The effect of oil-soluble rosemary extract, sodium erythorbate, their mixture, and packaging method on the quality of Turkey meatballs

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Abstract The effect of oil-soluble rosemary extract, sodium erythorbate and a mixture of oil-soluble rosemary extract and sodium erythorbate and packaging method (vacuum packaging and modified atmosphere packaging) on the quality of cooked turkey meatballs stored at 4 °C was determined. The physicochemical, microbiological and sensory analyses were performed. Oil-soluble rosemary extract was found to be the most effectual antioxidant and vacuum more effective than modified atmosphere packaging in preventing oxidative changes. Sodium erythorbate slowed down hydrolytic process and more effective in modified atmosphere packaged samples. A slighter change in the colour of turkey meatballs was noted during modified atmosphere storage. Microbial counts of mesophilic bacteria during storage were never higher than the spoilage limit (10^7 cfu/g). All additives reduced microbial population and better effect was achieved by the combination of modified atmosphere packaging and additives. Sensory analysis results indicated the significant advantages in using rosemary individually or with sodium erythorbate in retarding warmed-over-flavour development in cooked poultry product.

Keywords Antioxidant · Method of packaging · Turkey meatballs · Physicochemical quality · Microbial quality · Sensory properties

Introduction

Turkey meat is particularly prone to oxidation due to a high content of polyunsaturated fatty acids and a high concentration of free iron, as well as the turkey's low ability to store dietary vitamin E (Mielnik et al. 2006). The oxidation process is one of the primary causes of quality losses in stored meat products. The oxidation process greatly reduces the nutritional value of lipids. The colour alters as the pigments oxidize and the flavour and aroma also change as a result of the accumulation of secondary volatiles. Biologically active compounds can be destroyed and, in some cases, toxic and carcinogenic substances accumulate (Akarp et al. 2008). Rancidity and warmed-over-flavour (WOF) 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).

Sodium erythorbate has been shown to extend the shelf-life of meat products. It increased colour stability in turkey ham, turkey franks and turkey patties (Hasiak et al. 1984; Barringer et al. 2005). The addition of sodium erythorbate decreased microbial counts in turkey patties (Barringer et al. 2005). Wilkinson et al. (2001) investigated the antioxidant activity of sodium erythorbate in fresh and freeze-dried chicken.

Natural antioxidants are becoming increasingly popular. Many reports on the effective reduction of lipid oxidation pertain to extracts from plants of the family Labiatae, in particular rosemary – *Rosmarinus officinalis* L. (Waszkowiak 2008). Rosemary extract contains numerous active substances, the most important being the phenolic derivatives of diterpenes, i.e. carnosol, carnosolic acid, rosmanol, epirosmanol, isorosmanol and rosmarinic acid (Frankel et al. 1996). Rosemary extracts have been demonstrated to

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strongly inhibit hydroperoxidant formation (Frankel et al. 1996). A number of researchers have reported their antioxidant properties in various meats (Formanek et al. 2003; Sánchez-Escalante et al. 2003; Bragagnolo et al. 2005). As shown by some authors, selected compounds present in rosemary extracts could have antibacterial activity (Campo et al. 2000; Djenane et al. 2002; Fernández-López et al. 2005). According to Campo et al. (2000), the compounds responsible for antibacterial action were presumably phenolic di-terpenoides, the main components of the apolar fraction of rosemary extracts.

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). Nitrogen is used to replace oxygen in MAP products to prevent rancidity and inhibit the growth of aerobic organisms. Carbon dioxide is the major anti-microbial factor of MAP. Both packaging methods enable to increase the shelf-life of poultry meat and products by inhibiting the growth of both spoilage and pathogenic micro-organisms (Ntzimani et al. 2008). The effect of rosemary extracts has been well investigated in vitro and in raw meat systems. However, relatively few studies have focused on the inhibition of the growth of foodborne pathogens and on changes in the colour and sensory quality of precooked meat, associated with lipid oxidation.

The aim of the present work was to determine the effect of oil-soluble rosemary extract on lipid oxidation, colour stability, the microbiological and sensory quality of refrigerated vacuum- and modified atmosphere-stored turkey meatballs, and to compare this effect to that exerted by a synthetic antioxidant (sodium erythorbate).

