The Effect of Rosemary, Sodium Erythorbate and Their Mixture and Packaging Method on the Quality of Turkey Meatballs

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The effect of ground rosemary (R), sodium erythorbate (SE), a mixture of ground rosemary and sodium erythorbate (MIX) and packaging method (vacuum packaging and modified atmosphere packaging) on the quality of cooked turkey meatballs stored at 4°C was investigated. The physicochemical and microbiological quality, and flavour attributes of turkey meatballs were determined. The investigated additives had varied effects on the colour stability of turkey meatballs. Rosemary was less effective as an antioxidant in turkey meatballs than sodium erythorbate, but when applied together with sodium erythorbate it inhibited lipid oxidation to a greater degree, particularly during modified atmosphere storage. Turkey meatballs with additives were characterized by a better microbial and sensory quality than control samples. Modified atmosphere packaging was more effective than vacuum packaging in maintaining the microbial and sensory quality stability of cooked turkey meatballs. However, vacuum packaging was more effective in preventing lipid oxidation in turkey meatballs.

Keywords: ground rosemary, sodium erythorbate, method of packaging, turkey meatballs, physicochemical quality, sensory properties, microbiological quality

Introduction

Poultry meat is getting an increasing market share in many countries and more consumers are considering product quality when choosing what to buy. Lipid oxidation is one of the most important parameters that influence the quality and acceptance of meat and poultry. Poultry meat is particularly sensitive to oxidative deterioration because it contains mostly unsaturated fats. Rancidity and warmed-over-flavours are important reasons for consumer rejection of meat products, and the food industry has an interest in developing new technologies that allow the processing of meat and poultry products with less oxidative deterioration (Bragagnolo *et al.*, 2005). Lipid oxidation may be reduced by the application of antioxidants and by restricting oxygen access during storage through vacuum or modified atmosphere packaging (Mielnik *et al.*, 2006).

In Poland synthetic antioxidants such as sodium erythorbate (sodium isoascorbate) are usually used to decelerate the oxidation process in poultry products. Sodium erythorbate

has been shown to extend the shelf-life of meat products. It increases colour stability in turkey patties (Barringer *et al.*, 2005). The addition of sodium erythorbate decreases microbial counts in kosher beef and in turkey patties (Zuckerman and Mannheim, 2001; Barringer *et al.*, 2005). Wilkinson *et al.* (2001) investigated the antioxidant activity of sodium erythorbate in fresh and freeze-dried chicken.

Natural antioxidants can be used to extend the shelf-life of cooked poultry (Beltran *et al.*, 2004; Racanicci *et al.*, 2004). Among natural antioxidants, rosemary is often the first choice for processed foods (Nissen *et al.*, 2000). *Rosmarinus officinalis* L. belongs to the Lamiaceae family of herbs, which in addition to being used as food flavouring is also known medicinally for its powerful antibacterial and antimutagenic properties, and as a chemopreventive agent (Wang *et al.*, 2008). The active antioxidative compounds of rosemary include carnosol, carnosic acid and its esters, and lesser amounts of rosmannol, rosmaridinphenol and rosmarinic acid. When added at levels below the flavour threshold, foods are unlikely to benefit from the antioxidative properties of this herb (Díaz-Maroto *et al.*, 2007). The findings of Zhang *et al.* (2009) demonstrated the strong potential of mixed rosemary

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as a natural preservative in fresh pork and ham products.

Vacuum packaging (VP) has been used in the meat industry for quite a long time, and it has become accepted by consumers. The VP process involves putting the product in a bag, and the air is then evacuated without the addition of any other gas. However, VP is reported to cause liquid exudation and product deformation in soft meat products. To overcome this problem, an alternative packaging method known as modified atmosphere packaging (MAP), has been developed. In this method, the product is placed into the pack and the air is replaced with a mixture of gases. The gases used most frequently are oxygen, nitrogen and carbon dioxide (McMillin, 2008). The elimination of O₂ from the package and the introduction of different concentrations of CO₂ and N₂, together with adequate refrigeration, inhibit the growth of aerobic micro-organisms, proteolytic bacteria, yeasts and fungi (Murcia *et al.*, 2003). Both packaging methods have been investigated as technologies which enable to increase the shelf-life of poultry meat and products by inhibiting the growth of both spoilage and pathogenic micro-organisms (Ntchimani *et al.*, 2008).

The purpose of this work was to determine the effectiveness of ground rosemary, sodium erythorbate, their mixture and packaging method (vacuum and modified atmosphere with a gas mixture of 80% N₂ and 20% CO₂) in delaying lipid oxidation, preserving the colour and improving the shelf-life of cooked turkey meatballs.

Materials and Methods

Materials Thigh muscles of male British United Turkeys BIG-6 (Frednowy, Poland) were purchased from the Indykpol Company (Olsztyn, Poland), rosemary powder was purchased from the "Kawon-Hurt" Herbal Plant (Gostyń, Poland), sodium erythorbate - from the Parchn Group Company (Xingangshan Town, Dexingxing City, Jiangxi Provincer, China).

Sample preparation After cutting and chilling, 1 kg portions of turkey meat were packed in polyethylene bags and deep-frozen at -25°C at the "Indykpol" Poultry Processing Plant in Olsztyn. After three days, half of the material was placed in the refrigerator at 3°C, where it was defrosted over 20 h and assigned to the first experiment (vacuum packaging). After 14 days of storage, the other half of turkey meat was placed in a refrigerator at 3°C, where it was defrosted over 20 h and assigned to the second experiment (modified atmosphere packaging). Defrosted meat was cut into 4–6 cm pieces and ground in a meat grinder, type MMU-10Z (Nakło, Poland) with a 4 mm mesh. Ground turkey meat was divided into four groups. Following the addition of wheat flour roll soaked in water (13%), beaten eggs (5%), flour (2%) and salt

(1% in relation to total mass weight) to meat (80%), the mass was mixed in a multifunctional food processor (Bauknecht, Warsaw, Poland). Experimental treatments were as follows: no additives (control-C), sodium erythorbate (SE) – 0.3 g/kg of total mass weight, rosemary (R) – 0.3 g/kg and a mixture of SE and R (MIX) – 0.15 g/kg and 0.15 g/kg respectively. Rosemary was ground using a grinder (Type WZ-1, Żnin, Poland) and it was mixed with part of the meat mass before mixing with the total mass. Sodium erythorbate was dissolved in water (20°C) in the amount of 15 g/100 mL and it was slowly added to the meat mass while mixing. While preparing a mixture of SE and R, the ingredients were added individually. Next the mass was formed into 90 g ± 1 g meatballs (8-cm in diameter).

Cooking Eighty-four meatballs were randomly selected from each treatment and placed on the oven tray (twelve meatballs at a time) and cooked in a BECK FCV 4 EDS steam-convection oven (BECK GmbH, Jagsthausen, Germany), with a measuring probe. Steam and hot air were used for heat treatment (air temperature – 180°C, steam saturation – 30%). The treatment was continued until a temperature of 82°C was reached inside the product. The cooked patties were stored overnight at 0°C prior to analysis.

