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Meat Science 67 (2004) 57–63
MEAT SCIENCE
www.elsevier.com/locate/meatsci

Comparison of modified atmosphere packaging and vacuum packaging for long period storage of dry-cured ham: effects on colour, texture and microbiological quality

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Received 14 April 2003; received in revised form 8 August 2003; accepted 8 September 2003

Abstract

Slices of dry-cured hams (*Biceps femoris* muscle) were stored during 8 weeks under vacuum and modified atmospheres (100% N_2 and a mixture of 20% CO_2 and 80% N_2) in order to study the modifications on colour, texture and microbial counts during that period. Lightness was found to be more stable when samples were stored with 20% CO_2 and 80% N_2 without statistical differences between vacuum and 100% N_2. A slight whiteness was observed in the vacuum packed samples. Yellowness increased during time in vacuum packed samples, although no differences were found among the three conditions at the end of the study. Redness values were not affected by time or by the packaging system. With regard to texture, values found for all samples were within the normal range for this type of products, although it was observed that modified atmosphere packaging preserved samples better from hardening than vacuum packaging. No safety problems were detected in relation to the microbial quality in any case. In general, no clear differences were found among the three packaging systems for colour, texture and microbial quality in the storage conditions studied.

Keywords: Dry-cured ham; Modified atmosphere packaging; Colour; Texture; Shelf life

1. Introduction

The food industry has developed different packaging technologies trying to extend the shelf life of perishable products such as meat and meat products. Among these technologies, vacuum packaging prevents product from contamination and evaporative losses, and modified atmosphere packaging also extends storage life (Stiles, 1990).

In general, modified atmosphere packaging (MAP) extends the shelf life of fresh meat in a significant way, but a control of temperature and initial microbiological quality of raw matter is required. In relation to meat products, there is less potential to extend their shelf life using MAP than with fresh meat since operations as drying, curing, smoking, fermentation, freezing, cooking and chilled storage already help to extend shelf life (Church, 1993). Nevertheless, microbial spoilage and colour deterioration are considered the most common problems during the shelf life of meat products (Church, 1993).

The application of MAP to processed meat has grown greatly in recent years, but optimisation of gas composition is critical to ensure both product quality and safety (Moller, Jensen, Olsen, Skibsted, & Bertelsen, 2000). CO_2 is, because of its antimicrobial activity, the most important component in the normally applied gas mixtures (Devlieghere, Debevere, & Van Impe, 1998) and N_2 is used as a filler (Sorheim, Nissen, & Nesbakken, 1999).

A lot of studies have been carried out in order to study the effectiveness of vacuum, different gas composition and packaging material on the preservation of fresh meat (Buys, Nortjé, Jooste, & Von Holy, 2000; García de Fernando, Nychas, Peck, & Ordóñez, 1995; Gill, 1996; Houben, van Dijk, Eikelenboom, & Hoving-

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doi:10.1016/j.meatsci.2003.09.005

Bolink, 2000; Sorheim et al., 1999), cooked meat products (Houben & van Dijk, 2001; Mataragas, Drosinos, & Metaxopoulos, 2003; Moller et al., 2003) and dry fermented sausages (Fernández-Fernández, Vázquez-Odériz, & Romero-Rodríguez, 2002; Yen, Brown, Dick, & Acton, 1988). In relation to dry-cured ham not many research articles can be found in the literature. However, the use of MAP is becoming extensive in industry and, above all, it is important for exportations (Ayuso, 2003).

Colour stability of cured meat packaged with modified atmospheres depends on a complex interaction between headspace oxygen level, product to headspace volume ratio and the level of illuminance. Moller et al. (2003) considering all these factors concluded that for a product/headspace volume ratio of 1:1 the colour is much better preserved than for larger headspace volumes, and in order to maintain a high a^*-value, it is necessary to keep the oxygen level low and also a low level of illuminance. García-Esteban, Ansorena, Sánchez, and Astiasarán (2003) found slight differences between vacuum and MAP storage of *Semimembranosus* muscle of dry-cured ham.

Studies carried out in fresh meat pointed out that vacuum packaging shows lower drip loss than MAP (Sorheim, Kropf, Hunt, Karwoski, & Warren, 1996). Dry-cured products such as ham do not have the problem of drip loss, but some moisture losses can be produced during storage that could affect textural properties. Córdoba (1990) stated that higher shear force values were observed in muscles of dry-cured ham with significant lower moisture content.

