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Microbial Inactivation of Paprika by a High-Temperature Short-X Time Treatment. Influence on Color Properties

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High-temperature short-time (HTST) treatments have been used to destroy the bioburden of paprika. With this in mind, we have designed a device to treat samples of paprika with a gas whose temperature, pressure, and composition can be selected. Temperatures and treatment times ranged from 130 to 170 °C and 4 to 6 s, respectively. The survival of the most commonly found microorganisms in paprika and any alteration in extractable and superficial color were examined. Data showed that the optimum HTST conditions were 145 °C, 1.5 kg/cm^2 of overpressure, 6 s operation time, and a thermal fluid of saturated steam. No microbial growth was detected during storage after thermal treatment. To minimize the color losses, treated (HTST) paprika samples should be kept under refrigeration.

KEYWORDS: Paprika; high-temperature short-time treatments; microbial inactivation; extractable color; surface color

INTRODUCTION

Paprika is a spice obtained when the ripe fruits of red pepper (*Capsicum annuum* L.) are dried and ground. The result is a brilliant red powder, with a high carotenoid content, which is used to impart a bright red color and distinctive flavor to meat and sausage products and to other processed foods.

Because spices and natural seasonings are of agricultural origin, they are commonly contaminated with microorganisms (bacteria, molds, and yeasts). The numbers and types of microorganisms vary with the particular material, its origin, climatic conditions, the harvesting, processing, storage, and transport methods used, the packaging, and the general environmental and handling circumstances, including the nature and extent of quality control measures. The paprika bioburden is constituted mainly by mesophilic bacteria, but anaerobic spore-forming bacteria, molds, and yeasts may also be present (*1, 2*). Among pathogenic bacteria of concern in paprika are *Salmonella*, *E. Coli*, *Clostridium perfringens*, *Staphylococus aureus*, and *Bacillus cereus* (*2, 3*).

The food industry must face up to the increasing demand by consumers for high quality foods, especially as regards their hygienic condition. Because paprika and other spices are used as food ingredients their level of contamination should also be limited. Among the methods used to ensure that paprika is hygienically acceptable, treatment with ethylene oxide (ETO) has been widely used despite the fact that it may affect sensorial parameters and is questionable from a toxicological point of view. Frequently anomalous aromas and color alterations appear, and volatile compounds are lost because of the low pressure that is necessary to remove this sterilizing agent (*4*−*7*). Furthermore, ETO is classified as a carcinogen and may react with chlorides in foods to produce the toxic and persistent ethylene chlorhydrins. Hence, the use of ETO for ridding spices of microbes is being phased out worldwide. In the European Union it is classified as R-48 and its use in foods is prohibited.

When alternative treatments have been tested for sterilizing paprika, the main problem is always the difficulty involved in applying a sterilization treatment to a powdered product. Microwaves have been tried but they do not effectively reduce microbe levels, probably because of the low moisture content of this product (*8, 9*). Ultraviolet radiation does not have enough penetrating power to decontaminate the powder, and, moreover, results in a high degree of carotenoid oxidation (*6*). Ionizing radiation is another alternative for inactivating foodborne microorganisms (*1*−*3, 10*−*17*). The availability of electron accelerators has opened up good prospects for food irradiation because no nuclear waste is generated and the installation necessary is much more straightforward than is necessary with that for radioisotopes. Although, to date, no study has demonstrated any long-term ill effects from this technique and the nutritional quality of the foods seems largely unaltered, many individuals and groups have voiced concern against the irradiation of foods, and the spice industry, among others, is still wary of the public's reaction.

The investigation reported in this paper studies the effect of high-temperature short-time (HTST) hygienization on paprika. Besides its effectiveness on the microbiological population we