Storage study Cooked turkey meatballs were vacuum packaged (VP) and modified atmosphere (a gas mixture of 80% N₂ and 20% CO₂) packaged (MAP) into bags of a five-layer PE-LD/adh/PA/ADH/PE-PD film (total thickness – 0.08 mm, PA layer thickness – 0.024 mm, oxygen permeability – 40 cm³/m²24 h⁻¹bar⁻¹, water vapour permeability – 10 g m⁻²24 h⁻¹bar⁻¹) using a TEPRO PP5 packaging unit (Koszalin, Poland). The samples were stored at 4°C for 5, 10, 15, 25 and 30 days.

Lipid oxidation analysis Lipid oxidation was assessed in 10 g of turkey meatballs by the 2-thiobarbituric acid (TBA) method of Tarladgis *et al.* (1960) modified by Pikul *et al.* (1989), after 0, 5, 10, 15, 20, 25 and 30 days of storage at 4°C. TBARS values were calculated from the standard curve of malondialdehyde and expressed as mg malondialdehyde kg⁻¹ product.

The antioxidant potential, expressed in terms of the percentage of antioxidant activity, was calculated by the equation (Jayatilakan *et al.*, 2007):

$$\% \text{AOA} = [\text{TBARS value of the control} - \text{TBARS of the sample}] \times 100 / [\text{TBARS value of the control}]$$

Acid value (AV) The acid value (AV) indicates how much free fatty acid has accumulated as a result of lipolysis. It was determined in fat extracted from the products after 0, 5, 10, 15, 20, 25 and 30 days of storage at 4°C, in accordance with the Polish Standard (PN-EN ISO 660, 2005).

Colour evaluation The colour of the samples was determined with a spectrophotometer (Dr Lange Spectro-color), d/8° with a 10 mm measuring aperture and SPECTRAL-QC computer software after calibration using Dr Langeblack and white standards. The results are given in the colour-coordination system CIE Lab [where L^* measures relative lightness ($L^* = 0$ darkness, $L^* = 100$ lightness), a^* relative redness (+60 = red, -60 = green), and b^* relative yellowness (+60 = yellow, -60 = blue)]. Colour was measured on the meat surface 30 min after the package had been opened after 0, 10, 20 and 30 days of storage.

Microbiological analysis A 10 g ground sample of each product was taken aseptically and placed in a sterile stomacher bag containing 90 mL of Ringer liquid. The sample in the bag was blended in a laboratory blender (Stomacher 400, Seward Laboratory, London, UK) for 2 min and submitted to serial dilutions with the same diluents. For the determination of mesophilic bacteria and psychrotrophic bacteria, appropriate serial dilutions were placed on plate count nutrient agar, and were incubated at 30°C for 72 h (mesophilic bacteria) and at 6.5°C for 7 days (psychrotrophic bacteria) prior to enumeration. Coliforms were enumerated by plating on violet red bile lactose agar (Merck, Warsaw, Poland) and then they were incubated at 30°C for 48 h. The counts of fungi were determined on YGC –Agar (Merck) after 96 h incubation at 25°C. To determine the presence of sulphate IV reducing *Clostridium* sp., adequate dilutions were inoculated into a liquid meat-liver agar medium and heated at 80°C for 15 min, and were incubated at 37°C for 48 h. All microbial counts were reported as a logarithmic value of colony forming units per gram of sample. Microbial populations in the samples were determined in triplicate before thermal processing, after thermal processing and after 15 and 30 days of storage at 4°C. Samples taken from three randomly selected meatballs per treatment were homogenized.

Sensory quality Meatballs were subjected to a sensory evaluation by the flavour profile method (Meilgaard *et al.*, 1999). The sensory panel consisted of five panellists trained in accordance with the Polish Standard (PN-ISO 11035, 1999). All judges were trained to be familiar with the flavour attributes to be measured (meaty, typical of poultry meat, aromatic, typical of roasted meat, spicy-rosemary, sour, WOF). The sensory assessment was performed after 0, 5, 10, 15, 20, 25 and 30 days of storage at 4°C. Two sensory evaluation sessions were conducted per day. The 2nd session comprised the replicates of the 1st session. The sessions were conducted at one-hour intervals. For flavour evaluation, 2 meatballs per treatment were cut into approximately uniform pieces. Directly before a sensory evaluation, samples were warmed to 65°C in a microwave oven (Daewoo, DMR-901, France).

Samples were served in random order to each panellist on a white porcelain dish, coded with random numbers. At the beginning of each session, the panel was presented with the reference samples for the extremes of scales of the flavour attributes to be measured. The intensity of particular attributes was determined on a 5-point scale: 0-lack of perception; 1-hardly noticeable perception; 2 – slightly noticeable perception; 3 – moderately noticeable perception; 4 – strongly noticeable perception; 5 – very strongly noticeable perception.

Statistical analysis Both experiments were performed in a completely randomized 4 × 7 factorial design. The experimental factors included four additives and seven storage times. Data obtained for the initial characterization of the tested additives and storage time were subjected to a two-way analysis of variance (ANOVA). Since significant interactions were found, independent one-way ANOVA tests were carried out on each variable (additives and storage time). When the ANOVA showed the differences to be significant, the obtained values were evaluated by Tukey's test. Additive treatments were compared each day. The level of significance was determined at $P < 0.05$. The correlations between sensory attributes and MDA were performed using Spearman's non-parametric rank correlation test. The results were processed statistically using STATISTICA version 8 software (StatSoft, 2008).

Results and Discussion

Lipid stability of heated turkey meatballs during storage

The analysis of variance for TBA data indicated that MDA content was significantly affected ($P < 0.001$) by both the additive and storage time. The effect of additives and storage time on the MDA content in turkey meatballs is presented in Table 1. The initial (0 days) MDA content of samples containing the tested additives was significantly lower ($P < 0.05$), compared with control samples. This suggests that the additives retarded lipid oxidation during and immediately after cooking. These results agree with my previous findings (Karpńska-Tymoszczyk, 2008) and those reported by Bragnolo *et al.* (2005) for ground rosemary added to turkey meatballs and minced chicken breast, and with the findings of Fernández-López *et al.* (2005) and Thongtan *et al.* (2005) who added rosemary extract to cooked beef.

In the present study MDA content showed an ambiguous tendency during storage, especially in vacuum-packaged samples. At the end of storage (30 days), a significantly ($P < 0.05$) lower MDA content was noted in all experimental treatments, compared with the control treatment, which indicates that all tested additives exhibited antioxidant properties. Similar results have been obtained by Sánchez-Escalante *et al.* (2001) who found that rosemary powder, either alone or

Table 1. Effect of additives, storage time and packaging method on the malondialdehyde (MDA) content of cooked turkey meatballs and the antioxidant activity of the tested additives (mean $\pm$ SD, n = 6).