MAP has even been used to accelerate ripening of dry-cured boneless hams observing that it is feasible to ripen them without negative influence on quality (Wang, 2001). Ripening of dry-cured hams under MA could reduce cholesterol oxidation products and mite and fungus growth (Sánchez-Molinero, Arnau, García Regueiro, & Rius, 2003). In Chinese-style sausages, a comparison of the lipid oxidation suffered by samples under vacuum and under MAP was carried out (Wang, Jiang, & Lin, 1995). However, no research work has been found in which the differences between vacuum and MAP conditions of storage of dry-cured ham were studied.

The aim of this work was to compare the evolution of colour, texture and microbiological quality of dry-cured ham during chilled storage of slices packed under vacuum and under two MA conditions (100% N_2 or 80% N_2 + 20% CO_2).

2. Materials and methods

2.1. Samples

Samples were taken from 12 Serrano dry-cured hams from the same batch, that were ripened for approximately 1 year. They were given by the factory La Unión Resinera Española (Teruel, Spain). Qualitative formulation of additives used for ripening included sodium chloride, sodium nitrite, potassium nitrate and sugars. These hams were sliced (12 mm thick) and packaged (with a packer Ramon Serie: VP Mod: 450) under one of the three conditions: vacuum, 100% N_2 (Extendapack 1, *Praxair*) and a gas mixture of 20% CO_2 and 80% N_2 (Extendapack 14, *Praxair*). Three slices of each ham were taken and the slices of four hams were stored under each condition. One slice of each ham was analysed just after packaging, another one 3 weeks later and the last one, 8 weeks later. The laminated film used for packaging consisted of seven layers: polyethylene (PE) of medium linear density, PE of medium density, polyamide (PA) modified, ethylene-vinylidene alcohol (EVOH) alloy, PA modified, polyethylene of linear low density and 4.5% ethylene-vinylidene acetate (EVA) (Super7E2, thickness of 140 μm, Vaessen-Schoemaker industrial, S.A.). This film has an oxygen transmission rate (OTR) of 8.3 cc/m^2/atm/24 h at 23 °C and 0% R.H. Packages were kept in chilled storage at 4 °C without light for 8 weeks. Packages had a headspace volume ratio of 1:1.

2.2. Instrumental colour measurement

Colour measurements were taken in triplicate on the *B. femoris* muscle of 12 mm slices. For these measures, reflectance spectra were determined with a UV/VS Perkin–Elmer Lambda 5 Spectrophotometer from 400 to 700 nm, at 10 nm intervals, using an integrating sphere. Colour system employed was Hunter Lab, with illuminant A and 10° observer angle (García-Esteban, Ansorena, Gimeno, & Astiasarán, 2003). The colour co-ordinates were calculated from the reflectance spectra by means of the PECOL (Perkin–Elmer) computer package.

2.3. Texture analysis

Texture parameters were determined by means of texture profile analysis (TPA) (Bourne, 1978; Henry, Katz, Pilgrim, & May, 1971). Measurements were taken at room temperature, with a TA-XT2 Texture Analyser (Stable Micro Systems, Godalming, UK) with a load cell of 5 kg. Measurements were taken on the *B. femoris* muscle of 12 mm slices, stored under the mentioned conditions. Compression was performed with a cylinder probe of one inch diameter (P/1R, delrin). Two uniaxial compressions were carried out until 30% of deformation of the original height, applying a crosshead speed of 3 mm/s and a chart speed of 1 mm/s.

Data collection and analysis were performed by means of the Texture Expert Stable Micro Systems computer program, version 1.16. Graphics to calculate different texture parameters: hardness, springiness, co-

hesiveness, gumminess and chewiness. Hardness was the peak force during the first compression cycle, springiness was the ratio of the time recorded between the start of the second area and the second probe reversal to the time recorded between the start of the first area and the first probe reversal, cohesiveness was the ratio of the area under the second curve to the area under the first curve, gumminess was the product of hardness and cohesiveness and chewiness was the product of hardness, cohesiveness and springiness.