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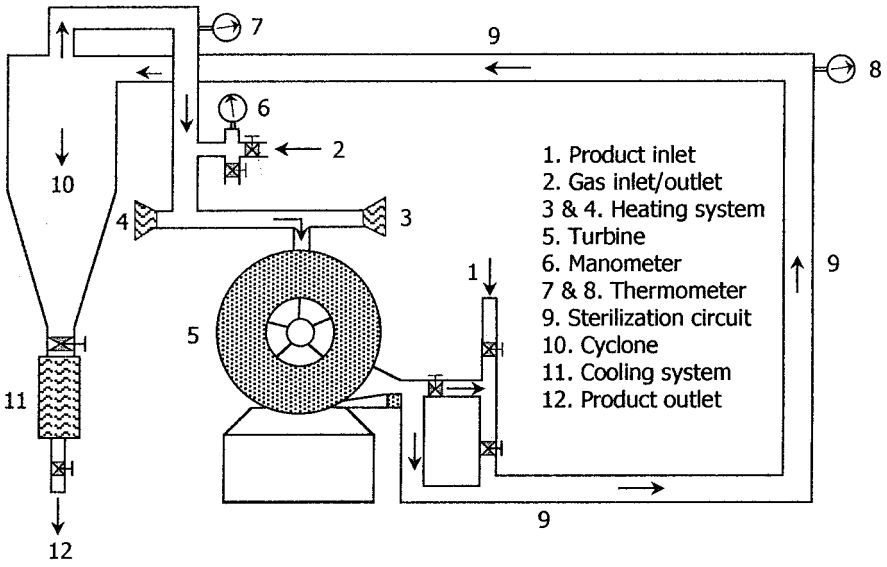

Figure 1. Scheme of the HTST sterilization installation.

consider the influence of this treatment on the color of the samples, which is the main quality attribute of this spice.

MATERIALS AND METHODS

Samples. Commercial paprika samples, of different color hue and obtained locally, were used in all the experiments. The raw material (red pepper fruits) came from different cultivars grown in Spain, Morocco, and South Africa.

Decontamination Treatments. Decontamination experiments were performed using a thermal treatment (HTST) applying a superheated gas. The installation and operation conditions are described below. The variables considered were temperature, pressure, and composition of the gaseous mixture.

Physicochemical Characterization of the Paprika Samples. Physicochemical characteristics were analyzed according to the methods of the American Spice Trade Association (*18*).

Surface color was measured using a Minolta CM-508I reflectance spectrophotometer with D_{65} as standard illuminant and 10° observer angle. The CIELAB color space was chosen to express the results (*19*). L*, a*, b*, C*, hue angle (*h*) and ΔE* (color difference) were determined. Data shown are the means of 15 determinations in each paprika sample.

Microbiological Count. The survival of the microorganisms most commonly found in paprika was analyzed. For total mesophilic bacteria, the pour plate technique, with standard plate count agar, was used according to American Public Health Association methods (*20*). Molds and yeast were determined after incubation in oxytetracycline glucose yeast extract agar (*21*). For *Enterobacteriaceae* count, the samples that showed growth after enrichment in EE Mossel broth were inoculated on violet red bile glucose agar, and colonies grown in this medium were identified according to the cytochrome-oxidase test and also on Kligler agar (*20*). Coliforms were determined with the most probable number technique using MacConkey broth (purple) (*22*). Sulfite-reducing clostridia count was performed in anaerobic conditions in agar for perfringens with Shahidi−Ferguson selective supplement (*20*). Culture responses were expressed as CFU/g. The thermal treatment resulting in a 90% reduction of viable CFU (D_{10} value), was obtained as the reciprocal of the slope of the linear regression of the log survivor values, as determined by least-squares analysis.

Thermal Treatments. Figure 1 shows the scheme of the installation used in the experiment to simulate HTST treatments. The device was able to treat 200-g samples of paprika in a discontinuous way; temperature, pressure, and gas composition could be selected. The treatment was carried out in adiabatic conditions, and, finally, the samples were fast cooled using a nitrogen stream to bring the temperature to below 40 °C to avoid alteration of the product.

Table 1. Microbial Count (CFU/g) as Result of the Treatment at 152 °C Using Dry Nitrogen at Different Pressures

ΔP[a] (kg/cm^2)	total count	*Entero-bacteriaceae*	coliforms	sulfite-reducing *clostridia*	molds and yeast
reference	$71\cdot10^5$	$24\cdot10^3$	$93\cdot10^2$	$1.5\cdot10^2$	$14.5\cdot10^3$
0	$15.5\cdot10^5$	4	43	<10	<100
0.5	$16.2\cdot10^5$	<3	23	<10	<100
1.4	$10.8\cdot10^5$	<3	15	<10	<100
2.1	$11.4\cdot10^5$	<3	4	<10	<100

[a] Increase over atmospheric pressure.

RESULTS AND DISCUSSION

Optimization of the Treatment Conditions. The time of the treatment was established by adjusting the length of the sterilization circuit; in standard conditions this lasted 6 s. The highest working temperature was 170 °C; higher temperatures, even in nitrogen atmosphere, produced considerable alterations of the paprika color.