Packaging method	Samples	Storage time [days]						
		0	5	10	15	20	25	30
Malondialdehyde [mg/kg]								
Vacuum packaging	C	0.40 ± 0.03 ^{Ca}	0.74 ± 0.08 ^{Ce}	0.42 ± 0.03 ^{Ca}	0.57 ± 0.02 ^{Cb}	0.61 ± 0.04 ^{Cbc}	0.45 ± 0.04 ^{Ba}	0.70 ± 0.01 ^{Dcd}
	SE	0.17 ± 0.02 ^{Aa}	0.32 ± 0.02 ^{Ad}	0.16 ± 0.02 ^{Aa}	0.29 ± 0.01 ^{Acd}	0.25 ± 0.02 ^{Abc}	0.23 ± 0.01 ^{Ab}	0.31 ± 0.01 ^{Ad}
	R	0.30 ± 0.03 ^{Ba}	0.73 ± 0.03 ^{Ce}	0.37 ± 0.02 ^{Cb}	0.56 ± 0.02 ^{Cd}	0.46 ± 0.02 ^{Bc}	0.44 ± 0.04 ^{Bc}	0.51 ± 0.01 ^{Ccd}
	MIX	0.30 ± 0.01 ^{Ba}	0.56 ± 0.01 ^{Bd}	0.30 ± 0.01 ^{Ba}	0.45 ± 0.01 ^{Bb}	0.51 ± 0.03 ^{Bcd}	0.45 ± 0.0 ^{Bb}	0.47 ± 0.01 ^{Bbc}
Modified atmosphere packaging (20% CO ₂ / 80% N ₂)	C	0.48 ± 0.03 ^{Ca}	0.66 ± 0.04 ^{Cb}	0.68 ± 0.05 ^{Bb}	0.98 ± 0.04 ^{Dc}	1.09 ± 0.02 ^{Dcd}	1.18 ± 0.08 ^{Cd}	1.32 ± 0.06 ^{Ce}
	SE	0.16 ± 0.04 ^{Aa}	0.20 ± 0.01 ^{Aab}	0.25 ± 0.01 ^{Abc}	0.37 ± 0.01 ^{Ade}	0.39 ± 0.02 ^{Ae}	0.25 ± 0.03 ^{Abc}	0.31 ± 0.03 ^{Acc}
	R	0.41 ± 0.04 ^{Ca}	0.51 ± 0.07 ^{Ba}	0.67 ± 0.06 ^{Bb}	0.81 ± 0.04 ^{Cc}	0.85 ± 0.02 ^{Cc}	0.66 ± 0.06 ^{Bb}	0.76 ± 0.02 ^{Bbc}
	MIX	0.25 ± 0.02 ^{Ba}	0.43 ± 0.01 ^{Bb}	0.62 ± 0.05 ^{Bc}	0.63 ± 0.04 ^{Bc}	0.72 ± 0.02 ^{Bcd}	0.77 ± 0.08 ^{Bd}	0.77 ± 0.01 ^{Bd}
Antioxidant activity [%]								
Vacuum packaging	SE	57.71 ± 6.31 ^B	57.53 ± 3.72 ^C	61.24 ± 6.38 ^C	49.07 ± 0.80 ^C	59.47 ± 4.51 ^B	48.56 ± 6.11 ^B	55.37 ± 1.37 ^B
	R	25.39 ± 8.67 ^{Ab}	2.15 ± 0.04 ^{Aa}	11.15 ± 1.42 ^{Aa}	1.40 ± 0.04 ^{Aa}	24.38 ± 6.17 ^{Ab}	0.70 ± 0.03 ^{Aa}	27.05 ± 2.46 ^{Ab}
	MIX	26.78 ± 3.47 ^{Abc}	24.40 ± 6.86 ^{Bbc}	27.10 ± 6.49 ^{Bbc}	21.32 ± 2.05 ^{Bbc}	16.14 ± 1.24 ^{Aab}	6.28 ± 2.43 ^{Aa}	32.59 ± 2.83 ^{Ac}
Modified atmosphere packaging (20% CO ₂ / 80% N ₂)	SE	66.66 ± 5.31 ^{Cab}	69.00 ± 1.10 ^{Cb}	63.57 ± 2.13 ^{Cab}	61.93 ± 0.66 ^{Ca}	64.03 ± 0.89 ^{Cab}	78.57 ± 1.58 ^{Cc}	76.60 ± 2.16 ^{Bc}
	R	14.81 ± 3.01 ^{Ab}	22.03 ± 5.77 ^{Abc}	1.48 ± 0.11 ^{Aa}	17.08 ± 1.27 ^{Abc}	22.56 ± 0.57 ^{Ac}	44.39 ± 1.92 ^{Bd}	42.78 ± 1.61 ^{Ad}
	MIX	48.24 ± 1.24 ^{Bc}	34.95 ± 2.33 ^{Bb}	8.86 ± 2.43 ^{Ba}	35.86 ± 1.30 ^{Bb}	34.15 ± 1.08 ^{Bb}	35.11 ± 2.71 ^{Ab}	42.51 ± 3.83 ^{Ac}

Samples: C-control, SE-with sodium erythorbate; R- with rosemary, MIX -with a mixture of sodium erythorbate and rosemary.
^{a, b, c, d, e} mean values in rows followed by different letters are significantly different at P < 0.05; ^{A, B, C} mean values in columns followed by different letters are significantly different at P < 0.05.

with ascorbic acid, was highly effective in inhibiting lipid oxidation in MA-packaged beef patties during refrigerated storage. In the screening experiment the samples with sodium erythorbate had the lowest (P < 0.05) MDA content, regardless of the time of VP and MAP storage. Vacuum-packaged products stored for longer than 5 days were characterized by a lower MDA content than samples packaged under modified atmosphere. These results are consistent with those reported by Lin and Lin (2002) who noted lower TBARS values in vacuum-packaged reduced-fat Chinese-style sausages than in sausages packaged under modified atmosphere (20%CO₂ + 80%N₂). Smiddy *et al.* (2002) concluded that MAP cooked chicken breast patties were more oxidised than vacuum-packaged samples during storage at 4°C, probably due to higher levels of oxygen in the former.

The rate of lipid oxidation during storage was inhibited to a higher degree (Table 1) in products containing sodium erythorbate as compared with those containing rosemary and a mixture of rosemary and sodium erythorbate. During storage, mostly a mixture of sodium erythorbate and rosemary were characterized by a higher rate of lipid oxidation than rosemary. This results respondent with those obtained by Baley *et al.* (2005) showed that the addition of sodium erythorbate suppressed the accumulation of secondary derivatives of lipid peroxidation in dry-fermented sausages, and that sodium erythorbate was more effective than rosemary. Yu *et al.* (2002) reported significant protection against lipid oxidation

in cooked turkey containing water-soluble rosemary extracts during refrigerated storage. Racanicci *et al.* (2004) observed that rosemary prevented oxidation in pre-cooked meatballs made from chicken breast during subsequent chill storage. Bragagnolo *et al.* (2005) demonstrated that raw chicken breast with rosemary showed a tendency to a lower TBARS level than samples without rosemary.

