, *P. camemberti* and *G. candidum* growth is not limited by the lactate content of the media when another source of carbon, such as proteins, is available.

Only 2 types of ripening trials were replicated with different sets of standardized milk: trials with unwrapped cheeses (3 replicates) and trials with cheeses wrapped with VFC film (2 replicates). The standard deviations calculated on cheese mass loss, CO_2 total production, and total O_2 consumption ranged from 6 to 14%, showing an acceptable reproducibility of the trials.

Water Mass Loss and Cheese Respiratory Activity

Water mass loss determined on d 23 of unwrapped and wrapped Camembert-type cheeses is presented in Table 1 and expressed in mass and percentage of cheese initial mass. The water mass loss rates (g/m^2 per d) and the water absorbed by the films on d 23 also are shown in Table 1. Figure 2 presents the evolution of cheese mass loss in relation to ripening time. The change in film water absorption in relation to time throughout ripening under wrapping is shown in Figure 3.

As a rule, the mass loss for wrapped and unwrapped cheeses increased linearly in relation to ripening time (Figure 2). The slopes of the curves corresponded to the mass loss rates, which were highly influenced by film type and especially the film's water permeability, which controlled cheese water release.

With these data, a comparison of the film behaviors tested was possible. The INVOS film was the least water permeable (0.55% of cheese mass was lost on d 23 and the loss rate was about of 2.6 g/m^2 per d). The VFB1 was the most water-permeable film (12% of cheese mass on d 23 and a loss rate of approximately 57 g/m^2 per d). The reference film (VFC) was more water permeable than INVOS and allowed for a small water loss (3.1% of cheese mass on d 23 and a loss rate of 14.4 g/m^2 per d) compared with VFB1. The VFB2 induced

Figure 2. Evolution of water mass loss (%) of wrapped and unwrapped cheeses in relation to time throughout ripening under wrapping. VFC film (CdL, Amcor Flexibles, Barbézieux, France) was considered as a reference for Camembert wrapping. The INVOS film (Invos II, INVOS a.s., Svarov, Czech Republic) was characterized by its very low water permeability, in contrast to VFB1 (270874, Amcor Flexibles), which allowed for very high water transfer. Film VFB2 (269422, Amcor Flexibles) was made from biodegradable material, polylactic acid, and paraffin of plant origin, in contrast to VFC, which was made with paraffin of fossil origin.

a cheese mass loss that was approximately twice as high as VFC, whereas its water vapor permeability was 3 times lower than that of VFC. The paraffin of vegetable origin used in the VFB1 film was more permeable than the one of fossil origin and allowed for a higher water transfer rate through the film.

The mass loss of unwrapped cheeses (13.6% of cheese mass on d 23 and a loss rate about of $64.2 \text{ g/m}^2 \text{ per d}$) was close to that of VFB1, confirming the very high water permeability of this film. It seemed important to study whether such large differences in water cheese mass losses could involve significant differences in ripening kinetics and cheese quality.

Three levels of water absorption on wrapping films were observed (Figure 3, Table 1): INVOS absorbed less than 1% water; VFB2 absorbed approximately 10% (starting from 4% after film saturation under an atmosphere with 75% relative humidity); and VFC and VFB1 absorbed 31 to 33% (starting from 12% after film saturation under an atmosphere with 75% RH). It was impossible to establish a relationship between film water absorption and permeability; nevertheless, it was assumed that the film composition was acting on water absorption and the film permeability on water loss.

Camembert-type cheese respiratory activity, expressed in terms of the amount of carbon dioxide produced and oxygen consumed on d 23, and the mean production and consumption rates, is presented in Table 3.

In all cases, including for unwrapped cheeses, a high level of cheese respiratory activity was observed, with respiration rates (CO_2 production, O_2 consumption) ranging from 7.6 to $12.2 \text{ g/m}^2 \text{ per d}$ and total CO_2 production and O_2 consumption ranging from 175 to 280 g/m^2 . As wrapped and unwrapped cheeses were in the same range of respiratory activity, it seems possible to consider that all of the films tested allowed for cheese respiration.