2.4. Microbial analysis

Microbial determinations were performed according to the following analytical methods: mesophile aerobic colonies (ISO 2293, 1988), lactic acid bacteria (ISO 15214, 1998), moulds and yeast counts (Berenguer, 1992), *Enterobacteriaceae* (ISO 5552, 1997), coliforms (AOAC 982.36, 2002), *Escherichia coli* (AOAC 982.36), sulfite-reducing spored anaerobic bacteria (Pascual, 1992), *Staphylococcus aureus* (ISO 6888-1, 1999), *Salmonella* (Method ISO 3565, 1975), *Listeria monocytogenes* (Automated Inmunoassay. Protocol Vidas. Validated by AFNOR: no. certificate BIO-12/03-03/96) and *Campylobacter jejuni* (Stern, Wojton, & Kwiatek, 1992).

2.5. Moisture determination

Moisture was determined according to the AOAC method (AOAC 950.46, 2002).

2.6. Oxygen analysis

Before opening packages (in order to perform determinations), oxygen in bags was measured with an Abiss Analyser (Model PAK01P No. 11 1631).

2.7. Data analysis

Experimental data were statistically processed using the SPSS version 9.0 software.

Mean values, standard deviation and coefficient of variation are shown in the tables. For colour and texture parameters, an ANOVA test was carried out to determine statistical differences along the storage period or differences among the storage systems. Principal component analysis (PCA) was carried out with texture, moisture and Hunter *L a b* colour parameters.

3. Results and discussion

3.1. Colour analysis

Results of colour measurement are shown in Table 1. It includes the three primary (*L*, *a* and *b*) colour co-ordinates used in the Hunter system to determine colour. Lightness (parameter *L*) at 0 days showed in all samples similar mean values to results of colour analysis performed in the same muscle in a previous study carried out by García-Esteban et al. (2003) to optimise the instrumental colour analysis in dry-cured ham. Lightness increased during storage in vacuum packed samples showing significantly higher values by the third week of storage, which could be due to a whitening surface observed in these slices. No changes were observed for this parameter in samples under vacuum during the following weeks. Samples under both modified atmospheres kept *L* constant during the whole period of storage, showing values at the end of the storage period very similar to those at the packaging moment. The lowest *L* values at 3 and 8 weeks corresponded to samples under $CO_2 + N_2$ which did not show differences with samples under N_2 but were significantly different from those stored under vacuum storage.

Parameter *b* (yellowness) also increased by the third week of storage only in vacuum packed samples, but no significant differences were found among the three packaging conditions at the end of the 8 weeks for yellowness. Differences in *b* along the storage period could be related to the intensity of the oxidation process that takes place during storage and might tend to increase yellowness of samples by rancidity, although no

Table 1
Colour evolution in *B. femoris* muscle during the storage period for all the packaging conditions

Packaging	Hunter A10	0 days	3 weeks	8 weeks
Vacuum	*L*	41.69aA (1.22)	46.64bB (2.71)	46.65bB (3.30)
	a	21.27aA (1.29)	19.36aA (2.50)	20.09aA (2.37)
	b	22.01aA (0.70)	23.59bA (1.37)	23.79bA (0.96)
N_2	*L*	42.43aA (1.28)	43.85aAB (1.40)	44.26aAB (1.95)
	a	21.57aA (1.60)	22.53aA (1.69)	21.74aA (0.96)
	b	23.78aB (1.37)	24.48aA (1.18)	24.04aA (1.48)
CO_2+N_2	*L*	41.94aA (0.67)	43.33aA (2.11)	41.47aA (2.75)
	a	20.92aA (2.67)	20.66aA (2.63; 12.73)	20.56aA (3.40)
	b	22.31aA (0.37)	23.02aA (1.24)	22.07aA (1.60)

Results are the mean of the three measurements made in four dry-cured hams.

Values in brackets are standard deviation.

Statistics in small letters compare the three periods in each storage condition and parameter.