Table 1 shows data concerning microorganism survival after each thermal treatment using dry nitrogen at 152 °C and several pressures. Although coliforms are a subgroup of *Enterobacteriaceae*, they were studied as an independent group.

All the thermal treatments reduced the number of colonies of *Enterobacteriaceae* and coliforms because they are very sensitive to high temperatures. In the same way, the most resistant microorganisms, such as sulfite-reducing clostridia, molds, and yeast, were almost totally destroyed.

When the total count is considered, it can be seen that, although destruction is close to 85%, microorganism survival at an overpressure of 2.1 kg/cm^2 nitrogen exceeds 10^6 CFU/g, which must be considered too high for a good quality paprika. According to these results we can conclude that, in an N_2 atmosphere, pressure hardly affects microbiological destruction.

The effect of thermal treatment at 152 °C on paprika color is summarized in **Table 2**. When the overpressure was 2.1 kg/cm^2 (the most effective for microbial destruction), the decrease in ASTA color was only 7.39%, an admissible value considering other sterilization procedures generate losses of around 10%. The destruction of the color was in the order of 5−6% at lower pressures. This small difference in the extractable color can mainly be attributed to the effect of temperature, because when

Table 2. Incidence of HTST Treatments Using Dry Nitrogen at 152 °C on the Extractable and Surface Color of Paprika

			surface color[b]					
ΔP (kg/cm^2)	ASTA color[a]	color loss (%)	L*	a*	b*	ΔE*	C*	h
reference	87.00 ± 0.05	-	37.63 ± 0.18	34.73 ± 0.16	42.41 ± 0.95	-	54.81	50.69
0	82.29 ± 0.09	5.41	37.68 ± 0.21	33.37 ± 0.14	41.40 ± 0.16	1.69	53.17	51.13
0.5	82.11 ± 0.15	5.62	37.00 ± 0.23	33.34 ± 0.26	43.04 ± 1.25	1.65	54.44	52.24
1.4	81.04 ± 0.13	6.85	36.71 ± 0.26	32.24 ± 0.28	41.46 ± 0.92	2.82	52.52	52.13
2.1	80.57 ± 0.21	7.39	35.98 ± 0.20	30.63 ± 0.19	39.29 ± 0.88	5.41	49.82	52.06

[a] ASTA color: mean ± SD of triplicate samples. [b] Surface color: mean ± SD of fifteen repetitions.

Table 3. Parameters of the Sterilization Treatments Using Nitrogen and Steam at 160 °C

treatment	ΔP (kg/cm^2)	% nitrogen	% water steam
1.B	1	50	50
1.D	1	- -	100
2.A	2	75	25
2.B	2	50	50
2.C	2	25	75
2.D	2	- -	100

Table 4. Microbial Count (CFU/g) as Result of the Treatment at 160 °C with Water Steam or with Nitrogen and Water Steam Simultaneously

	total count	*Entero-bacteriaceae*	coliforms	sulfite-reducing *clostridia*	molds and yeast
reference	$71\cdot10^5$	$2.4\cdot10^4$	$9.3\cdot10^3$	150	$1.4\cdot10^4$
treatment[a]					
1.B	$8.3\cdot10^5$	<30	<30	100	<100
1.D	$7\cdot10^4$	<3	<3	<10	<50
treatment					
2.A	$5.7\cdot10^5$	<3	3	10	<100
2.B	$10.4\cdot10^4$	<3	4	<10	<100
2.C	$3.2\cdot10^3$	<3	<3	<10	<100
2.D	<100	<3	<3	<10	<100

[a] See **Table 3** for definitions of the treatments.

the treatment was conducted at atmospheric pressure (reference) the loss of ASTA color reached 5.41%.

According to the surface color measurements, the parameter L* decreased as the pressure rose, which resulted in a darker paprika. At the same time, a* (redness) and b* (yellowness) diminished as the overpressure increased, meaning a loss of chromaticity (C*) because this parameter directly depends on a* and b*. Color differences (ΔE*) with respect to the reference sample were low, and only when the overpressure was 2.1 kg/cm^2 did ΔE* reach about 5.5 and become visually appreciable.

To summarize, high-temperature treatment with nitrogen had little effect on the color characteristics of the paprika and also had little effect on the reduction in the total microbial count.

To reduce the total microbial count, other treatments were designed. For example, the temperature was increased to 160 °C, and nitrogen and steam were tested as sterilizing agents. **Table 3** summarizes these experiments.