When comparing the respiratory activities, we observed that the wrapped cheeses with a high water mass loss (VFB1) exhibited the lowest level of respiratory activity (CO_2 production or O_2 consumption rates lower than $8 \text{ g/m}^2 \text{ per d}$), 30% lower than the ones measured with the unwrapped cheeses. The cheeses wrapped in reference film (VFC) exhibited the highest level of respiratory activity, followed by INVOS and VFB2, close to that of the unwrapped cheeses.

Microbial, Chemical, and Biological Evolutions

Microbial Evolution. The changes in the concentration between the wrapping day (d 0) and the end of ripening under wrapping (d 23) of the 4 strains used in Camembert-type cheese ripening are presented in Table 4 according to the packaging used.

Figure 3. Water absorption measured by the Karl Fisher method in wrapping films in relation to time throughout ripening under wrapping. VFC film (CdL, Amcor Flexibles, Barbézieux, France) was considered as a reference for Camembert wrapping. The INVOS film (Invos II, INVOS a.s., Svarov, Czech Republic) was characterized by its very low water permeability, in contrast to VFB1 (270874, Amcor Flexibles), which allowed for very high water transfer. Film VFB2 (269422, Amcor Flexibles) was made from biodegradable material, polylactic acid, and paraffin of plant origin, in contrast to VFC, which was made with paraffin of fossil origin.

Table 3. Respiratory activity of Camembert-type cheeses as a function of ripening conditions; mean CO₂ production and O₂ consumption were observed on d 23 of ripening (after wrapping)

Trial ¹	Mean CO ₂ total production (g/m ²)	CO ₂ mean production rate (g/m ² per d)	Mean O ₂ total consumption (g/m ²)	O ₂ mean consumption rate (g/m ² per d)
Unwrapped cheese	220	9.6	200	8.7
VFC	280	12.2	275	12.0
VFB1	175	7.6	175	7.6
VFB2	215	9.5	235	10.2
INVOS	270	11.7	230	10.0

¹VFC film (CdL, Amcor Flexibles, Barbézieux, France) was considered as a reference for Camembert wrapping. The INVOS film (Invos II, INVOS a.s., Svarov, Czech Republic) was characterized by its very low water permeability, in contrast to VFB1 (270874, Amcor Flexibles), which allowed for very high water transfer. VFB2 was made from biodegradable material, polylactic acid, and paraffin of plant origin, in contrast to VFC, which was made with paraffin of fossil origin.

Regardless of the wrapping film used and for the unwrapped cheeses, *K. marxianus*, *G. candidum*, and *P. camemberti* showed variations lower than 1 log₁₀, not considered to be significant. However, a trend in the decrease of *K. marxianus* was observed, except for VFC film. Considering that the wrapping day (d 0) corresponded to the 12th d of ripening in the chamber, the

populations of these 3 strains were established and no growth was expected for these strains (Leclercq-Perlat et al., 2004a). Only *B. aurantiacum*, whose growth begins when the surface pH of cheese is higher than 5.8 (McSweeney and Sousa, 2000), showed a significant increase [from 1.5 (INVOS film) to 3.3 (unwrapped cheeses) in log₁₀].