Materials and methods

Materials

Thigh muscles of male British United BIG-6 turkeys (Frednowy, Poland) were purchased from the Indykpol Company (Olsztyn, Poland), oil-soluble rosemary extract (0792 Stabilotion OS) was purchased from RAPS GmbH & CO.KG Company (Kulmbach, Germany), and 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 packaged in polyethylene bags and deep-frozen at -25° at the “Indykpol” Poultry Processing Plant in Olsztyn. After three days, half of the material was transported to the laboratory at the University of Warmia and Mazury and placed in the refrigerator at 3°C , where it was defrosted over 20 h and assigned to the first experiment (vacuum packaging). The remaining meat portions were transported to the laboratory at the beginning of the second experiment (modified atmosphere packaging), after 14 days of storage. 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, oil-soluble rosemary extract (OR)—0.3 g/kg and a mixture of OR and SE (MIX)—0.15 g/kg and 0.15 g/kg respectively. In MIX samples, the content of sodium erythorbate and oil-soluble rosemary extract was half lower than in SE and OR samples, respectively, to reduce the addition of synthetic antioxidants and to improve the sensory quality of turkey meatballs.

Oil-soluble rosemary extract 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 OR, the ingredients were added individually. Next the mass was formed into 90 ± 1 g meatballs (8 cm in diameter, 1 cm in thickness).

Cooking

Eighty-four meatballs were randomly selected from each treatment and placed on the oven tray (12 meatballs at a time) and cooked in the 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 patties analysed after cooking were stored overnight at 0°C .

Storage study

Cooked turkey meatballs were vacuum packaged (VP-Experiment I) and modified atmosphere (a gas mixture of 80% N_2 and 20% CO_2) packaged (MAP- Experiment II) with the MULTIVAC A 300 packaging unit (Multivac,

Wolfertschwenden Germany) 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 – $40 \text{ cm}^3/\text{m}^{-2}24 \text{ h}^{-1}\text{bar}^{-1}$, water vapour permeability – $10 \text{ gm}^{-2}24 \text{ h}^{-1}\text{bar}^{-1}$). The samples were stored at $3 \text{ }^{\circ}\text{C} \pm 1 \text{ }^{\circ}\text{C}$ for 5, 10, 15, 25 and 30 days.

Analytical methods

Lipid oxidation analysis Lipid oxidation was monitored by measuring the levels of thiobarbituric acid reactive substances (TBARS) after 0, 5, 10, 15, 20, 25 and 30 days of

storage at $4 \text{ }^{\circ}\text{C}$. TBARS values were determined by the distillation method of Tarladgis et al. (1960), modified by Pikul et al. (1989), which involved the addition of butylated hydroxytoluene (BHT) before sample homogenization to prevent autooxidation. The TBARS of each sample were used to measure absorbance at 538 nm. 1,1, 3,3-tetraethoxypropane was used as a standard for the TBARS assay. TBARS values were calculated as mg malondialdehyde (MDA) per kg of meat sample.

The antioxidant potential, expressed in terms of the percentage of antioxidant activity, was calculated from the equation (Jayathilakan et al. 2007).

$$\% \text{AOA} = \frac{[\text{TBARS value of the control sample} - \text{TBARS value of the sample with additives}] \times 100}{[\text{TBARS value of the control sample}]} \quad (1)$$

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 $4 \text{ }^{\circ}\text{C}$, in accordance with the Polish Standard PN-EN ISO 660 (PN-EN ISO 660 2005).

Colour evaluation The colour of the samples was determined with a spectrophotometer (Dr Lange Spectro-color), $d/8^{\circ}$ 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 ($+60=\text{red}$, $-60=\text{green}$) and b^* - relative yellowness ($+60=\text{yellow}$, $-60=\text{blue}$)]. Colour was measured on the meat surface 30 min after the package had been opened.