The results of the treatments described in **Table 3** are shown in **Table 4**. The main differences were observed in the total count. With treatment 1.B a destruction of 88% was achieved. Treatment 1.D (steam at 1 kg/cm^2 of overpressure) reduced the microbial bioburden by almost 99%, the remaining total count being below 10^5 CFU/g. When the overpressure was 2 kg/cm^2 the effectiveness of the treatment increased with the level of the steam in the gaseous mixture. With steam percentages of 25, 50, and 75%, lethalities of 91.9, 98.5, and 99.95%,

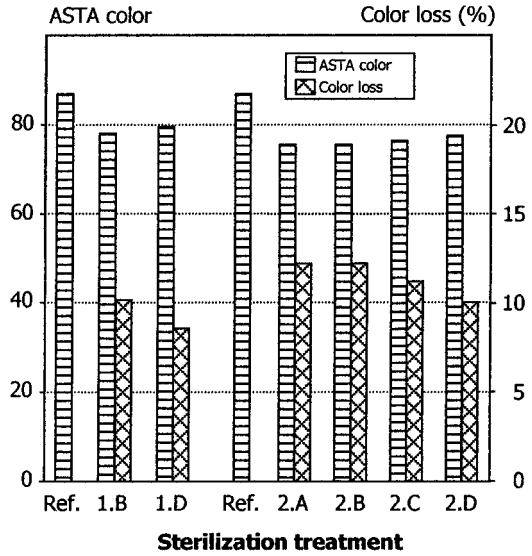

Figure 2. Loss of extractable color (ASTA) after the sterilization treatments at 160 °C with nitrogen and steam.

respectively, were obtained. In treatment 2.D (steam at 2 kg/cm^2), almost total sterilization was achieved, as no type of microbiological count could be detected afterward.

Figure 2 shows the influence of the thermal treatments summarized in **Table 3** on the ASTA color of the samples. The alteration of the extractable color was somewhat higher in this series of experiments, a circumstance that we attributed to the slightly higher temperature used in order to avoid condensation of the water steam at the cold points of the installation. Nevertheless, the losses of color (close to 10%) were within acceptable values.

Table 5 shows data corresponding to surface color in the paprika samples treated at 160 °C with nitrogen and steam. The chromatic parameters L*, a*, and b* fell below those of the reference sample; the paprika obtained being darker as a consequence of the slight increase in its moisture content, while the red and yellow hues also diminished slightly. Even under the most drastic conditions, the color was not excessively affected, as can be appreciated from the values of ΔE*, which never exceeded 7%. The paprika took on a granular appearance, probably due to the agglomeration of the smallest paprika particles as a result of the increased moisture in the sterilization circuit. However, during the cooling stage this excess humidity was lost, although particle agglomeration remained a problem.

As the best results were obtained with a thermal fluid consisting entirely of steam, new experiments with slightly reduced temperatures were performed in an attempt to limit color losses. The new conditions tested were as follows: 100% steam, 1.5 kg/cm^2 pressure, 6 s operation time, and temperatures of 145 and 135 °C. With both temperatures, microorganism survival was lower than 10^4 CFU/g; the losses of extractable

Table 5. Surface Color of the Paprika Samples after the Sterilization Treatments at 160 °C with Nitrogen and Steam

	surface color[a]					
	L*	a*	b*	ΔE*	C*	h
reference	37.63 ± 0.18	34.73 ± 0.16	42.41 ± 0.95	-	54.81	50.69
treatment[b]						
1.B	36.00 ± 0.26	30.26 ± 0.23	37.13 ± 0.78	7.11	47.90	50.82
1.D	36.02 ± 0.27	31.71 ± 0.15	38.09 ± 0.79	5.51	49.56	50.22
treatment						
2.A	36.37 ± 0.10	31.64 ± 0.19	40.35 ± 0.61	3.92	51.28	51.90
2.B	35.00 ± 0.25	30.29 ± 0.21	38.51 ± 0.57	6.47	48.99	51.81
2.C	34.98 ± 0.21	30.77 ± 0.21	38.24 ± 0.44	6.33	49.08	51.18
2.D	34.74 ± 0.13	31.02 ± 0.15	37.65 ± 0.09	6.69	48.78	50.51

[a] Means ± SD (fifteen repetitions). [b] See **Table 3** for definitions of the treatments.