Table 4. Decimal logarithm of viable cell concentrations of the 4 strains used for Camembert-type cheese ripening determined at the cheese surface on wrapping day (d 0) and after ripening (d 23)¹

Trial ²	d 0 log ₁₀ (Cv) ± SD	d 23 log ₁₀ (Cv) ± SD	Δlog ₁₀ (Cv)
<i>Kluyveromyces marxianus</i>			
Unwrapped	7.52 ± 0.03	7.12 ± 0.04	−0.40
VFC	7.55 ± 0.04	7.48 ± 0.01	−0.07
VFB1	7.39 ± 0.07	6.60 ± 0.1	−0.79
VFB2	7.37 ± 0.07	6.82 ± 0.01	−0.55
INVOS	7.00 ± 0.03	6.20 ± 0.02	−0.80
<i>Geotrichum candidum</i>			
Unwrapped	7.37 ± 0.05	7.58 ± 0.04	0.21
VFC	7.49 ± 0.06	7.96 ± 0.04	0.47
VFB1	7.60 ± 0.6	7.76 ± 0.05	0.16
VFB2	7.0 ± 0.1	7.89 ± 0.05	0.89
INVOS	7.68 ± 0.03	7.64 ± 0.06	−0.04
<i>Penicillium camemberti</i>			
Unwrapped	4.10 ± 0.06	4.6 ± 0.2	0.50
VFC	3.90 ± 0.06	5.06 ± 0.08	1.16
VFB1	4.5 ± 0.2	4.91 ± 0.01	0.41
VFB2	4.82 ± 0.05	3.85 ± 0.04	−0.97
INVOS	4.59 ± 0.06	4.54 ± 0.03	−0.05
<i>Brevibacterium aurantiacum</i>			
Unwrapped	4.58 ± 0.05	7.90 ± 0.01	3.32
VFC	4.8 ± 0.2	7.06 ± 0.02	2.26
VFB1	5.20 ± 0.05	7.44 ± 0.01	2.24
VFB2	5.89 ± 0.09	8.8 ± 0.1	2.91
INVOS	6.65 ± 0.01	8.12 ± 0.08	1.47

¹ΔLog₁₀(Cv): variation in the decimal logarithm strain concentration between d 0 and 23; Cv = viable cell concentration in cfu/g of wet cheese for *K. marxianus*, *G. candidum*, and *B. aurantiacum*, or in spores/g of wet cheese for *P. camemberti*.

²VFC film (CdL, Amcor Flexibles, Barbézieux, France) was considered as a reference for Camembert wrapping. The INVOS film (Invos II, INVOS a.s., Svarov, Czech Republic) was characterized by its very low water permeability, in contrast to VFB1 (270874, Amcor Flexibles), which allowed for very high water transfer. VFB2 was made from biodegradable material, polylactic acid, and paraffin of plant origin, in contrast to VFC, which was made with paraffin of fossil origin.

Figure 4. Changes in core cheese pH in relation to time throughout ripening under wrapping. VFC film (CdL, Amcor Flexibles, Barbézieux, France) was considered as a reference for Camembert wrapping. The INVOS film (Invos II, INVOS a.s., Svarov, Czech Republic) was characterized by its very low water permeability, in contrast to VFB1 (270874, Amcor Flexibles), which allowed for very high water transfer. Film VFB2 (269422, Amcor Flexibles) was made from biodegradable material, polylactic acid, and paraffin of plant origin, in contrast to VFC, which was made with paraffin of fossil origin.

Surface and Core pH of Cheese in Relation to Film Used. No significant evolution of pH was observed on the surface; all pH values ranged around 7.7 ± 0.2 (data not shown). This result was expected because the increase of pH surface generally occurs between 5 and 7 d before wrapping during the curd surface deacidification process (Leclercq-Perlat et al., 2004a). Wrapping did not change the surface pH of the Camembert-type cheeses, regardless of the film used for wrapping as well as for unwrapped cheeses.

The changes in core pH of Camembert-type cheeses are shown in Figure 4. Two types of pH evolutions were observed: (1) a very small increase (from 4.7 to 5.7–5.8 on d 23) for unwrapped cheeses and cheeses wrapped with VFB1, corresponding to the conditions where the cheese water loss was the highest; and (2) an important increase (from 4.7 to 6.6–7.4 on d 23) for the cheeses wrapped with the 3 other films tested, which allowed for the lowest cheese water losses.