Lipolysis produces free fatty acids by hydrolysis of triacylglycerols and phospholipids. Lipid autooxidation preferentially involves free fatty acids. In consequence, lipolysis may affect the sensory properties of meat products (Summo *et al.*, 2010). An analysis of variance showed that the tested additives and storage time significantly affected the acid value (data not shown). As regards hydrolytic degradation of the lipid fraction, a significant increase in the acid value was observed over the study period in all vacuum-packaged samples (3.96–5.49 mg NaOH/g), which corroborates the findings of other authors (Fernandez-Fernandez *et al.*, 2001; Summo *et al.*, 2010) and my previous work (Kapińska-Tymoszczyk, 2008). The above can be attributed to both the lipolytic activity of lactic acid bacteria and the activity of endogenous lipases and phospholipases (Summo *et al.*, 2010), promoted by the high moisture content of samples (67.79–68.44%, data not shown).

In MAP samples with sodium erythorbate changes in the acid value were not significant (3.75–4.39 mg NaOH/g), while an ambiguous tendency was observed in the other

samples (3.62–4.49 mg NaOH/g). The obtained results indicate that the addition of sodium erythorbate slowed down lipolysis during the storage of turkey meatballs, and that the gas mixture (20% CO₂ + 80% N₂) was more effective in preventing these changes than vacuum packaging. These results correspond with the findings of Fernández-Fernández *et al.* (2002) who observed that the acid value in chorizo sausages packed under modified atmosphere (100% CO₂, 100% N₂, and 50%CO₂ + 50%N₂) and vacuum increased gradually with storage time, reaching the highest level in vacuum-packed samples. According to Balev *et al.* (2005), the addition of 1g kg⁻¹ sodium erythorbate slowed down but did not prevent lipolysis in dry-fermented sausages.

The effect of antioxidants on colour parameters of heated turkey meatballs during storage L* and a* values showed differences (P < 0.05) with respect to experimental treat-

ments (additives) and storage time in turkey meatballs packaged by both methods, while b* values were affected by the additives only in VA-packaged samples (Table 2). Control meatballs and samples with sodium erythorbate exhibited a tendency to higher values of lightness, in comparison with samples containing rosemary or a mixture of sodium erythorbate and rosemary, but significant differences was stated only after 10 days of vacuum and after 20 days of MA storage. Lightness values increased with storage time (P < 0.05) only in control samples packaged by both methods. These results suggest that the presence of antioxidant compounds could retard MMb formation in meatballs prior to cooking, as a result browned slowly, and therefore L* values decreased. Fernández-López *et al.* (2003) observed lower L* values in cooked pork meat treated with rosemary than in control samples. According to Mínguez *et al.* (as cited in Fernández-

Table 2. Effect of additives, storage time and packaging method on the colorimetric values of cooked turkey meatballs (mean ± SD, n=18).

Colorimetric values	Samples	Storage time [days]			
		0	10	20	30
Vacuum packaging					
L*	C	60.84 ± 2.44 ^{ab}	61.77 ± 1.44 ^{Bab}	60.63 ± 1.86 ^a	62.28 ± 1.17 ^b
	SE	61.07 ± 2.32	61.45 ± 1.60 ^{AB}	61.16 ± 1.88	61.95 ± 1.89
	R	60.37 ± 2.09	60.09 ± 2.19 ^A	60.49 ± 2.35	61.49 ± 1.63
	MIX	60.12 ± 2.94	60.66 ± 1.87 ^{AB}	60.48 ± 2.35	61.51 ± 1.36
a*	C	5.04 ± 0.36 ^{Cb}	4.75 ± 0.18 ^{Ba}	4.83 ± 0.21 ^{Bab}	4.65 ± 0.37 ^{Ba}
	SE	4.59 ± 0.30 ^{Bb}	4.09 ± 0.48 ^{Aa}	4.13 ± 0.45 ^{Aa}	4.05 ± 0.46 ^{Aa}
	R	4.23 ± 0.41 ^{Ab}	4.12 ± 0.34 ^{Aab}	3.97 ± 0.32 ^{Aab}	3.88 ± 0.26 ^{Aa}
	MIX	4.23 ± 0.30 ^{Ab}	4.19 ± 0.38 ^{Ab}	4.10 ± 0.46 ^{Aab}	3.85 ± 0.27 ^{Aa}
b*	C	18.62 ± 0.96	18.27 ± 0.73	18.29 ± 1.08	18.22 ± 0.80 ^A
	SE	18.85 ± 1.28	18.87 ± 1.34	19.14 ± 1.81	19.20 ± 1.49 ^B
	R	18.85 ± 1.73	19.13 ± 2.10	18.47 ± 1.53	19.08 ± 1.41 ^{AB}
	MIX	19.34 ± 1.93	18.79 ± 1.44	19.05 ± 1.72	19.40 ± 1.68 ^B
Modified atmosphere packaging (20% CO ₂ / 80% N ₂)					
L*	C	60.28 ± 1.94 ^a	62.07 ± 2.84 ^{ab}	62.38 ± 2.72 ^{Bab}	62.45 ± 1.98 ^b
	SE	60.56 ± 2.66	61.25 ± 2.28	61.90 ± 2.33 ^B	62.06 ± 1.61
	R	59.92 ± 2.65	60.55 ± 2.13	61.84 ± 1.40 ^{AB}	61.95 ± 1.84
	MIX	59.95 ± 3.57	60.42 ± 2.59	59.77 ± 2.86 ^A	61.08 ± 2.24
a*	C	5.06 ± 0.34 ^{Bc}	4.93 ± 0.63 ^{Bbc}	4.53 ± 0.74 ^{Bab}	4.35 ± 0.50 ^{ABa}
	SE	4.87 ± 0.54 ^{ABb}	4.69 ± 0.36 ^{Bb}	4.86 ± 0.16 ^{Bb}	4.35 ± 0.31 ^{ABa}
	R	4.52 ± 0.45 ^{Ab}	4.24 ± 0.40 ^{Aab}	4.04 ± 0.27 ^{Aa}	4.14 ± 0.30 ^{Aa}
	MIX	4.68 ± 0.51 ^{ABab}	4.28 ± 0.18 ^{Aa}	4.87 ± 0.61 ^{Bb}	4.53 ± 0.53 ^{Bab}
b*	C	19.33 ± 1.19	19.13 ± 1.41	19.85 ± 1.91	20.00 ± 1.67
	SE	18.84 ± 1.05	19.20 ± 1.49	20.27 ± 1.81	19.96 ± 2.18
	R	19.33 ± 1.70	19.14 ± 1.70	18.80 ± 1.08	19.37 ± 2.00
	MIX	19.61 ± 2.36	19.32 ± 1.80	20.02 ± 2.35	20.14 ± 2.35

Samples: C, control, SE, with sodium erythorbate; R, with rosemary, MIX, with a mixture of sodium erythorbate and rosemary. a, b, c - mean values in rows followed by different letters are significantly different at P < 0.05; A, B, C - mean values in columns followed by different letters are significantly different at P < 0.05.