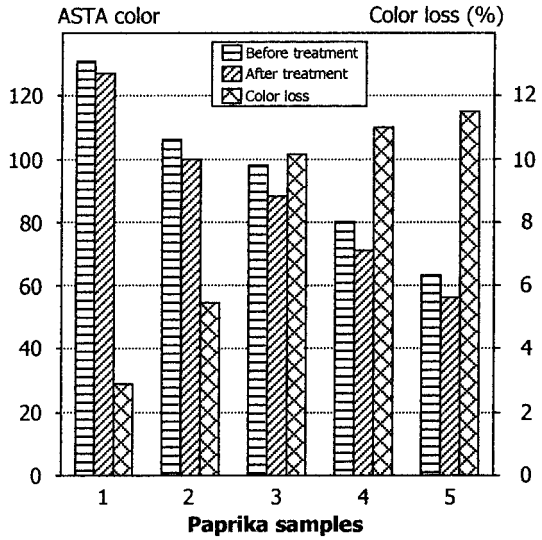

Figure 3. Degradation of the extractable color in five paprika samples after the HTST treatment at 145 °C and 1.5 kg/cm^2.

color were 7%, and the color differences expressed in the CIELAB space (ΔE*) were around 4. However, treatment at 135 °C produced a paprika with a high moisture content due to steam condensation at the cold points in the line, since 135 °C is very near to the saturation temperature of steam (127 °C at 1.5 kg/cm^2). The final cooling stage did not eliminate this excess humidity.

The results of the experiments described show that the optimum HTST conditions to ensure the hygienic quality of paprika were a thermal fluid of saturated water, a temperature of 145 °C, 1.5 kg/cm^2 of pressure, and a 6 s operation time. When these conditions were applied to five paprika samples to verify their effectiveness the samples showed a total count lower than $2 \cdot 10^4$ CFU/g. *Enterobacteriaceae*, coliforms, and sulfite-reducing *clostridia* were absent, and the molds and yeast were present at less than 10^2 CFU/g. **Figure 3** shows the extractable color of these samples and its degradation after treatment.

Color losses ranged between 5 and 12%, being slightly higher in the samples of low ASTA graduation. This can be explained by the way in which paprika is obtained in the manufacturing process by mixing the dry fruit pericarp with the ground seed, the samples of low ASTA color were those having a higher proportion of seed. As seeds are rich in unsaturated lipids, these samples undergo more intensive autoxidation reactions during HTST treatment.

Table 6 shows the changes observed in the surface color of the paprika samples analyzed. It can be seen that after treatment at 145 °C and 1.5 kg/cm^2, L*, a*, and b* varied slightly, with b* (yellowness) being the most affected. The color difference (ΔE*) ranged between 4 and 7. It has been established that two paprika samples with ΔE* ≥ 3 can be visually differentiated, and therefore all the sterilized samples could be distinguished from the reference sample because of their duller and more granular aspect. Nevertheless, their overall quality was judged satisfactory. The increased moisture content of the sterilized paprika was between 0.46 and 1.24%, being in all cases lower than 6.5%, and so their microbial stability was guaranteed.

Finally, we studied microbiological stability during the storage of two paprika samples decontaminated by the optimized HTST process. The samples (25 kg) were maintained 3 months in polyethylene bags in two different storage conditions: ambient (25 °C and 38−50% relative humidity) and refrigerated (4 °C and 60% relative humidity). It has been shown that temperatures under 4 °C result in alterations when the paprika is removed from the chamber. The physicochemical characterization of the samples investigated is shown in **Table 7**.

Table 8 shows the microbiological counts made in the HTST-treated and untreated samples stored in ambient and cold conditions. Of note is the fact that the counts of *Enterobacteriaceae*, coliforms, sulfite-reducing *clostridia*, molds, and yeast in the untreated samples diminished after storage, especially in the case of ambient storage, although the total count hardly changed during these 3 months. In the samples maintained in refrigerated conditions the counts of *Enterobacteriaceae*, coliforms, sulfite-reducing *clostridia*, molds, and yeast, were hardly reduced, and there was even a slight increase in the total count.

The effectiveness of the HTST treatment described is confirmed by the low microbial counts of the treated samples. Moreover, there was no detected growth of *Enterobacteriaceae*, coliforms, sulfite-reducing *clostridia*, molds, or yeast during storage. This demonstrates that microbial destruction was almost complete in both samples and that they remained uncontaminated throughout the storage period despite the slight increase in moisture (1%). The total count was higher in only one of the samples, but this increase was not significant.