A higher pH core increase is considered a consequence of accelerated ripening. Therefore, the wrapping films that limit water mass loss promote ripening kinetics.

Lactate Consumption. The decrease in lactate concentration on the surface and in the core of unwrapped cheeses and of cheeses wrapped with VFC and VFB1 is shown in Figure 5a, b. The same trends were observed in lactate concentration for cheeses wrapped with VFB2 and INVOS.

The lactate concentration in the cheese core was higher than on the cheese surface. However, at the end

Figure 5. Changes in lactate concentrations of cheese surface (a) and core (b) in relation to time throughout ripening under wrapping. VFC film (CdL, Amcor Flexibles, Barbézieux, France) was considered as a reference for Camembert wrapping. The VFB1 film (270874, Amcor Flexibles) allowed for very high water transfer.

of ripening under wrapping, all lactate concentrations were in a narrow low range (0 to 2 g/kg of wet cheese). It appeared that the lactate concentration kinetics, on the cheese surface and in the core, were related to the water mass losses (Table 1); when the water mass loss was higher (unwrapped cheese and VFB1 wrap), the lactate concentration decrease was lower in relation to ripening time. An increase in lactate consumption was considered to increase the cheese-ripening kinetics (and the cheese core pH). These results confirmed the favorable effect of wrapping leading to low cheese water mass losses during ripening.

Evolution of Nitrogen Fractions. The ASN and NPN indexes, as well as NH_4^+ concentration of the cheeses sampled during all the trials (unwrapped and wrapped cheeses), showed a linear increase in the rind and in the core of the cheese, from d 0 to 23. The

Figure 6. Increase of acid-soluble nitrogen (ASN) and NPN indexes (%) and of NH₄⁺ concentration (g/kg of DM) in cheese core between d 0 and 23 (unwrapped cheeses and wrapped cheeses). VFC film (CdL, Amcor Flexibles, Barbézieux, France) was considered as a reference for Camembert wrapping. The INVOS film (Invos II, INVOS a.s., Svarov, Czech Republic) was characterized by its very low water permeability, in contrast to VFB1 (270874, Amcor Flexibles), which allowed for very high water transfer. Film VFB2 (269422, Amcor Flexibles) was made from biodegradable material, polylactic acid, and paraffin of plant origin, in contrast to VFC, which was made with paraffin of fossil origin.

increases in ASN index, NPN index, and NH₄⁺ concentration in the core of the cheese between d 0 and 23 are shown in Figure 6. The less important increases were noticed for cheeses wrapped with VFB1, which also showed the lowest respiratory activity and pH evolution. The VFC, VFB2, and INVOS films allowed for higher proteolysis rates. These evolutions were in agreement with the respiratory activity, core pH evolution, and mass loss. The evolution of the nitrogen fractions of unwrapped cheeses were close to the one measured for VFB1. These results were in agreement with the pH evolution, but not with the respiratory activity. The same kind of results were observed in the cheese rinds (data not shown).

Evolution of the Cheese Appearance Descriptors

The increase of the creamy underrind thickness of the cheese in relation to ripening time is shown in Figure 7. The 5 cheese appearance descriptors used for the sensory evaluation at the end of ripening (wrapped and unwrapped cheeses) are given in Table 5.

As shown in Figure 7, the thickness of the cheese creamy underrind, which represents the ripening progress in the cheese core, increased during ripening, regardless of the unwrapped and wrapped cheese trials. The full cheese ripening corresponded to a thickness of 15 mm (half of the cheese thickness). Starting from 1.7 to 3.6 mm on wrapping day (d 0), the thickness

Table 5. Evaluation of cheese appearance descriptors in relation to wrapping films, performed on d 23

Cheese appearance descriptor (rated from 1 to 5)	Unwrapped cheese	Films used for cheese wrapping ¹			
		VFC	VFB1	VFB2	INVOS
<i>Penicillium camemberti</i> appearance	4	5	4	4	4
Cheese odor	1	4	1	4	4
Cheese color	1	3	2	4	4
Cheese core hardness	1	3	1	4	3
Underrind consistency	1	3	2	3	4

