Stability of Sliced Mozzarella Cheese in Modified-Atmosphere Packaging

ROSA MARIA VERCELINO ALVES,1 CLAIRE ISABEL GRIGOLI DE LUCA SARANTÓPOULOS,1 ARIE GIMENES FERNANDES VAN DENVER,2 and JOSÉ DE ASSIS FONSECA FARIA3

1CETEA (Food Packaging Technology Center), 2CTL (Dairy Technology Center), and 3FEA (Department of Food Technology), State University of Campinas, Instituto de Tecnologia de Alimentos (ITAL), C.P. 139, CEP 13073-001, Campinas, SP, Brazil

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ABSTRACT

Twelve slices of mozzarella cheese (about 174 g) were packaged in expanded polystyrene trays placed in gas-barrier bags under three different atmospheres (100% N2, 100% CO2, and 50% CO2/50% N2). A gas headspace-to-cheese ratio of 2.5 liters/kg of cheese was initially set in the modified-atmosphere packages. Simulating conventional Brazilian packaging, some trays were wrapped in PVC stretched film. Periodically, the product stored at 7 ± 1°C was evaluated as to its sensorial quality, microbiological condition, and physical and chemical characteristics. The headspace volume and gas composition of modified-atmosphere packages were evaluated. The mozzarella cheese did not show any physical or chemical alteration in all packaging treatments. These characteristics were not factors which limited shelf life in air or in modified atmospheres. The critical parameter was sensory degradation. The shelf life of sliced mozzarella in conventional air pack was 13 days. N2 atmospheres had only a minor effect on shelf life compared with air. Samples under N2 were satisfactory up to 16 days. A significant shelf life increase was verified under CO2 atmospheres compared with air, as follows: 63 days (a 385% increase) and 45 days (a 246% increase) for product under 100% CO2 and 50% CO2/50% N2, respectively. The bacteriostatic and fungistatic effects of CO2 were verified. The growth of psychrotrophic bacteria, molds, and yeasts was slower under CO2 atmospheres. Mold and yeast development was inhibited under 100% CO2 (2 liters of CO2 per kg of cheese).

Key words: Mozzarella, cheese, MAP, shelf life

Consumers are becoming more demanding in their choice of food products; the need for high-quality, convenient, and innovative fresh foods, without chemical preservatives, has grown considerably. This particular behavior has encouraged food producers and processors to introduce new technologies in order to become more competitive.

As far as dairy products are concerned, cheese production is an outstanding segment of the market. Among the different types of cheese, mozzarella now has the highest production volume in Brazil (5). One of the trends of this market, which is directed toward meeting consumers’ desire for convenience, is to make sliced cheese available in supermarkets and grocery stores.

Slicing mozzarella requires constant handling at selling points due to its short shelf life. Since mozzarella presents a high humidity and a mild flavor, it has to be protected from dehydration, microbiological development, and flavor changes resulting from odor absorption from its storage environment. Another factor that contributes to quality loss of sliced mozzarella is the adhesion of its slices in the package, which makes it difficult for the consumer to use.

Superficial dehydration, one of the problems sliced mozzarella presents under refrigeration, can be solved by using plastic packages with low water-vapor permeability. The absorption of off flavors from the storage environment can be avoided by using organic vapor-barrier packages or by controlling storage conditions. Microbiological deterioration can be retarded through oxygen (O2) exclusion and/or through the presence of carbon dioxide (CO2) in the package headspace. The absence of oxygen restricts the development of molds, some kinds of yeasts, and aerobic bacteria. Carbon dioxide acts in a different manner; it is an active gas that acts mainly on aerobic microorganisms, retarding their growth, even in the presence of oxygen (1, 6).

The vacuum package is a good alternative for cheese preservation because of the reduced amount of oxygen. However, it is not adequate for sliced mozzarella, because the vacuum pressure enhances adhesion of its slices. On the other hand, a packaging system with modified atmosphere surrounding the product is a very attractive option, for it retards microbiological deterioration without compacting the slices (7, 21, 22).