In evaluating the applicability of a thermal treatment for sanitizing paprika samples, not only the microbial and physicochemical stability of the samples must be assessed, but also the effect on color, which is its main quality attribute. **Table 9** shows the extractable and surface color characteristics of the paprika samples at the end of three months of storage.

The extractable color of untreated samples stored under refrigerated conditions did not alter to any great extent, with losses of 1.87 and 0.6% being recorded in both samples. In sample 1 this degradation was slightly higher because of lower ASTA grading and greater lipid content; the lipids were

Table 6. Influence of the HTST Treatment at 145 °C and 1.5 kg/cm^2 with Water Steam on the Surface Color of Several Paprika Samples

	initial surface color			surface color after HTST treatment			
sample	L*	a*	b*	L*	a*	b*	ΔE*
1	33.57 ± 0.33	35.24 ± 0.24	35.77 ± 0.60	31.29 ± 0.19	33.50 ± 0.20	30.87 ± 0.62	5.68
2	34.78 ± 0.11	33.95 ± 0.17	33.91 ± 0.19	32.04 ± 0.27	32.10 ± 0.23	29.53 ± 0.60	5.39
3	37.67 ± 0.18	37.53 ± 0.18	49.54 ± 1.38	35.28 ± 0.15	36.68 ± 0.29	42.58 ± 0.79	7.41
4	37.76 ± 0.29	32.86 ± 0.14	39.62 ± 0.59	33.57 ± 0.33	35.24 ± 0.24	35.77 ± 0.60	6.17
5	38.73 ± 0.18	33.20 ± 0.26	48.78 ± 1.27	39.30 ± 0.13	31.99 ± 0.18	44.57 ± 0.86	4.41

Means ± SD of fifteen repetitions.

Table 7. Physicochemical Characteristis of the Paprika Samples Used in the Storage Experiments

	moisture (%)	total ashes (%)	sand (%)	total lipids (%)	color (ASTA units)
sample 1	4.89	4.97	0.80	14.94	87.00
sample 2	5.84	6.20	1.08	13.72	136.30

Table 8. Evolution of the Microbial Bioburden in HTST Treated Paprika after Three Months of Storage in Cold or Room Conditions

		sample 1			sample 2		
		initial	cold conditions	room conditions	initial	cold conditions	room conditions
total count	untreated	$41 \cdot 10^5$	$43 \cdot 10^5$	$40 \cdot 10^5$	$75 \cdot 10^5$	$80 \cdot 10^5$	$77 \cdot 10^5$
	HTST treated	$8 \cdot 10^2$	$7 \cdot 10^2$	$14 \cdot 10^2$	$36 \cdot 10^2$	$18 \cdot 10^2$	$11 \cdot 10^2$
Enterobacteriaceae	untreated	$48 \cdot 10^3$	$24 \cdot 10^3$	$15 \cdot 10^2$	$24 \cdot 10^3$	$43 \cdot 10^2$	$14 \cdot 10^2$
	HTST treated	<3	<3	<3	<3	<3	<3
coliforms	untreated	$75 \cdot 10^2$	$23 \cdot 10^2$	$9 \cdot 10^2$	$93 \cdot 10^2$	$15 \cdot 10^2$	$9 \cdot 10^2$
	HTST treated	<3	<3	<3	<3	<3	<3
sulfite-reducing *clostridia*	untreated	200	50	<100	250	50	<100
	HTST treated	<10	<10	<10	<10	<10	<10
molds and yeast	untreated	$29 \cdot 10^3$	$10 \cdot 10^3$	$75 \cdot 10^2$	$21 \cdot 10^3$	$19 \cdot 10^3$	$25 \cdot 10^2$
	HTSt treated	<100	<100	<100	<100	<100	<100

Table 9. Evolution of the Extractable and Surface Color after Three Months of Storage in Cold or Room Conditions