López *et al.*, 2003), L^* values in meat could be influenced by lipid oxidation. The L^* values noted in the above study could be due to the inhibitory effect of rosemary on lipid oxidation. Yu *et al.* (2002) found that rosemary extracts significantly decreased the Hunter L -values (lightness) of cooked turkey meat during 12 days of storage at 4°C.

In all samples redness decreased as the storage time progressed ($P < 0.05$), which is consistent with the findings of Fernández-López *et al.* (2003) and Fernández-López *et al.* (2005). In the screening experiment, redness showed more stability in samples with additives (Table 2). In the vacuum packaged samples with sodium erythorbate, a^* values decreased significantly after 10 days of storage, and in MA-packaged samples only at the final stage of storage. The redness of samples with rosemary and a mixture of sodium erythorbate and rosemary showed smaller changes during vacuum storage, compared with modified atmosphere storage. During vacuum storage, control meatballs were characterized by higher a^* values than samples containing additives. After 10 days of storage under modified atmosphere, the a^* values of control samples and of samples with sodium erythorbate were higher, compared to meatballs with rosemary or with a mixture of sodium erythorbate and rosemary. This could be caused by the intense colour of rosemary. A possible browning reaction in rosemary could also contribute to colour change. Dogan and Dogan (2004) reported that polyphenol oxidase enzymes, widespread in many plants, are responsible for browning. In the presence of oxygen, these enzymes oxidize plant phenolic compounds to corresponding quinones, which then condense to form dark-colour compounds. During longer MA storage (20 and 30 days), meatballs with sodium erythorbate and a mixture of rosemary and sodium erythorbate were characterized by higher values of a^* than samples with rosemary. This suggests that the addition of sodium erythorbate, alone or in combination with rosemary, could protect colour by retarding the formation of metmyoglobin in stored turkey meatballs. According to Bavelev *et al.* (2005), the addition of 1g kg⁻¹ sodium erythorbate did not change the colour properties of the cross-sectional surface of dry-fermented sausage. Lee *et al.* (2005) found that sodium erythorbate, applied alone and combined with rosemary extract, appeared to be effective in slowing the decline of a^* values. McBride *et al.* (2007) demonstrated that rosemary extract did not improve meat redness in beef burgers. It has been reported that rosemary is an effective stabiliser of colour in beef, and that this ability may be enhanced through the addition of reducing agents such as ascorbic acid (Sanchez-Escalante *et al.*, 2001; Lee *et al.*, 2005).

In the present experiment, yellowness values were affected ($P < 0.05$) only by additives in vacuum-packaged

meatballs. After 30 days of storage, SE and MIX samples were characterized by higher b^* values than control samples (Table 2).

The microbial quality of raw, heated and stored turkey meatballs The results of microbial analyses of turkey meatballs are presented in Table 3. The initial contamination of raw turkey meatballs with total mesophilic bacteria was at a level of 10⁵ cfu/g. Thermal processing caused a reduction in the counts of these bacteria. The counts of aerobic mesophilic micro-organisms did not change after 15 days of vacuum storage. However, MA-packaged samples with the addition of rosemary and a mixture of sodium erythorbate and rosemary were characterized by lower counts of mesophilic bacteria after this period, while their counts in control samples and in samples with sodium erythorbate were similar as after thermal processing. After 30 days of vacuum storage, the counts of mesophilic bacteria increased in control samples and in samples with sodium erythorbate. After 30 days of MA storage, the counts of mesophilic bacteria increased only in control samples. This is indicative of the antimicrobial activity of all additives. Lower counts of total mesophilic bacteria in samples with additives were recorded in turkey meatballs packaged under modified atmosphere, compared with vacuum-packaged ones.

The total count of psychrotrophic bacteria per gram of raw meatballs was 10³–10⁴ cfu/g. As a result of thermal processing, the counts of psychrotrophic bacteria decreased in samples with all additives, while in control samples they remained at the same level as in raw turkey meatballs. During vacuum storage the population size of psychrotrophic bacteria increased after 15 days in control samples and in samples with sodium erythorbate, and it remained almost unchanged until 30 days. In samples with rosemary and a mixture of rosemary and sodium erythorbate, the counts of psychrotrophic bacteria decreased after 15 days of vacuum storage, and increased after 30 days of storage. During MA storage, the counts of psychrotrophic micro-organisms increased only in control samples after 30 days (10⁵ cfu/g). Their population size did not change in samples with sodium erythorbate, and was found to decrease in samples with rosemary (10 cfu/g) and with a mixture of both additives (<10 cfu/g). The addition of rosemary and rosemary + sodium erythorbate to the products presumably prevented psychrotrophic bacteria from growing to a higher degree under MA conditions.

Fungal contamination of raw meatballs reached 10³ cfu/g in control samples and 10² cfu/g in samples with additives. Thermal processing enabled a complete elimination of fungi, and no fungal growth was noted over refrigerated storage.

The total count of coliforms in raw control meatballs destined for vacuum and MA packaging was 10³ and 10⁴ cfu/

Table 3. Effect of thermal processing and cold storage on the microbiological counts [cfu/g] of turkey meatballs with different additives, packaged under vacuum and modified atmosphere conditions (n = 3).