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 and psychrotrophic bacteria, appropriate serial dilutions were plated on plate count nutrient agar, and were incubated at $30 \text{ }^{\circ}\text{C}$ for 72 h (mesophilic bacteria) and at $6.5 \text{ }^{\circ}\text{C}$ 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 $30 \text{ }^{\circ}\text{C}$ for 48 h. The counts of fungi were determined on YGC – Agar (Merck) after 96 h incubation at $25 \text{ }^{\circ}\text{C}$. To determine the presence of sulphate IV reducing *Clostridium* sp., adequate dilutions were inocu-

lated into a liquid meat-liver agar medium, were heated at $80 \text{ }^{\circ}\text{C}$ for 15 min and incubated at $37 \text{ }^{\circ}\text{C}$ 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 $3 \text{ }^{\circ}\text{C} \pm 1 \text{ }^{\circ}\text{C}$. 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 panelists trained in accordance with the Polish Standard ISO 11035 (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 $4 \text{ }^{\circ}\text{C}$. 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, two meatballs per treatment were cut into approximately uniform pieces. Samples were served in random order to each panelist 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 five-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

The results were processed statistically using STATISTICA 7.1 software (StatSoft Inc. 2008). Data obtained for the initial characterization of the tested additives and storage time were subjected to a two-way analysis of variance, and Tukey's test was applied to determine significant differences between the additives and storage time. The level of significance was determined at $P<0.05$.

Results and discussion

The effect of oil-soluble rosemary extract and sodium erythorbate on lipid stability

An analysis of variance indicated that MDA content was significantly affected by both the additives and storage time (data not shown). The pattern of changes in MDA concentrations during storage was quite ambiguous (Table 1). After 30 days of vacuum storage, the content of MDA in samples with sodium erythorbate (SE) was similar to its initial content, while in the remaining samples it was significantly ($P<0.05$) lower. Such a trend was also reported by Liu et al. (2009). The decrease in TBA values during storage could be attributed to MDA interactions with amino

acids, sugars (Janero 1990), or to further oxidation of MDA to other organic products of lipid oxidation (alcohol and acid), which are not determined by reaction with thiobarbituric acid (Fernández-López et al. 1997).

According to Schormüller (as cited in Cadun et al. 2008), the TBA value should be lower than 3 mg MDA equiv./kg in high-quality materials and should not be higher than 5 mg MDA equiv./kg in good quality materials. The consumption limit is 7–8 mg MDA equiv./kg. In the present experiments (Table 1), the good quality of cooked turkey meatballs was maintained until the end of the storage period. MDA content was significantly ($P<0.05$) lower in experimental samples (SE, OR, MIX) than in control (C) samples throughout storage. All additives were highly effective in inhibiting lipid oxidation, but oil-soluble rosemary extract was found to be the most potent antioxidant (Table 1). The antioxidant activity of rosemary extract is attributed mainly to its content of carnosol, rosmanol, rosmamidiphenol, rosmariquinone, and carnosic and rosmarinic acid, which break the free radical chain reaction by donating hydrogen atoms (Zheng and Wang 2001). The addition of rosemary, with or without sodium erythorbate (MIX and OR), substantially inhibited lipid oxidation until d 30 of vacuum or modified atmosphere storage. These results are consistent with those reported by other authors (Yu et al. 2002; Sánchez-Escalante et al.

Table 1 Effect of additives, storage time and packaging system on the malondialdehyde (MDA) content of cooked turkey meatballs and the antioxidant activity of the tested additives