Statistics in capital letters compare the three storage conditions for each parameter at each storage period.

measures of oxidation intensity are available to support this hypothesis. Wang et al. (1995) analysing the lipid oxidation in Chinese-style sausage stored at two temperatures (4 and 15 °C) in vacuum and MA packaging found that TBA and peroxide values were lower in MA than in vacuum conditions at both temperatures. A slight but significant higher value was observed in this parameter at 0 days between samples with N_2 and the two other conditions. This difference was probably due to the variability among the different hams. With regard to redness (*a*), which has been used as an indicator of colour stability in meat and meat products, no differences were detected nor during the storage periods nor during the three storage conditions. Yen et al. (1988) compared five packaging materials with OTR between 1 and 90 $cm^3/m^2/atm/24$ h, in vacuum packed dry salami and found no significant decrease in *a*-value when OTR was below 30 $cm^3/m^2/atm/24$ h. A decrease in *a*-values was found in cooked cured ham packaged with films with OTRs of 10 (Moller et al., 2003), showing that colour stability decreased when residual oxygen increased. In the present work, packaging film used had a low OTR and the oxygen analysis performed showed very low levels of oxygen during the storage (0.1%), and colour stability was kept in these samples. 0.1% or less residual oxygen protected sliced, pasteurised ham from discoloration when exposed to light during chilled retail display (Moller et al., 2000).

Consequently, only slight differences in lightness were found between vacuum and MAP stored samples without differences in redness and yellowness among the three studied conditions.

3.2. Texture analysis

Changes in hardness during dry-cured ham ripening have been attributed to both water content and state of proteins (Monin et al., 1997). These changes could continue also during the storage period, where modification of the water content could be observed. In vacuum and N_2 packed samples, there was a significant decrease in moisture at 3 weeks, decreasing significantly ($p < 0.05$) from 55.56% to 53.85% and from 56.63% to 55.81%, respectively. No decrease was observed in samples packed with $CO_2 + N_2$. During the rest of the storage no statistical differences were observed in moisture in any of the conditions, showing at 8 weeks values of 54.23, 56.32 and 53.38 for vacuum, N_2 and $N_2 + CO_2$ batches, respectively. Bartkowiski, Dryden, and Marchello (1982) found that beef stored under controlled atmospheres contained more moisture than when it was stored in vacuum. Ruiz, Ventanas, Cava, Timón, and García (1998) studying the influence of slice location on the sensory characteristics of Iberian ham observed significant changes in the appearance and texture. Texture parameters were evaluated by TPA analysis carried out in *B. femoris* (Table 2). When studying their evolution throughout the storage period, it could be observed that samples packed with N_2 or $N_2 + CO_2$ showed no statistical differences in any parameter during the period studied with regard to those values observed at the packaging moment. However, vacuum packaging increased hardness, cohesiveness, gumminess and chewiness already by the third week of storage and these values were maintained at 8 weeks. Guerrero, Gou, and Arnau (1999) evaluating texture of *B. femoris* of dry-cured hams found values for hardness compression fell between 2600 g in hams elaborated with high pH meat and 4700 g in those elaborated with normal pH meat. Values around 2320 g were obtained for hardness in the same muscle by Monin et al. (1997) after 251 days of ripening. Virgili, Parolari, Schivazappa, Soresi Bordini, and Borri (1995) evaluating the

Table 2
Texture parameters measured on *B. femoris* muscle of dry-cured ham slices packaged under different conditions for the period of time studied

Packaging	Parameters	0 days	3 weeks	8 weeks
Vacuum	Hardness (g)	2030aA (147)	2544bA (443)	2669bB (334)
	Springiness (mm)	0.813aA (0.03)	0.839aA (0.07)	0.850aB (0.07)
	Cohesiveness	0.556aA (0.03)	0.610bB (0.01)	0.613bB (0.03)
	Gumminess (g)	1130aA (113)	1551bB (260)	1636bB (227)
	Chewiness (g mm)	922aA (126)	1303bB (235)	1391bB (227)
N_2	Hardness (g)	1552aA (542)	1922aA (573)	1679aA (528)
	Springiness (mm)	0.705aA (0.07)	0.777aA (0.129)	0.690aA (0.09)
	Cohesiveness	0.508aA (0.02)	0.498aA (0.06)	0.505aA (0.03)
	Gumminess (g)	781aA (252)	974aA (353)	855aA (293)
	Chewiness (g mm)	554aA (195)	787aA (369)	609aA (270)
CO_2+N_2	Hardness (g)	1954aA (804)	2160aA (902)	2178aAB (815)
	Springiness (mm)	0.787aA (0.12)	0.757aA (0.07)	0.802aB (0.09)
	Cohesiveness	0.548aA (0.06)	0.548aA (0.06)	0.569aB (0.07)
	Gumminess (g)	1100aA (541)	1230aAB (615)	1291aAB (616)
	Chewiness (g mm)	914aA (552)	954aAB (519)	1085aB (613)

Results are the mean of the four measurements made in four dry-cured hams.