Microorganisms	Sample type	Raw	After thermal processing	After 15 days of storage	After 30days of storage
Vacuum packaging					
Total mesophilic	C	6.7×10^5	3.3×10^4	3.9×10^4	2.0×10^5
	SE	3.1×10^5	5.6×10^3	6.8×10^3	5.4×10^4
	R	4.2×10^5	3.3×10^4	3.2×10^4	4.8×10^4
	MIX	3.0×10^5	2.2×10^3	3.9×10^3	3.3×10^3
Total psychrotrophic	C	3.2×10^3	4.2×10^3	4.0×10^4	5.6×10^4
	SE	2.2×10^3	3.3×10^2	3.3×10^3	4.2×10^3
	R	2.1×10^4	4.0×10^2	< 10	5.6×10^1
	MIX	3.3×10^3	4.3×10^2	< 10	7.2×10^1
Fungi	C	4.8×10^3	< 10	< 10	< 10
	SE	3.8×10^2	< 10	< 10	< 10
	R	5.1×10^2	< 10	< 10	< 10
	MIX	2.3×10^2	< 10	< 10	< 10
Total coliforms	C	4.6×10^3	< 10	< 10	5.3×10^3
	SE	4.5×10^2	< 10	< 10	< 10
	R	6.6×10^2	< 10	< 10	< 10
	MIX	3.7×10^2	< 10	< 10	< 10
Presence of sulphate (IV)- reducing <i>Clostridium</i> sp.	C	ND	ND	ND	ND
	SE	ND	ND	ND	ND
	R	ND	ND	ND	ND
	MIX	ND	ND	ND	ND
Modified atmosphere packaging (20% CO ₂ / 80% N ₂)					
Total mesophilic	C	5.8×10^5	4.0×10^4	4.0×10^4	9.0×10^5
	SE	3.1×10^5	4.1×10^3	3.7×10^3	3.6×10^3
	R	4.3×10^5	3.5×10^3	6.2×10^2	4.3×10^2
	MIX	2.7×10^5	3.6×10^3	5.6×10^2	5.2×10^2
Total psychrotrophic	C	3.5×10^3	6.3×10^3	6.1×10^3	4.2×10^5
	SE	4.2×10^3	4.3×10^2	4.5×10^2	5.5×10^2
	R	2.0×10^4	5.2×10^2	3.8×10^1	6.4×10^1
	MIX	7.2×10^3	2.8×10^1	< 10	< 10
Fungi	C	1.8×10^3	< 10	< 10	< 10
	SE	9.4×10^2	< 10	< 10	< 10
	R	4.5×10^2	< 10	< 10	< 10
	MIX	4.8×10^2	< 10	< 10	< 10
Total coliforms	C	6.8×10^4	< 10	< 10	80
	SE	5.3×10^3	< 10	< 10	< 10
	R	4.4×10^3	< 10	< 10	< 10
	MIX	4.3×10^3	< 10	< 10	< 10
Presence of sulphate (IV)- reducing <i>Clostridium</i> sp.	C	ND	ND	ND	ND
	SE	ND	ND	ND	ND
	R	ND	ND	ND	ND
	MIX	ND	ND	ND	ND

ND - not detected, Samples: C- control; SE-with sodium erythorbate; R-with rosemary, MIX-with a mixture of sodium erythorbate and rosemary.

g, respectively. In raw meatballs with additives their counts were 10^2 and 10^3 cfu/g respectively. It is possible that the bacteria were transmitted during the preparation of meat-

balls, and were completely destroyed during heat treatment. During storage, coliforms grew (after 30 days) considerably only in vacuum-packaged control samples.

Clostridium sp. colonies were not found in raw turkey meatballs and they were not present during storage.

Djenane *et al.* (2002) reported that beef steaks treated with rosemary extract + vitamin C, packed in modified atmosphere, exhibited lower counts of psychrotrophic aerobic flora during 30 days of storage, compared with control samples and with samples containing other additives (vitamin C, vitamin E + vitamin C, taurine + vitamin C). Rižnar *et al.* (2006) found that the addition of oil-soluble rosemary extracts to vacuum-packed chicken frankfurters significantly reduced the aerobic plate count, compared to controls stored at 4 or 12°C. Barringer *et al.* (2005) demonstrated that powdered sodium erythorbate reduced the populations of coliforms, mesophiles and psychrotrophs in turkey patties. García-Esteban *et al.* (2004) noted that after 8 weeks of stor-

age mesophile aerobic colonies slightly increased, compared with initial counts, in vacuum-packed dry-cured ham slices whereas a decrease was found in samples packaged under a modified atmosphere of 20% CO₂ + 80% N₂. Gök *et al.* (2008) reported that MA-packed (30% CO₂ + 65% N₂) Turkish pastrima was characterized by better microbial properties than vacuum-packed samples during storage. According to Rubio *et al.* (2006), from the microbial point of view, a gas mixture (20% CO₂ + 80% N₂) is more effective in extending the shelf-life of dry-cured beef slices than vacuum packaging.

The sensory quality of heated turkey meatballs during storage The results of a sensory evaluation of turkey meatballs after cooking and during storage under vacuum and modified atmosphere conditions are shown in Tables

Table 4. Effect of additives and storage time on the sensory attributes of vacuum-packaged turkey meatballs (mean ± SD, n = 10).

		Storage time [days]						
Flavour	Samples	0	5	10	15	20	25	30
Meaty	C	4.0 ± 0.0 ^b	4.0 ± 0.0 ^b	3.5 ± 0.6 ^{ab}	3.8 ± 0.5 ^{ab}	3.4 ± 0.5 ^{ab}	3.3 ± 0.5 ^{ab}	3.0 ± 0.0 ^a
	SE	4.0 ± 0.0	4.0 ± 0.0	3.5 ± 0.6	3.8 ± 0.5	3.8 ± 0.5	3.6 ± 0.5	3.3 ± 0.5
	R	3.8 ± 0.5 ^b	3.8 ± 0.5 ^b	3.8 ± 0.5 ^b	3.5 ± 0.6 ^{ab}	3.5 ± 0.6 ^{ab}	2.8 ± 0.5 ^{ab}	2.5 ± 0.6 ^a
	MIX	3.8 ± 0.5	3.8 ± 0.5	3.8 ± 0.5	3.8 ± 0.5	3.5 ± 0.6	3.0 ± 0.0	3.0 ± 0.0
Typical of poultry meat	C	3.8 ± 0.5 ^b	3.8 ± 0.5 ^b	3.5 ± 0.6 ^{ab}	3.8 ± 0.5 ^b	3.4 ± 0.5 ^{ab}	2.5 ± 0.6 ^a	2.5 ± 0.6 ^a
	SE	3.8 ± 0.5	3.8 ± 0.5	3.8 ± 0.5	3.8 ± 0.5	3.8 ± 0.5	3.5 ± 0.6	3.0 ± 0.8
	R	4.0 ± 0.0 ^b	4.0 ± 0.0 ^b	3.8 ± 0.5 ^b	3.5 ± 0.6 ^b	3.5 ± 0.6 ^b	2.5 ± 0.6 ^a	2.1 ± 0.3 ^a
	MIX	3.8 ± 0.5 ^b	3.8 ± 0.5 ^b	3.8 ± 0.5 ^b	3.8 ± 0.5 ^b	3.5 ± 0.6 ^{ba}	2.8 ± 0.5 ^{ab}	2.5 ± 0.5 ^a
Aromatic	C	3.5 ± 0.6 ^b	3.8 ± 0.5 ^b	2.5 ± 0.6 ^{abA}	2.8 ± 0.6 ^{ab}	2.8 ± 0.5 ^{ab}	2.5 ± 0.6 ^{Aab}	2.0 ± 0.0 ^a
	SE	3.3 ± 1.0	3.3 ± 0.5	3.0 ± 0.8 ^{AB}	3.0 ± 0.8	3.3 ± 0.5	3.0 ± 0.0 ^B	2.5 ± 0.6
	R	3.9 ± 0.6	3.9 ± 0.5	4.0 ± 0.6 ^B	4.0 ± 0.6	3.8 ± 0.5	3.5 ± 0.0 ^B	3.3 ± 0.5
	MIX	4.0 ± 0.6	3.8 ± 0.5	3.5 ± 0.8 ^{AB}	3.8 ± 0.5	3.5 ± 1.2	3.3 ± 0.5 ^B	3.0 ± 0.6
Typical of roasted meat	C	4.0 ± 0.0 ^b	3.8 ± 0.5 ^b	3.5 ± 0.6 ^b	3.5 ± 0.6 ^b	3.5 ± 0.6 ^b	2.0 ± 0.0 ^{Aa}	2.0 ± 0.0 ^a
	SE	4.0 ± 0.0	3.5 ± 0.6	3.5 ± 0.6	3.5 ± 0.6	3.5 ± 0.6	3.3 ± 0.5 ^B	3.0 ± 1.0
	R	4.0 ± 0.0 ^b	3.5 ± 0.6 ^{ab}	3.5 ± 0.6 ^{ab}	3.5 ± 0.6 ^{ab}	3.5 ± 0.6 ^{ab}	3.0 ± 0.0 ^{Bab}	2.8 ± 0.5 ^a
	MIX	3.8 ± 0.5	3.8 ± 0.5	3.5 ± 0.6	3.5 ± 0.6	3.3 ± 0.5	2.8 ± 0.5 ^B	2.8 ± 1.0 ^A
Spicy	C	NE	NE	NE	NE	NE	NE	NE
	SE	NE	NE	NE	NE	NE	NE	NE
	R	3.3 ± 0.5 ^B	2.8 ± 0.5 ^B	3.0 ± 0.8 ^B	3.3 ± 0.5 ^B	2.8 ± 0.5 ^B	2.5 ± 0.6 ^B	2.5 ± 0.6 ^B
	MIX	2.0 ± 0.0 ^A	2.0 ± 0.0 ^A	2.0 ± 0.0 ^A	2.0 ± 0.0 ^A	1.8 ± 1.0 ^A	1.0 ± 1.2 ^A	1.3 ± 0.5 ^A
Sour	C	0.0	0.0	0.0	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0
	SE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	R	0.0	0.0	0.0	0.5 ± 0.6	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0
	MIX	0.0	0.0	0.0	0.0	0.0	0.0	0.8 ± 0.3
WOF	C	0.0	0.0	1.0 ± 0.0 ^a	1.5 ± 0.5 ^{ab}	2.0 ± 0.0 ^{Bbc}	2.3 ± 0.5 ^{Bbc}	2.5 ± 0.6 ^{Bc}
	SE	0.0	0.0	0.0	1.0 ± 0.0	1.0 ± 0.0 ^A	1.0 ± 0.0 ^A	1.0 ± 0.0 ^A
	R	0.0	0.0	0.0	1.0 ± 0.0	1.0 ± 0.0 ^A	1.3 ± 0.5 ^A	1.5 ± 0.6 ^A
	MIX	0.0	0.0	0.0	0.0	0.0	1.0 ± 0.0 ^A	1.0 ± 0.3 ^A