			extractrable color		superficial color					
sample			ASTA	destruction (%)	L*	a*	b*	ΔE*	C*	h
1	untreated	initial	83.26	- - -	37.60 ± 0.06	34.37 ± 0.05	45.32 ± 0.79	- - -	57.10	52.53
		3 months cold conditions	81.70	1.87	38.27 ± 0.26	34.86 ± 0.10	43.31 ± 0.38	2.12	55.59	51.17
		3 months room conditions	73.83	11.33	38.39 ± 0.05	34.27 ± 0.13	43.66 ± 0.63	1.89	55.50	51.87
	HTST treated	initial	75.38	9.46	36.19 ± 0.44	32.10 ± 0.37	34.32 ± 1.02	11.40	47.00	46.91
		3 months cold conditions	73.85	11.30	34.51 ± 0.23	31.27 ± 0.29	35.55 ± 0.68	10.71	48.76	48.56
		3 months room conditions	66.23	20.45	34.26 ± 0.18	30.64 ± 0.12	34.74 ± 0.58	11.82	46.32	48.59
2	untreated	initial	132.59	- - -	33.60 ± 0.22	35.33 ± 0.12	38.98 ± 0.54	- - -	52.60	47.81
		3 months cold conditions	131.80	0.60	34.16 ± 0.15	35.31 ± 0.11	38.19 ± 0.16	0.92	52.01	47.24
		3 months room conditions	112.51	15.14	34.68 ± 0.13	34.55 ± 0.25	37.61 ± 0.53	1.89	51.07	47.43
	HTST treated	initial	125.34	5.47	30.73 ± 0.18	30.90 ± 0.24	28.00 ± 0.91	12.19	41.70	42.18
		3 months cold conditions	121.40	8.40	29.49 ± 0.10	31.10 ± 0.15	28.97 ± 0.27	11.57	42.50	42.97
		3 months room conditions	93.56	29.44	29.43 ± 0.29	29.98 ± 0.25	29.73 ± 0.62	11.42	42.22	44.76

responsible for the peroxidation of carotenoids, as already mentioned. When the untreated paprika samples were storaged in room conditions the color degradation was higher: between 11 and 15%.

Thermal HTST treatment led to an initial degradation of extractable color of 9.46 and 5.47% for samples 1 and 2, respectively, with data of the same order as those obtained in previous experiments. These values increased slightly after storage in refrigerated conditions (11.3 and 8.40%), but at room temperature the losses were higher (20.45 and 29.44%), which shows the absolute necessity of keeping thermally decontaminated paprika samples under refrigeration.

Surface color did not change noticeably in the untreated samples, and the storage conditions had no influence. Only b* (yellowness) decreased but very slightly. The derived parameters (C*, *h*, and ΔE*) were not significantly modified.

As regards the decontaminated samples, it can be observed that HTST treatment caused some alterations in surface color. The paprika became darker (lower L*) and also the reddish and yellowish hues were less intense (lower a* and b*). The parameter b* was the most affected, decreasing from 39 to 28, perhaps because yellow carotenoids are more labile than the red carotenoids. Color degradation during HTST treatment and subsequent storage, as judged from the color difference (ΔE*), was around 11−12, meaning that the reference samples could be visually distinguished from the treated samples. Although degradation of the extractable color was substantial both in the samples stored in room conditions and under refrigeration, the visual difference was very slight.

We conclude that HTST treatment of paprika is an effective hygienization process and can be considered as an alternative to the use of ethylene oxide, which is being phased out. Nevertheless, HTST promotes lipid peroxidation and color degradation, and so the resulting paprika must be stored in refrigerated conditions. If we compare the effect of the HTST processing of paprika with that obtained by means of irradiation (*2*), it can be observed that the effectiveness of both hygienization systems as regards microbial survival is very similar, despite the fact that color degradation is slightly higher in the HTST process, although well within commercially acceptable limits.

Economically the HTST process is an interesting alternative to ionization. Capital investment is much reduced compared with that necessary for ionization plants, which use radioactive isotopes or accelerated electrons. Moreover, the cost and simplicity of the industrial equipment means that individual companies can have their own sanitizing installations and thus save on transport and logistical costs.

Regarding the costs derived exclusively from HTST treatment, we have estimated that they are in the order of 0.10−0.12 $/kg, for a batch of about 1000 kg/h of hygienized paprika. This cost is highly competitive given the microbiological and chemical−physical quality of the resulting paprika. It is very important to consider that HTST processing of foods is universally accepted and that there is no problem with consumer resistance which frequently arises with irradiated foods.

LITERATURE CITED

(1) Monk, J. D.; Beuchat, L. R.; Doyle, M. P. Irradiation inactivation of food-borne microorganisms. *J. Food Prot*. **1995**, *58*, 197−208.

(2) Nieto-Sandoval, J. M.; Almela, L.; Fernández-López, J. A.; Muñoz, J. A. Effect of electron beam irradiation on color and microbial bioburden of red paprika. *J. Food Prot.* **2000**, *63*, 633−637.