Values in brackets are standard deviation.

Statistics in small letters compare the three periods in each storage condition and parameter.

Statistics in capital letters compare the three storage conditions for each parameter at each storage period.

texture of 120 hams at the end of maturation detected a hardness range between 730 and 4370 g also in the *B. femoris* muscle. At the end of the storage period, vacuum packed samples showed, among the three packaging systems, the highest hardness value (2669g), significantly higher than the one found for samples with N_2 but without significant differences with samples with $CO_2 + N_2$.

It could be concluded that modified atmosphere packaging preserved samples from hardening and deterioration of textural properties more efficiently than vacuum packaging. Nevertheless, taking into account the normal variability found for this parameter, all values were considered normal for this type of product.

3.3. Microbiological quality

Table 3 shows results of the microbiological analysis of hams at the beginning and at the end of the study. Wang (2001) applying MAP for reducing ripening time of dry-cured boneless hams stated that the stability of microbiological quality is attributed to low water activity in dry-cured ham and bacteriostatic effect of modified atmospheres. *Enterobacteriaceae,* considered to be hygienic indicators, were found to be less than 10 cfu/g at the end of the curing process. In all the storage conditions, the final product showed no differences in the parameters related to hygienic-sanitary quality compared to the initial slices. A special care has to be taken of the growth of psychrotrophic pathogens such as *L. monocytogenes* under modified atmospheres. García de Fernando et al. (1995) stated that both vacuum and modified atmosphere packaging under 100% N_2 readily support the growth of some pathogens such as *L. monocytogenes*. In our work *L. monocytogenes* was not detected in any sample. *Lactic acid bacteria* (LAB) counts were around 10^2 during the whole period of storage. These LAB naturally dominate the microflora of many meat products chill-stored under vacuum or in an environment enriched with CO_2 (Holzpfel, Geisen, & Schillinger, 1995; Stiles, 1996). Mataragas et al. (2003) proved that some LAB strains may be used as protective cultures to inhibit the growth of *L. monocytogenes* or its bacteriocins in vacuum or MA (80% CO_2 + 20% N_2) packaged sliced cooked cured pork at 4 °C.

S. aureus has also been controlled because it is one of the risk factors in food poisoning. Portocarrero, Newman, and Mikel (2002) pointed out that higher salt content and lower water activity values on country-cured hams play an important role in controlling the growth and toxin production of *S. aureus*. In this work no increases were found in *S. aureus* counts during the 8 weeks of storage in none of the studied conditions and values of water activity were always lower than 0.8. There was absence of *Salmonella* and *C. jejuni*.

Final aerobic mesophile counts were, in all cases, lower than 10^4 cfu/g, which were the values found at the end of both fast and slow curing of dry-cured ham (Marín, Carrascosa, & Cornejo, 1996). Mesophile aerobic colonies at 8 weeks slightly increased with regard to initial counts in vacuum packed samples whereas a decrease was found in samples under 100% N_2 and 20% CO_2 + 80% N_2.

Physicochemical parameters were subjected to a PCA. Components 1 and 2 explained the 73.44% of variance, being component 1 mainly defined by texture parameters and component 2 by lightness and *b* (Fig. 1). The plot of samples as a function of the two principal components (Fig. 2) resulted in an overlapped diagram, without clear differences among the different storage conditions, despite the differences found in the ANOVA test for lightness, moisture and hardness between vacuum and MAP conditions at the end of the study. These results showed that no clear advantage of the modified atmospheres was observed with regard to vacuum packaging of dry-cured ham.