¹VFC film (CdL, Amcor Flexibles, Barbézieux, France) was considered as a reference for Camembert wrapping. The INVOS film (Invos II, INVOS a.s., Svarov, Czech Republic) was characterized by its very low water permeability, in contrast to VFB1 (270874, Amcor Flexibles), which allowed for very high water transfer. VFB2 was made from biodegradable material, polylactic acid, and paraffin of plant origin, in contrast to VFC, which was made with paraffin of fossil origin.

Figure 7. Evolution of the thickness of the cheese's creamy underind in relation to time throughout ripening under wrapping. VFC film (CdL, Amcor Flexibles, Barbézieux, France) was considered as a reference for Camembert wrapping. The INVOS film (Invos II, INVOS a.s., Svarov, Czech Republic) was characterized by its very low water permeability, in contrast to VFB1 (270874, Amcor Flexibles), which allowed for very high water transfer. Film VFB2 (269422, Amcor Flexibles) was made from biodegradable material, polylactic acid, and paraffin of plant origin, in contrast to VFC, which was made with paraffin of fossil origin.

reached 7 to 13.5 mm on d 23 as a function of the trials. Significant differences in the thickness increases were observed, and 2 groups could be distinguished: those with a thickness of 7 to 9 mm and those with a thickness of 12 to 13 mm. On d 23, the mean underind thickness of the unwrapped cheeses was the lowest (7 ± 2 mm), and that of the cheeses wrapped with the most water-permeable film (VFB1) was low (9 ± 1 mm) as well. The 3 other films, which were less water permeable, made it possible to obtain a higher mean underind thickness: 13 ± 1 , 13.0 ± 0.5 , and 12 ± 1 mm for VFB2, VFC, and INVOS films, respectively (Figure 7). Consequently, the cheeses wrapped with the less permeable films and that lost less than 6% water exhibited the highest ripening level. This conclusion was confirmed when analyzing the rating of the cheese appearance descriptors (Table 5). Ratings for *P. camemberti* appearance (score of 4 or 5) did not differ significantly, probably because this microorganism had appeared before the cheese was packaged. However, all of the other descriptors showed better ripening progress when the cheeses were wrapped with films that allowed a cheese mass loss of less than 6% on d 23. Odor (with scores of 4 vs. 1) and core hardness (with scores of 3 and 4 vs. 1) were especially significant (Table 5). Cheese color and underind consistency revealed smaller differences between the 2 groups of cheeses, but the trends remained the same with more advanced ripening for

the cheeses that had lost the smallest quantity of water. Therefore, unwrapped cheeses and cheeses ripened with VFB1 film lost a lot of water (more than 12% on d 23) and were too dry and poorly ripened. The cheeses wrapped with INVOS film lost a small amount of water (0.55% on d 23) and appeared to be over-ripened with a runny underind in some places, making them unmarketable. Only the cheeses with intermediate values of water mass loss (from 3 to 6% on d 23) were well ripened and considered to be satisfactory.

Relationships Between Ripening Variables: Effect of Film Properties

Figure 8 gives the relationship between the thickness of the cheese creamy underind and the increase of pH at the cheese core (measured on d 23), 2 descriptors that are easy to measure and that are representative of the ripening process. The water permeability of the wrapping films tested (Table 1) is also given in Figure 8. The higher the pH core increase, the higher the underind thickness. Moreover, a negative relationship was observed between these 2 descriptors and the permeability of the wrapping films.