The technology of packaging products in modified atmosphere is a food-preserving technique which presents many advantages, such as product shelf-life increase, which results in production, storage and distribution economy; the possibility of commercializing a high-quality product, with its freshness preserved; the option of implementing packaging centers with automatic lines for high production vol-

* Author for correspondence. Tel: 00-55-192-415222; Fax: 00-55-192-418445.
umes; and easy separation of product slices, that is, conven-
ience for the consumer (13, 18).

This packaging technology, however, also presents
disadvantages, such as the high cost of packaging and
control equipment, the package itself and the gases; the need
for quality control of the raw material and the packaging
process; and the need for temperature control.

To be considered economically reliable and attractive,
the modified-atmosphere packaging (MAP) technology must
be specifically optimized for each particular product. This
technology involves key parameters as follows: initial
quality of the product, specificity of the gas mixture,
efficiency of packaging equipment, package properties, and
temperature control.

Literature about cheese in MAP is restricted. Several
research studies on cottage cheese were conducted with
emphasis on the inoculation of microorganisms and on their
growth (3, 4, 14); others evaluate the stability of this kind of
cheese in MAP (11, 12, 20). There are two Brasillian studies
of the shelf life of cheeses in MAP, using round-shaped
buffalo-milk mozzarella cheese (17) and grated Parmesan
cheese (19).

In the study of buffalo-milk mozzarella cheese, Sarantó-
poulos, Oliveira, Eiroa, and Shirose (17) verified an increase
in the shelf life of about 240%. MAP for Parmesan grated
cheese allowed a shelf life of 98 days, whereas in air, the
shelf life of this product would not be longer than a few days
(19). The literature shows the shelf life of cottage cheese
as 10 to 21 days (4, 12) and when in atmospheres with CO₂,
the product is acceptable for 28 days (12) and 45 days (11).

The use of atmospheres with high CO₂ levels for dairy
products is very questionable, because in some papers, high
levels of CO₂ led to development of an off flavor (11, 20),
and in others, the product with a high level of CO₂ in MAP
was preferred in a sensory analysis (14).

Therefore, the objective of this study was to evaluate
the efficiency of packaging systems with modified atmo-
sphere on the quality of sliced mozzarella cheese. Thus, the
packaging of sliced mozzarella under modified atmosphere
in gas-barrier bags was optimized, the product stability at
7 ± 1°C was evaluated, and its shelf life under three
different types of modified atmospheres was determined. For
comparison, the shelf life of the product packed in the
conventional air system was also analyzed.

**MATERIALS AND METHODS**

**Sample preparation**

Mozzarella cheese, commercially produced in 3-kg pieces and
vacuum packaged, was sliced after 15 days of storage at 1 ± 1°C.
On the day it was sliced, the cheese had the characteristics
described in Table 1.

Twelve slices of mozzarella cheese (about 174 g) packaged
under three different modified atmospheres (100% N₂, 100% CO₂,
and 50% CO₂/50% N₂) were laid on an expanded polystyrene
(EPS) tray (210 by 140 by 15 mm) and introduced into gas-barrier
packages composed of an ethylene-vinyl acetate copolymer sand-
wich with a center layer of vinylidene chloride-vinyl chloride
copolymer (EVA/PVDC/EVA). These packages consisted of bags
measuring 18 by 28 cm, with oxygen and carbon dioxide permeabil-
ity rates of 26.53 and 79.90 cm²/m²/day respectively at 1 atm (ca.
101 kPa) 24°C, and in dry condition. Simulating conventional
Brazilian packaging, the product on the tray was wrapped in a
stretched polyvinyl chloride (PVC) film (oxygen permeability rate,
9.539 cm²/m²/day at 1 atm, 24°C, and in dry condition).

Packaging under modified atmospheres was accomplished by
using a vacuum chamber Selovac (São Paulo, Brazil) CV-18 machine,
with gas injection, after establishing a vacuum of 25 in. Hg (ca. 85 Pa).
The injection conditions of the gases were optimized in order to obtain a
gas headspace-to-cheese weight ratio of 1 to 3 liters of gas per kg of
the product, as recommended in the literature (6).

**Shelf-life study**

In order to determine the shelf life of the sliced mozzarella
cheeses submitted to four types of atmospheres (air, 100% CO₂,
100% N₂, and 50% CO₂/50% N₂), 24 packages for each treatment
were prepared. The samples were stored at 7 ± 1°C in the dark.