Specification	Samples	Storage time [days]						
		0	5	10	15	20	25	30
Malondialdehyde [mg/kg]								
Vacuum packaging	C	2.3±0.09 ^{eD}	1.6±0.03 ^{eD}	1.6±0.12 ^{cC}	1.6±0.02 ^{cD}	1.1±0.09 ^{aD}	1.9±0.03 ^{dD}	1.3±0.07 ^{bC}
	SE	0.87±0.08 ^{cC}	1.1±0.02 ^{dC}	0.56±0.01 ^{aB}	0.54±0.05 ^{aC}	0.70±0.04 ^{bC}	0.83±0.03 ^{cC}	0.81±0.04 ^{bcB}
	OR	0.26±0.02 ^{dA}	0.21±0.01 ^{cA}	0.20±0.02 ^{cA}	0.15±0.01 ^{bA}	0.09±0.01 ^{aA}	0.19±0.02 ^{bcA}	0.19±0.01 ^{cA}
	MIX	0.44±0.01 ^{dB}	0.34±0.00 ^{cB}	0.34±0.01 ^{cA}	0.30±0.01 ^{bcB}	0.19±0.01 ^{aB}	0.34±0.03 ^{cB}	0.29±0.02 ^{bA}
Modified atmosphere packaging (20% CO ₂ /80% N ₂)	C	2.1±0.02 ^{eD}	2.0±0.09 ^{cC}	1.6±0.16 ^{abC}	1.7±0.04 ^{bC}	1.9±0.02 ^{cD}	1.5±0.02 ^{aD}	2.1±0.05 ^{cD}
	SE	0.66±0.07 ^{aC}	0.91±0.03 ^{bB}	0.69±0.03 ^{aB}	0.92±0.05 ^{bB}	1.56±0.05 ^{cC}	1.02±0.03 ^{bC}	1.59±0.01 ^{cC}
	OR	0.25±0.02 ^{aA}	0.43±0.01 ^{dA}	0.25±0.03 ^{aA}	0.35±0.01 ^{bcA}	0.35±0.03 ^{bcA}	0.31±0.02 ^{bA}	0.36±0.01 ^{cA}
	MIX	0.45±0.03 ^{abB}	0.53±0.05 ^{cA}	0.43±0.02 ^{abA}	0.40±0.02 ^{aA}	0.48±0.01 ^{bB}	0.43±0.02 ^{abB}	0.49±0.02 ^{bcB}
Antioxidant activity [%]								
Vacuum packaging	SE	62.5±2.88 ^{bcA}	34.2±0.51 ^{aA}	64.5±2.81 ^{bcA}	65.9±3.72 ^{cA}	33.8±6.52 ^{aA}	55.4±1.82 ^{bA}	37.4±4.22 ^{aA}
	OR	88.9±0.74 ^{abC}	86.7±0.15 ^{abC}	85.1±5.78 ^{aB}	90.3±0.45 ^{abC}	91.9±0.41 ^{bC}	89.9±1.24 ^{abC}	85.0±0.90 ^{aC}
	MIX	81.1±0.98 ^B	78.8±0.40 ^B	77.7±2.90 ^B	80.9±0.70 ^B	81.8±1.74 ^B	81.8±1.32 ^B	77.7±2.37 ^B
Modified atmosphere packaging (20% CO ₂ /80% N ₂)	SE	68.1±3.59 ^{cA}	54.7±1.89 ^{dA}	56.7±3.82 ^{dA}	45.4±2.70 ^{cA}	17.9±1.99 ^{aA}	30.5±1.46 ^{bA}	24.5±1.62 ^{abA}
	OR	87.7±1.05 ^{cC}	78.7±1.57 ^{aB}	84.5±2.71 ^{bcC}	79.4±0.24 ^{aB}	81.6±1.41 ^{abC}	78.8±1.49 ^{aC}	82.7±0.29 ^{abC}
	MIX	78.4±1.51 ^{bB}	73.3±2.90 ^{abB}	73.1±3.80 ^{abB}	76.2±1.12 ^{abB}	74.8±0.33 ^{abB}	70.6±1.78 ^{aB}	76.9±1.13 ^{bB}

C control, SE with sodium erythorbate, OR with rosemary oil extract, MIX with mixture of sodium erythorbate and rosemary oil extract;

a,b,c,d,e Values with different superscripts in a row differ significantly ($P<0.05$) ($n=6$)

A,B,C,D Values with different superscripts in a column differ significantly ($P<0.05$) ($n=6$)