Principal component analysis was applied to the 10 most significant ripening variables (mass loss; respiratory activity: CO_2 , O_2 ; *Brevibacterium aurantiacum*

Figure 8. Relationship between the cheese creamy underind thickness and the increase of cheese core pH observed on d 23 with wrapping films with different water permeability. VFC film (CdL, Amcor Flexibles, Barbézieux, France) was considered as a reference for Camembert wrapping. The INVOS film (Invos II, INVOS a.s., Svarov, Czech Republic) was characterized by its very low water permeability, in contrast to VFB1 (270874, Amcor Flexibles), which allowed for very high water transfer. Film VFB2 (269422, Amcor Flexibles) was made from biodegradable material, polylactic acid, and paraffin of plant origin, in contrast to VFC, which was made with paraffin of fossil origin. UNW = unwrapped.

Figure 9. Principal component analysis of the 10 most significant ripening variables [mass loss, O_2 consumption, CO_2 , *Brevibacterium aurantiacum* growth (Ba), cheese core pH increase (Δ pH), and 5 descriptors of cheese appearance] to discriminate between the ripening trials performed with wrapped (films INVOS, VFC, VFB1, and BFD2) and unwrapped cheeses. Water vapor permeability (WVP) is used as a supplementary variable. VFC film (CdL, Amcor Flexibles, Barbézieux, France) was considered as a reference for Camembert wrapping. The INVOS film (Invos II, INVOS a.s., Svarov, Czech Republic) was characterized by its very low water permeability, in contrast to VFB1 (270874, Amcor Flexibles), which allowed for very high water transfer. Film VFB2 (269422, Amcor Flexibles) was made from biodegradable material, polylactic acid, and paraffin of plant origin, in contrast to VFC, which was made with paraffin of fossil origin.

growth; increase of core pH; and descriptors of appearance) to discriminate between the 5 ripening trials, 4 with the different wrapping films and 1 with unwrapped cheeses. Figure 9 presents the projection of the 10 active variables and one supplementary variable (water vapor permeability) on the factor plane. The factor coordinates of the 5 trials also were included. A principal component analysis factorial map defined by factor 1 and factor 2 accounts for 79 and 11% of the variance, respectively, or a total of 90%.

Based on the magnitudes of the factor coordinates for the variables in the analysis and the supplementary variable, as well as the signs of these correlations, an opposition was observed between core pH increase, cheese appearance, water vapor permeability (high negative correlations, $R > 0.9$), and mass loss (high positive correlation) on the first axis. Two groups of wrapping conditions can be defined: the first includes unwrapped cheeses and VFB1, and the second includes VFC, VFB2, and INVOS.

Brevibacterium aurantiacum growth was the most correlated variable with the second axis ($R = 0.75$). This variable accounted for the difference of coordi-

nates observed on this axis between unwrapped cheeses and VFB1 trials and between VFC, VFB2, and INVOS trials. On the third factor, the difference of coordinates between VFC and VFB2 was due mainly to CO_2 production ($R = 0.65$) (data not shown).

These experiments were classified into the 3 following groups as a function of film water vapor permeability: (1) very low water permeability (INVOS film) that involved fast ripening but an over-runny creamy under-rind at the end of the process; (2) a high water vapor permeability (VFB1 and unwrapped cheeses) that led to a partial drying of the cheese surface and an important limitation in ripening; (3) a mean permeability (VFC, VFB2) that allowed fast ripening with a high quality of cheese. This last result was targeted for wrapping film selection for Camembert-type cheese packaging.

CONCLUSIONS

Because the 4 wrapping films tested were gas permeable, considerable cheese respiratory activity was observed after wrapping and the cheese-ripening process continued. The effect of wrapping films on cheese ripen-

ing and quality was observed on d 23 after wrapping. Cheese ripening was observed to be a function of the films' water permeability. Permeability that was either too low or too high led to cheeses that were too dry and poorly ripened or over ripened (appearance of a liquid underirind), respectively. Intermediate values of water permeability (3 to 6% water loss on d 23) led to the best cheese quality (good ripening of the cheese core). Unwrapped cheeses presented the same behavior as cheeses wrapped with films that allowed high water loss (more than 12% of water loss on d 23).

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