Periodically, triplicate samples under each gas treatment were
analyzed as to the headspace volume and gas composition, microbiologi-
cal and sensorial quality, and physical and chemical characteristics.
These same analyses were carried out for the samples packed in air,
except for the headspace volume and gas composition.

**Headspace volume and gas composition**

The headspace volume was obtained from the difference
between the total package volume and the product, tray, and bag
volume. The total package volume and the tray volume were both
determined by weighing and converting to volume the water
displaced when the whole package or the empty tray was sub-
merged in a container with water at 7 ± 1°C. The product volume
was calculated by multiplying the product weight in each package
by the mean density of the cheese obtained by weighing portions of
cheese and measuring volumes of displaced water at 7 ± 1°C
(mean of 30 repetitions). The volume of the bag was determined by
measuring the package thickness and area.

The headspace gas composition was determined by with-
drawing an aliquot of the package headspace gas through a septum
by means of a gas-tight syringe. The gases were analyzed in a gas
chromatograph (model 2527, C. G. Instrumentos Científicos, São
Paulo, Brazil) with a thermal conductivity detector operating with
argon as the carrier gas, a 5A molecular sieve column (O₂ and N₂),
and a Poropak Q Column (CO₂) (16).

**Microbiological analyses**

Samples of 25 g of cheese were ground and dispersed in 225
ml of 2% sodium citrate. Serial dilutions of this solution were

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prepared for microbial counts. Total counts were conducted through the drop plate method (23). The total counts of aerobic psychrotrophs were accomplished after incubation at 7°C for 10 days on plate count agar (Difco Laboratories, Detroit, MI). The molds and yeasts were counted after an incubation at 21°C for 5 days on acidified potato dextrose agar (Difco).

The determination of total and fecal coliforms was conducted by the most probable number technique (MPN), after enrichment in 2% brilliant green bile broth (Difco) with incubation at 35°C for 24 h for total coliforms, and in E. coli broth (Difco) with incubation at 44°C for 24 h for fecal coliforms (8).

Physical and chemical evaluations

pH measurements were taken by means of a Micronal potentiometer after homogenization of 20 g of the cheese in 20 ml of water at 40°C. Total protein was determined through the official Kjeldahl method by multiplying the total nitrogen value by 6.38 (9, 10). Soluble nitrogen was determined by the nitrogen content of the supernatant, obtained after isoelectric precipitation of the caseins (2). An index of the extent of proteolysis was calculated through the following relation: \[ (\% Ns × 6.38)/Pt × 100 \] (24), where Pt is total protein and Ns is soluble nitrogen.

Sensory analysis

The sensory profile changes were evaluated by a team of nine trained judges. The sliced mozzarella cheese was analysed as to its off odor, off flavor and overall quality by using a nine-point scale with the following connotations: 1, absent and 5, extremely strong flavor and odor; 5, very good and 1, very bad overall quality. The results were submitted to an analysis of variance (ANOVA) and the statistical significance (5% level) was determined by the Tukey test.

Shelf-life prediction

The results of the overall quality were used to define the product shelf life in each treatment, since this parameter combined the alterations of flavor and odor. Therefore, through the statistics software Statgraphics version 4.0, it was possible to obtain the functional relation between the overall quality loss and the shelf life.

RESULTS AND DISCUSSION

Headspace gas composition and volume

The packages with 100% CO₂ and 50% CO₂/50% N₂ had an average of 2.5 liters of gas per kg of cheese.

In packages under CO₂ atmospheres, the gas headspace-to-cheese weight ratio is very important, since CO₂ affects the growth of bacteria, molds and yeasts. During storage, the average volume of headspace in packages under 100% CO₂ was 340 ml; therefore, there were 2.0 liters of CO₂ per kg of cheese. In packages with 50% CO₂/50% N₂, the average volume of CO₂ was 143 ml. Thus, there was 0.8 liter of CO₂ per kg of cheese.