In summary, it could be concluded that, with regard to colour, texture, moisture and microbiological stabil-

Table 3
Microbiological stability of dry-cured ham slices packed under different conditions during the period of time studied

Microbiological parameters	Vacuum		100% N_2		20%CO_2 + 80%N_2	
	0 days	8 weeks	0 days	8 weeks	0 days	8 weeks
Mesophile aerobic colonies (cfu/g)	7.5×10^2	9.45×10^3	7.4×10^3	1.95×10^3	1.65×10^4	4.35×10^3
Lactic acid bacteria (cfu/g)	$<1.0\times10^2$	$<1.0\times10^2$	$<1.0\times10^2$	$<1.0\times10^2$	$<1.0\times10^2$	$<1.0\times10^2$
Moulds and yeasts count (cfu/g)	5.0×10^2	4.0×10^2	8.0×10^2	3.5×10^2	3.15×10^2	3.5×10^2
Enterobacteriaceae (cfu/g)	$<1.0\times10^1$	$<1.0\times10^1$	$<1.0\times10^1$	$<1.0\times10^1$	$<1.0\times10^1$	$<1.0\times10^1$
Coliforms (cfu/g)	<3	<3	<3	<3	<3	<3
E. coli (cfu/g)	<3	< 3	<3	<3	<3	<3
Sulfite-reducing spored anaerobic bacteria (cfu/g)	$<1.0\times10^1$	$<1.0\times10^1$	$<1.0\times10^1$	$<1.0\times10^1$	$<1.0\times10^1$	$<1.0\times10^1$
Salmonella (cfu/25 g)	Absent	Absent	Absent	Absent	Absent	Absent
Staphylococcus aureus (cfu/g)	$<10^2$	$<1.0\times10^2$	$<1.0\times10^2$	$<1.0\times10^2$	$<1.0\times10^2$	$<1.0\times10^2$
Listeria monocytogenes (cfu/25 g)	Absent	Absent	Absent	Absent	Absent	Absent
Campylobacter jejuni (cfu/25 g)	Absent	Absent	Absent	Absent	Absent	Absent

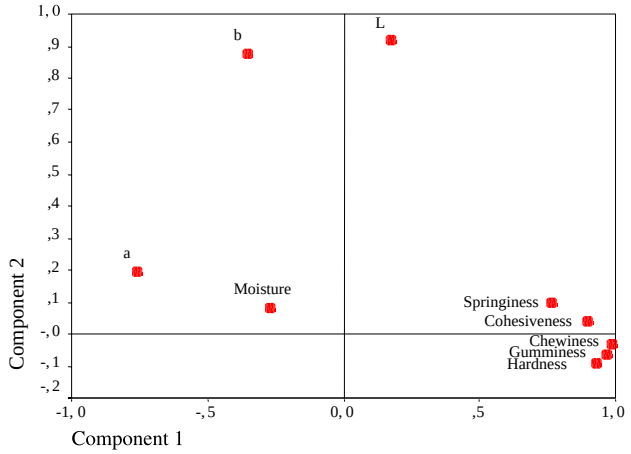

Fig. 1. Plot of the loadings obtained for the parameters included in the principal component analysis (moisture, Hunter Lab co-ordinates and texture parameters). Component 1 explained 55.24% of the variance. Component 2 explained 18.16% of the variance.

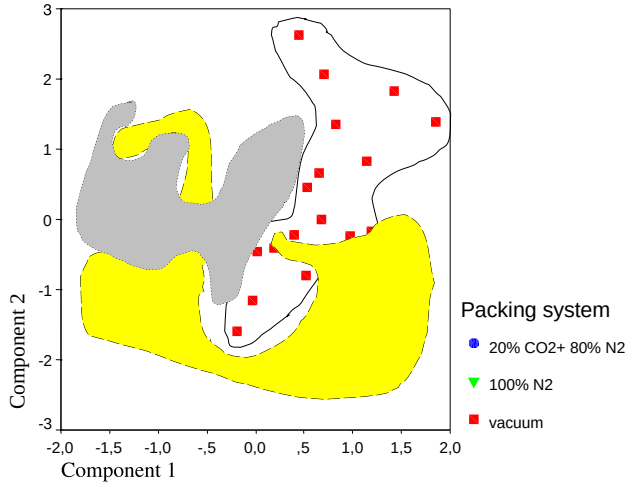

Fig. 2. Plot of analyzed samples (cured ham packed in different conditions) in the principal component analysis test.

ity, dry-cured ham stored in vacuum and modified atmospheres (100% N_2 and 20% CO_2 + 80% N_2) did not show clear differences.

Acknowledgements

Authors are grateful to "*La Unión Resinera Española, S.A.*" (Spain) for the financial support to carry out this study. M. García-Esteban is grateful to the "*Ministerio de Educación, Cultura y Deporte*" for her FPU grant. "*Praxair*" and "*Anvisa, S.A.*" for their help.

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