2003; Fernández-López et al. 2005; Lund et al. 2007). The results of the present work show that oil-soluble rosemary extract (OR) was most effective in delaying lipid oxidation, and sodium erythorbate alone (SE) had a weaker antioxidant activity than a mixture of sodium erythorbate and oil-soluble rosemary extract (MIX) (Table 1), which may suggest a synergistic action of sodium erythorbate and oil-soluble rosemary extract. Karpińska-Tymoszczyk (2006) found that sodium erythorbate slowed down lipid oxidation in poultry meatballs during 15 days of storage, but to a lower degree than ground sage. Wilkinson et al. (2001) demonstrated that sodium erythorbate delayed lipid oxidation in freeze-dried beef and chicken. This is contrast with the findings of Balev et al. (2005), who reported 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. In the present experiments MDA content was lower in vacuum-stored turkey meatballs than in MA-stored samples. This could be caused by a higher amount of oxygen in MA-packaged samples, in comparison with vacuum-packaged ones, because complete removal of oxygen is extremely difficult. These findings agree with those reported by other authors (Nolan et al. 1989; Smiddy et al. 2002). According to Nolan et al. (1989), the use of both vacuum and modified atmosphere packaging techniques has been shown to be effective in controlling oxidation in cooked pork and turkey. Smiddy et al. (2002) concluded that MAP cooked chicken breast patties were more oxidised than vacuum-packaged samples during storage at 4 °C.

The acid value was significantly affected by both storage time and additives (in both experiments- Table 2). The acid value increased gradually with storage time, and it was highest in control vacuum-packaged samples. A slower

hydrolytic process was observed in MA-packaged samples. Greater differences in the acid values of turkey meatballs were found in MA-packaged samples, and the lowest values were noted in samples with sodium erythorbate (SE). The results of the present experiments partially correspond with the findings of Ferández-Fernández et al. (2002) who reported that lipophilic reactions took place in chorizo sausages stored under modified atmosphere (100% CO₂, 100% N₂, and 50%: 50% CO₂/N₂) and vacuum, but more slowly in MA-packaged samples. Balev et al. (2005) showed that the addition of 1 gkg⁻¹ sodium erythorbate slowed down lipolysis in dry-fermented sausages during the drying process.

Colour parameters

An analysis of variance showed that the analyzed additives and storage time significantly affected the colour lightness (L*) of turkey meatballs packaged by both methods (data not shown). The effect of the tested additives on colour changes in cooked turkey meatballs during refrigerated storage is shown in Table 3. The addition of sodium erythorbate (SE), oil-soluble rosemary extract (OR) and their mixture (MIX) decreased the lightness (L*) values of cooked turkey meatballs, but not all differences were significant. During vacuum storage, lightness (L*) did not change significantly ($P>0.05$) in C and OR samples, and it increased significantly ($P<0.05$) in SE and MIX samples, in comparison with meatballs immediately after cooking. L* values increased in MA-packaged samples with sodium erythorbate (SE) throughout the storage period, while in the other samples (C, OR, MIX) they did not change significantly ($P>0.05$).

Redness (a*) values were affected by the additives and storage time in both experiments (Table 3). All additives (SE, OR, MIX) caused an increase in the redness of turkey

Table 2 Effect of additives, storage time and packaging system on the acid value (mg NaOH/g) of cooked turkey meatballs