In packages into which 100% N₂ was injected, the concentration of residual oxygen in the headspace, immediately after packaging, was ≈1%. In this system, it is this proportion that determines microbiological inhibition. Analyses on the 4th and 8th storage days showed that the oxygen level increased to about 3%, then dropped to 0.2% on the 18th storage day. The initial oxygen level increase resulted from the mixture of the residual air left between the slices and on the EPS tray and the gas mixture injected in the package headspace. The later drop of this gas concentration can be credited to the oxygen consumed in the metabolism of the aerobic microorganisms. The growth of the aerobic and anaerobic microorganisms was responsible for the increase of the CO₂ concentration, which varied from 0.2% initially up to 5.1% on the 18th storage day. The initial N₂ concentration was 99.0% and between the 4th and the 18th storage days it varied in the range of 97.1 to 94.4%.

The initial O₂ concentration in the packages with 100% CO₂ was 1.4% and during 58 days of storage at 7 ± 1°C it ranged from 3.3% to 4.1%. This oxygen probably came from the residual air left between the slices and adsorbed on the EPS tray. However, it did not diminish during the storage period, for no microbiological growth was verified due to the action of CO₂. Another fact that confirms the existence of residual air left in the packages is the reduction of the initial concentration of CO₂ from 97% to 76 to 81% range during storage, and the increase of the percentage of N₂ from 2%, initially, to the 16 to 20% range.

In the packages injected with 50% CO₂/50% N₂, the initial concentration of oxygen was 0.8% and, during storage, it reached 4.3% on the 9th day and then dropped to 0.5% on the 50th day. The initial increase in the oxygen concentration and its later reduction might also be a consequence of the diffusion of the residual air in the package and of the microbial growth during storage. The oxygen level reduction occurred as of the 25th storage day. This confirms the action of CO₂ in retarding the development of aerobic microorganisms, which initially were present at a concentration of 38.7% and, between the 9th and the 58th storage days, varied between 31.1 and 37.1%. In this case, no major changes in the percentages of N₂ resulting from the equilibrium with the residual air was observed (60.5% initially, and varying from 62.6 to 67.1% during storage), because the initial proportion of nitrogen was already close to that found in the atmosphere. Slow microbiological development, indicated by the consumption of oxygen, did not result in a significant increase in the proportion of carbon dioxide.

Microbiological analyses

Coliforms were not detected in any of the analyses accomplished throughout the shelf-life study. This indicates the use of adequate sanitary practices during the product packaging in the four treatments.

From the 4th to the 14th storage day, the counts of aerobic psychrotrophs in the mozzarella cheese in air and under 100% N₂ increased. Then the counts stabilized at levels of 8.3 log CFU/g and 7.5 log CFU/g, respectively (Figure 1). In the product under 50% CO₂/50% N₂, the growth of aerobic psychrotrophs occurred from the 9th to the 25th storage day, when they stabilized around 7.1 log CFU/g. That growth occurred at a lower rate than the one verified in the product in air and under 100% N₂ due to the action of CO₂. In the mozzarella cheese under 100% CO₂, the growth of aerobic psychrotrophs was only verified from the 29th storage day on and reached counts higher than 6.5 log CFU/g on the 58th storage day. Such results reveal that
FIGURE 1. Growth of aerobic psychrotrophs in sliced mozzarella cheese during storage at 7 ± 1°C.

The growth of yeasts in the mozzarella cheese in air and under 100% N₂ was observed after the 8th storage day. From the 14th day, the counts of yeasts stabilized at 8.4 log CFU/g for the product in air. The cheese under 100% N₂ presented lower counts of yeasts than cheese stored in air throughout the study. On the 18th day of storage, when the cheese under 100% N₂ was sensorially rejected, the counts of yeasts reached levels of 7.6 log CFU/g. The population of yeasts in the cheese under 50% CO₂/50% N₂ showed some growth from the 9th to the 29th storage day, when it stabilized at levels of about 7.0 log CFU/g. The growth in the product under 50% CO₂/50% N₂ occurred at a slower speed than the growth in the product in air and under 100% N₂. That can also be credited to the action of CO₂.

Based on the results of the microbiological evaluations, one can conclude that the use of packaging systems under 100% CO₂ atmosphere for sliced mozzarella cheese inhibits the growth of molds and yeasts and retards the development of aerobic psychrotrophic bacteria in comparison with the conventional air system. When the mixture 50% CO₂/50% N₂ was used, the development of molds and yeasts and of aerobic psychrotrophic bacteria was retarded. The 100% N₂ atmosphere had little effect, in comparison with the conventional air system, in reducing the counts of yeasts in all the periods analyzed, and the counts of aerobic psychrotrophs from the 11th storage day.