Samples: C- control SE-with sodium erythorbate; R-with rosemary, MIX-with a mixture of sodium erythorbate and rosemary, NE - not estimated, ^{a, b, c} - Mean values in rows followed by different letters are significantly different at P < 0.05, ^{A, B} - Mean values in columns followed by different letters are significantly different at P < 0.05.

4 and 5. After thermal processing, turkey meatballs were characterized by similar intensity of meaty, typical of poultry meat and roasted flavours. Samples with rosemary and with a mixture of sodium erythorbate and rosemary had a more intense aromatic flavour and a moderate and slight rosemary flavour. The intensity of the following flavours: meaty, typical of poultry meat, typical of roasted meat and aromatic decreased during storage, but the changes were significant only in some samples at the final stage of storage. However, more intensive changes were observed in vacuum-packaged turkey meatballs than in those packaged under modified atmosphere.

The shelf-life and acceptability of processed, ready-to-eat uncured meats is limited because of the rapid onset of rancidity, denoted as warmed-over flavour (WOF). This becomes

evident within a few days of refrigerated storage of cooked meat products (Jayathilakan *et al.*, 2007). In the present experiment, WOF developed in all vacuum-packaged samples after different periods of time. After 10 days it was detected as hardly noticeable in control samples, after 15 days in SE and R samples, and after 25 days in MIX samples. WOF intensity increased significantly during longer storage only in control samples. WOF of hardly noticeable intensity was detected after 15 days of storage in control MAP samples and after 30 days of storage in samples with sodium erythorbate, with rosemary and with a mixture of rosemary and sodium erythorbate. Sodium erythorbate, rosemary and a mixture of rosemary and sodium erythorbate were effective in retarding WOF development. A sour flavour of low intensity was noted in control, R and MIX samples after 15 and 30 days of

Table 5. Effect of additives and storage time on the sensory attributes of vacuum-packaged turkey meatballs (mean $\pm$ SD, n = 10).