(3) Van Calenberg, S.; Van Cleemput, O.; Huyghebaert, A.; Vanhaelewyn, G., Callens, F.; Mondelaers, W. Comparison of the effect of X-ray and electron beam irradiation on some selected spices. *Lebensm.-Wiss. Technol.* **1998**, *31*, 252−258.

(4) Vajdi, M.; Pereira, R. R. Comparative effects of ethylene oxide, gamma irradiation and microwave treatments on selected spices. *J. Food Sci.* **1973**, *38*, 893−895.

(5) Farkas, J.; Andrassy, E. Comparative analysis of spices decontaminated by ethylene oxide or gamma radiation. *Acta Aliment.* **1988**, *17*, 77−94.

(6) Kiss, I.; Farkas, J.. Irradiation as a method for decontaminating spices. *Food Rev. Int.* **1988**, *4*, 77−92.

(7) Bolander, C. R.; Toma, R. B.; Davis, R. M.; Medora, N. P. Irradiated versus fumigated spices in sausage. *Int. J. Food Sci. Nutr.* **1995**, *46*, 319−325.

(8) Heddleson, R. A.; Doores, S. Factors affecting microwave heating of foods and microwave induced destruction of foodborne phatogens. A review. *J. Food. Prot*. **1994**, *57*, 1025−1037.

(9) Heddleson, R. A.; Doores, S.; Anantheswaran, R. C.; Kuhn, G. D. Viability loss of *Salmonella* species, *Staphylococcus aureus*, and *Listeria monocytogenes* in complex foods heated by microwave energy. *J. Food Prot.* **1996**, *59*, 813−818.

(10) Llorente Franco, S.; Giménez, J. L.; Martínez Sánchez, F.; Romojaro, F. Effectiveness of ethylene oxide and gamma irradiation on the microbiological population of three types of paprika. *J. Food Sci.* **1986**, *51*, 1571−1574.

(11) Farkas, J. Microbiological safety of irradiated foods. *Int. J. Food Microbiol*. **1989**, *9*, 1−15.

(12) Shigemura, R.; Gerdes, D. L.; Hall, W. R. Effect of gamma procesing on prepackaged black and white pepper (*Piper nigrum* L.). *Food Sci. Tecnol.* **1991**, *24*, 135−138.

(13) Narvaiz, P.; Lescano, G.; Kairiyama, E. Physicochemical and sensory analyses of egg powder irradiates to inactivate *Salmonella* and reduce microbial load. *J. Food Saf.* **1992**, *12*, 263−282.

(14) Hau, L. B.; Liew, M. H.; Yeh, L. T. Preserving of grass prawns by ionizing radiation. *J. Food Prot.* **1992**, *55*, 198−202.

(15) Patterson, M. F.; Damoglou, A. P.; Buick, R. K. Effects of irradiation doses and storage temperature on the growth of *Listeria monocytogenes* on poultry meat. *Food Microbiol.* **1993**, *10*, 197−203.

(16) Lefebvre, N. C.; Thibault, R.; Charbonneau, R.; Piette, J. P. G. Improvement of shelf life and wholesomeness of ground beef by irradiation, 2. Chemical analysis and sensory evaluation. *Meat Sci.* **1994**, *36*, 371−380.

(17) Radomyski, T.; Murano, E. A.; Olson, D. G.; Murano, P. S. Elimination of pathogens of significance in food by low-dose irradiation: a review. *J. Food Prot.* **1994**, *57*, 73−86.

(18) ASTA (American Spice Trade Association). *Official Analytical Methods*, 4th ed.; American Spice Trade Association Inc.: Englewood Cliffs, NJ, 1997.

(19) Nieto-Sandoval, J. M.; Fernández-López, J. A.; Almela, L.; Muñoz, J. A. Dependence between apparent color and extractable color in paprika. *Color Res. Appl.* **1999**, *24*, 93−97.

(20) American Public Health Association. *Compendium of Methods for the Microbiological Examination of Foods*, 3rd ed; American Public Health Association: Washington, DC, 1992.

(21) Mossel, D. A. A.; Klynen-Semmeling, A. M. C.; Vincente, H. M. Oxytetracycline−glucose−yeast extract agar for selective enumeration of moulds and yeast in foods and clinical material. *J. Appl. Bacteriol.* **1970**, *33*, 454−457.

(22) World Health Organization. *Guidelines for Drinking-Water Quality*, Vol. 1, 2nd ed.; World Health Organization: Geneva, Switzerland, 1993.

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