Considering the effect of the intrinsic characteristics of mozzarella cheese (pH of 5.4 to 5.5, water activity at 30°C of 0.95, and use of thermophilic cultures) combined with the packaging conditions (low storage temperature and low availability of O₂), the spoilage organisms of the product were expected to be mostly yeasts (15).

In the three packaging systems with modified atmosphere, the residual oxygen verified some days after packaging was similar (3.0 to 4.0%). Hence, it can be concluded that what really inhibited the growth of yeasts was the presence of CO₂. In the product under 50% CO₂/50% N₂, the effect of the carbon dioxide was smaller than in the product under 100% CO₂, because there were 2.5 times less CO₂ per kg of the product.

Such results are in agreement with those in the literature; although CO₂ is not believed to be so effective as to inhibit yeast growth, its effect is also known as a complex phenomenon that does not depend only upon the kind of microrganism present, but also upon the CO₂ concentration, the water activity of the product, pH, temperature, number and age of the microrganisms present, among other factors (6).

In studies of other kinds of cheeses in MAP, the efficiency of CO₂ in inhibiting or retarding microbiological development, thus prolonging the shelf life of the cheeses, has also been verified (3, 11, 17, 19, 20).

**Physical and chemical evaluations**

The pH increased from 5.2 to 5.6 in all treatments. The changes in total protein were small, varying from 21.8 to 23.7%; however, there was an increase in soluble nitrogen during storage, which indicates the occurrence of proteolysis in the product. This was more accentuated in cheeses under 100% CO₂ (2.44% of Ns × 6.38 on the 58th storage day) and under 50% CO₂/50% N₂ (1.83% of Ns × 6.38 on the 50th storage day), because they were stored for a longer period of time. The index utilized to evaluate the extent of proteolysis varied from 5.46% initially to 5.87% (14th day) in air, 5.34% (14th day) in 100% N₂, 10.45% (58th day) in 100% CO₂, and 8.43% (50th day) in 50% CO₂/50% N₂. This indicates that the proteolysis that occurred in the mozzarella
cheese submitted to the three MAPs was small during the storage period the analysis.

Sensory analysis

The sensory evaluation of the products under air and 100% N₂ on the 18th storage day was not undertaken because there was visible microbiological development.

From the 11th storage day, the development of off odor in the mozzarella cheese under air (Figure 3) became significantly higher \((P < 0.05)\) than in the cheese under 100% N₂. The cheeses under atmospheres with CO₂ started to develop some slight off odor only in the last two storage periods of each treatment.

Generally speaking, the development of off flavor (Figure 4) was more perceptible than the off odor and was often identified as fermented, bitter, or yeasty. From the 11th day the development of off odor in the cheese in air was significantly accentuated \((P < 0.05)\) in relation to the one observed in the product under 100% N₂. The development of off flavor in the mozzarella cheese under 50% CO₂/50% N₂ was significantly more intense than that observed in the product under 100% CO₂ as of the 43rd storage day. In both atmospheres with CO₂, the development of off flavor was slower than in the other treatments.

From the 11th storage day, the cheeses in air presented an overall quality significantly inferior \((P < 0.05)\) to the ones under 100% N₂ (Figure 5). The overall quality loss of cheeses under CO₂ atmospheres was more gradual and, from the 43rd storage day, the mozzarella cheese under 50% CO₂/50% N₂ presented overall quality significantly inferior \((P < 0.05)\) to that of the products under 100% CO₂.

If the results of sensory and microbiological analyses are compared, one can observe that in the treatments in air, 100% N₂, and 50% CO₂/50% N₂, the alterations of the sensory attributes analyzed were accentuated when the counts of yeasts in the product were at levels of 7.0 log CFU/g. These counts were verified in cheeses under air, 100% N₂, and 50% CO₂/50% N₂ on the 11th, 14th and 29th storage days, respectively.