Flavour	Samples	Storage time [days]						
		0	5	10	15	20	25	30
Meaty	C	3.8 $\pm$ 0.5	3.8 $\pm$ 0.5	3.8 $\pm$ 0.5	3.8 $\pm$ 0.5	3.8 $\pm$ 0.5	3.0 $\pm$ 0.0	3.0 $\pm$ 0.0
	SE	3.8 $\pm$ 0.5	3.8 $\pm$ 0.5	3.4 $\pm$ 0.5	3.3 $\pm$ 0.5	3.5 $\pm$ 0.6	3.5 $\pm$ 0.6	3.0 $\pm$ 0.0
	R	3.8 $\pm$ 0.5	3.3 $\pm$ 0.5	3.0 $\pm$ 0.0	3.3 $\pm$ 0.5	3.8 $\pm$ 0.5	3.5 $\pm$ 0.6	3.0 $\pm$ 0.0
	MIX	3.8 $\pm$ 0.5	3.8 $\pm$ 0.5	3.8 $\pm$ 0.5	3.8 $\pm$ 0.5	3.5 $\pm$ 0.6	3.5 $\pm$ 0.6	3.0 $\pm$ 0.0
Typical of poultry meat	C	4.3 $\pm$ 0.5 ^b	3.8 $\pm$ 0.5 ^{ab}	3.8 $\pm$ 0.5 ^{abAB}	3.3 $\pm$ 0.5 ^{ab}	3.8 $\pm$ 0.5 ^{ab}	2.8 $\pm$ 0.5 ^a	2.8 $\pm$ 0.5 ^a
	SE	4.1 $\pm$ 0.3 ^b	3.5 $\pm$ 0.6 ^{ab}	4.0 $\pm$ 0.0 ^{bbB}	3.3 $\pm$ 0.5 ^{ab}	3.5 $\pm$ 0.6 ^{ab}	3.6 $\pm$ 0.5 ^{ab}	2.8 $\pm$ 0.5 ^a
	R	3.8 $\pm$ 0.5	3.8 $\pm$ 0.5	3.3 $\pm$ 0.5 ^A	3.4 $\pm$ 0.5	3.8 $\pm$ 0.5	3.5 $\pm$ 0.6	3.0 $\pm$ 0.0
	MIX	4.0 $\pm$ 0.0 ^b	4.0 $\pm$ 0.0 ^b	4.0 $\pm$ 0.0 ^{bbB}	3.8 $\pm$ 0.5 ^b	3.5 $\pm$ 0.6 ^{ab}	3.8 $\pm$ 0.5 ^b	2.8 $\pm$ 0.5 ^a
Aromatic	C	3.0 $\pm$ 0.0 ^A	3.0 $\pm$ 0.8	2.8 $\pm$ 0.5 ^A	2.8 $\pm$ 0.5 ^A	2.8 $\pm$ 0.5	2.3 $\pm$ 0.5 ^A	2.3 $\pm$ 0.5 ^A
	SE	3.3 $\pm$ 0.5 ^{AB}	3.0 $\pm$ 0.0	2.8 $\pm$ 0.5 ^A	2.5 $\pm$ 0.6 ^A	3.0 $\pm$ 0.8	2.8 $\pm$ 0.5 ^{AB}	2.3 $\pm$ 0.5 ^A
	R	4.3 $\pm$ 0.5 ^B	3.8 $\pm$ 0.5	4.0 $\pm$ 0.6 ^B	4.0 $\pm$ 0.6 ^B	3.5 $\pm$ 0.8	4.0 $\pm$ 0.6 ^B	3.5 $\pm$ 0.8 ^B
	MIX	4.0 $\pm$ 0.6 ^B	3.8 $\pm$ 0.5	3.5 $\pm$ 0.8 ^{AB}	3.5 $\pm$ 0.0 ^{AB}	3.5 $\pm$ 0.8	3.8 $\pm$ 1.0 ^B	3.3 $\pm$ 0.5 ^B
Typical of roasted meat	C	3.5 $\pm$ 0.6	3.5 $\pm$ 0.6	3.3 $\pm$ 0.5	2.8 $\pm$ 0.5	3.5 $\pm$ 0.6	3.0 $\pm$ 0.0	2.8 $\pm$ 0.5
	SE	3.8 $\pm$ 0.5	3.0 $\pm$ 0.0	3.5 $\pm$ 0.6	2.8 $\pm$ 0.5	3.3 $\pm$ 0.5	3.0 $\pm$ 0.0	2.8 $\pm$ 0.5
	R	3.5 $\pm$ 0.6	3.5 $\pm$ 0.6	3.5 $\pm$ 0.6	3.3 $\pm$ 0.5	3.3 $\pm$ 0.5	3.5 $\pm$ 0.6	3.0 $\pm$ 0.0
	MIX	3.5 $\pm$ 0.6	3.5 $\pm$ 0.6	3.5 $\pm$ 0.6	3.3 $\pm$ 0.5	3.4 $\pm$ 0.5	3.3 $\pm$ 0.5	2.8 $\pm$ 0.5
Spicy	C	NE	NE	NE	NE	NE	NE	NE
	SE	NE	NE	NE	NE	NE	NE	NE
	R	3.4 $\pm$ 0.5 ^B	3.3 $\pm$ 0.5 ^B	3.3 $\pm$ 0.5 ^B	2.8 $\pm$ 0.5 ^B	2.9 $\pm$ 0.6 ^B	3.0 $\pm$ 0.8 ^B	2.3 $\pm$ 0.5
	MIX	2.3 $\pm$ 0.5 ^A	2.3 $\pm$ 0.5 ^A	2.0 $\pm$ 0.0 ^A	1.8 $\pm$ 0.5 ^A	1.8 $\pm$ 0.5 ^A	1.8 $\pm$ 0.5 ^A	1.8 $\pm$ 0.5
WOF	C	0.0	0.0	0.0	1.0 $\pm$ 0.5	1.0 $\pm$ 0.5	1.3 $\pm$ 0.5	1.5 $\pm$ 0.6
	SE	0.0	0.0	0.0	0.0	0.0	0.0	1.0 $\pm$ 0.0
	R	0.0	0.0	0.0	0.0	0.0	0.0	1.0 $\pm$ 0.0
	MIX	0.0	0.0	0.0	0.0	0.0	0.0	1.0 $\pm$ 0.0

Samples: C- control SE-with sodium erythorbate; R-with rosemary, MIX-with a mixture of sodium erythorbate and rosemary, NE - not estimated, ^{a, b} - Mean values in rows followed by different letters are significantly different at $P < 0.05$, ^{A, B} - Mean values in columns followed by different letters are significantly different at $P < 0.05$.

storage respectively.

According to Gray *et al.* (1996), the process of WOF development in meat products can be attributed to the auto-oxidation of meat lipids, which gives rise to hydroperoxides, which, via many different pathways, decompose into a large number of volatile compounds. During oxidative degradation of unsaturated fatty acids, present in meat systems, undesirable flavour and odour occur, due to the formation of aldehydes, ketones and alcohols (Drumm and Spanier, 1991). In the present work, the trend observed in WOF values was consistent with the values of the antioxidant activity of the additives and packaging method (Tables 1, 4 and 5).

There was a significant correlation (only in samples packaged under MA) between MDA content and typical of poultry meat and roasted flavours ($r = -0.57$ and $r = -0.57$, respectively). In VA-packaged samples, the acid value was negatively correlated with meaty flavour ($r = -0.82$), typical of poultry meat flavour ($r = -0.83$), aromatic flavour ($r = -0.73$) and roasted flavour ($r = -0.91$), and it was positively correlated with WOF ($r = 0.68$). Spicy flavour was positively correlated with aromatic flavour ($r = 0.69$ and $r = 0.69$ in VP and MAP samples, respectively). WOF was negatively correlated with meaty, typical of poultry, aromatic and roasted flavours (in VP and MAP samples), while a positive correlation was observed between WOF and sour flavour (only in VP samples).

Ntzimani *et al.* (2008) reported similar odour and taste scores for smoked turkey breast fillets stored under vacuum and modified atmosphere (30% CO₂ + 70% N₂, 50% CO₂ + 50% N₂). In a study conducted by Fernández-López *et al.* (2005), the results of a sensory analysis, particularly aroma and acceptability scores, indicated the significant advantages of using rosemary in rancidity-susceptible meat products. Sánchez-Escalante *et al.* (2003) showed that beef patties treated with rosemary (alone or with ascorbic acid) maintained fresh beef odour for longer time than controls. Keokamnerd *et al.* (2008) reported that the addition of rosemary to ground chicken had a positive effect on cooked meat flavour.

As shown by the results of the present study, ground rosemary applied alone or with sodium erythorbate protected turkey meatballs against oxidation. The colour stability of turkey meatballs did not show clear differences depending on the tested additives. All additives prevented the spoilage of turkey meatballs. Vacuum-packaged samples showed higher lipid stability than samples stored in a gas mixture (20% CO₂ / 80% N₂), and MAP seems more effective in preserving the microbial and sensory quality of turkey meatballs.

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