The total inhibition of yeast development in the sliced mozzarella cheese under 100% CO₂ was responsible for the better preservation of the sensorial qualities of the product. However, around the 60th storage day, sensory degradations inherent to the product started taking place and led it to its rejection. This can also be verified in the vacuum-packed market mozzarella cheese, which limits the product shelf life to around 60 days (1).

In studies with cottage cheeses, the major concern was the flavor alterations due to CO₂ concentrations higher than 40%. Some authors have proved that such CO₂ concentrations cause a flavor characterized as sour, fermented, and gasous right in the beginning of the storage period, besides producing dripping losses (11, 20). However, Maniar, Marcy, Bishop, and Duncan (12) considered that a 100% CO₂ atmosphere best maintained the sensorial characteristics of cottage cheese at 4°C for 28 days.
Shelf-life prediction

The functional relation between the overall quality (OQ) of the cheese and the storage period (t) (in days), for the four different packaging treatments, is given by the following equations.

1. Air, from the 1st to the 14th day: \( OQ = 4.8859 + 0.0129t - 0.0116t^2; (r^2 = 0.97) \).
2. 100% \( N_2 \), from the 1st to the 14th day: \( OQ = 4.6960 + 0.0666t - 0.0111t^2; (r^2 = 0.98) \).
3. 50% \( CO_2 \)/50% \( N_2 \), from the 1st to the 50th day: \( OQ = 5.0753 - 0.0475t; (r^2 = 0.95) \).
4. 100% \( CO_2 \), from the 1st to the 58th day: \( OQ = 4.8006 - 0.0281t; (r^2 = 0.90) \).

Considering a moderate overall quality (3 on the sensorial scale) as the limit of acceptability of this product, the shelf life for sliced mozzarella cheese in the four different treatments, stored at 7 ± 1°C, can be predicted as air, 13 days; 100% \( N_2 \), 16 days; 50% \( CO_2 \)/50% \( N_2 \), 44 days; and 100% \( CO_2 \), 64 days.

A minor shelf-life increase of this product packed under 100% \( N_2 \) in relation to the conventional air system was verified. However, some significant lasting quality of sliced mozzarella cheese under carbon dioxide atmospheres was verified as can be confirmed by the shelf-life increase of 238% and 392% for the products under 50% \( CO_2 \)/50% \( N_2 \) and 100% \( CO_2 \), respectively. Similar results were attained for round buffalo-milk mozzarella cheese, but with a shelf-life increase of 240% (17).

CONCLUSIONS

On the basis of the results attained in this study, the following conclusions can be drawn.

The inert atmosphere of 100% \( N_2 \) was not effective for controlling the microbial deterioration of sliced mozzarella cheese, probably because the residual oxygen determined after the equilibrium of the gases in the headspace was around 3 to 4%.

The efficacy of carbon dioxide in controlling microbiological deterioration was demonstrated in systems under modified atmosphere with \( CO_2 \). It was also proved that the increment of the relation from 0.8 to 2.0 liters of \( CO_2 \) per kg of cheese led to an increase in the efficacy of this gas. In cheeses under an atmosphere with 0.8 liters of \( CO_2 \) per kg of cheese (50% \( CO_2 \)/50% \( N_2 \)), there was a reduction in the rate of development of aerobic psychrotrophs and molds and yeasts. In cheeses under an atmosphere with 2.0 liters of \( CO_2 \) per kg of cheese (100% \( CO_2 \)), the beginning of the growth of aerobic psychrotrophs was retarded and their growth rate was diminished. Also, the growth of molds and yeasts in the cheeses was totally inhibited.

Atmospheres with high percentage of \( CO_2 \) did not cause undesirable changes in the mozzarella flavor.

The shelf life of sliced mozzarella cheese at 7 ± 1°C, based on the overall quality evaluation, for the four different packaging systems was under conventional air, 13 days; under 100% \( N_2 \), 16 days; under 50% \( CO_2 \)/50% \( N_2 \), 44 days; and under 100% \( CO_2 \), 64 days.

Of the four systems evaluated, the atmosphere with 100% \( CO_2 \) constitutes an interesting MAP alternative for commercializing sliced mozzarella cheese, making possible a shelf life comparable to the vacuum-packed product.

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REFERENCES