Method of packaging	Samples	Storage time [days]						
		0	5	10	15	20	25	30
Vacuum packaging	C	3.7±0.05 ^a	4.0±0.15 ^{ab}	4.1±0.04 ^b	4.2±0.05 ^b	4.2±0.03 ^b	4.6±0.15 ^{cB}	4.9±0.13 ^{dB}
	SE	3.7±0.14 ^a	3.8±0.14 ^a	3.8±0.05 ^{ab}	3.9±0.03 ^{abc}	4.0±0.15 ^{abc}	4.1±0.19 ^{bcA}	4.2±0.03 ^{cA}
	OR	3.7±0.07 ^a	3.9±0.05 ^a	3.9±0.07 ^{ab}	3.9±0.28 ^{abc}	4.0±0.11 ^{abc}	4.3±0.07 ^{bcAB}	4.3±0.10 ^{cA}
	MIX	3.7±0.03 ^a	3.8±0.03 ^a	4.1±0.18 ^{ab}	4.1±0.19 ^{ab}	4.2±0.17 ^{ab}	4.3±0.22 ^{bAB}	4.4±0.14 ^{bA}
Modified atmosphere packaging (20% CO ₂ /80% N ₂)	C	3.9±0.07 ^{aB}	3.9±0.14 ^{aB}	4.0±0.06 ^{aB}	4.0±0.02 ^{abB}	4.0±0.08 ^{abAB}	4.2±0.08 ^{bcAB}	4.4±0.08 ^{cB}
	SE	3.6±0.08 ^{aAB}	3.7±0.04 ^{abA}	3.7±0.00 ^{abA}	3.8±0.12 ^{abA}	3.8±0.12 ^{abA}	3.9±0.06 ^{bA}	4.2±0.11 ^{cAB}
	OR	3.8±0.10 ^{aB}	3.9±0.10 ^{abB}	4.0±0.01 ^{abB}	4.0±0.06 ^{abB}	4.1±0.08 ^{bcB}	4.3±0.17 ^{cdB}	4.4±0.06 ^{dB}
	MIX	3.5±0.10 ^{aA}	3.7±0.10 ^{abAB}	3.7±0.03 ^{abA}	3.8±0.06 ^{bcAB}	3.9±0.03 ^{bcdAB}	4.0±0.11 ^{cdA}	4.1±0.11 ^{dA}

C control, SE with sodium erythorbate, OR with rosemary oil extract, MIX with mixture of sodium erythorbate and rosemary oil extract

^{a,b,c,d} Values with different superscripts in a row differ significantly ($P<0.05$) ($n=6$)

^{A,B} Values with different superscripts in a column differ significantly ($P<0.05$) ($n=6$)

Table 3 Effect of additives, storage time and packaging system on the colorimeter values of turkey meatballs

Method of packaging	Samples	Storage time [days]			
		0	10	20	30
Lightness (L*)					
VP	C	59.7±3.79 ^B	60.8±2.13 ^B	59.8±1.31 ^B	61.6±1.77 ^B
	SE	56.3±1.11 ^{aA}	58.6±2.35 ^{abAB}	57.3±1.73 ^{abA}	59.0±1.85 ^{baA}
	OR	56.2±2.14 ^A	56.2±2.83 ^A	57.6±1.25 ^A	57.6±1.79 ^A
	MIX	56.3±2.46 ^{aA}	58.0±1.50 ^{abAB}	57.6±1.69 ^{abA}	59.4±1.71 ^{baB}
MAP	C	60.4±0.58	61.2±1.74	61.2±1.35 ^B	61.5±1.06
	SE	59.1±2.35 ^a	60.9±0.85 ^{ab}	61.2±0.96 ^{bB}	60.4±1.23 ^{ab}
	OR	58.6±1.81	60.7±1.56	58.6±3.13 ^A	60.1±1.55
	MIX	59.2±2.58	59.9±1.85	59.7±1.48 ^{AB}	60.6±1.46
Redness (a*)					
VP	C	2.3±0.33 ^{aA}	3.6±0.77 ^b	4.0±0.41 ^b	3.7±0.69 ^b
	SE	4.7±0.52 ^{bB}	3.9±0.47 ^a	3.8±0.66 ^a	3.6±0.59 ^a
	OR	4.1±0.39 ^{bB}	3.7±0.68 ^{ab}	3.6±0.42 ^{ab}	3.3±0.46 ^a
	MIX	4.3±0.77 ^{bB}	3.9±0.64 ^{ab}	3.5±0.45 ^a	3.6±0.38 ^{ab}
MAP	C	2.0±0.26 ^{aA}	3.0±0.67 ^b	3.2±0.64 ^b	3.2±0.59 ^{bB}
	SE	3.1±0.61 ^B	3.0±0.27	3.2±0.56	3.2±0.32 ^B
	OR	2.9±0.41 ^B	2.9±0.36	2.9±0.36	2.4±0.35 ^A
	MIX	3.0±0.42 ^B	3.0±0.37	2.9±0.37	2.9±0.30 ^{AB}
Yellowness (b*)					
VP	C	20.1±1.12 ^{aA}	20.9±1.50 ^{abA}	22.3±0.88 ^{baA}	21.9±1.00 ^{baA}
	SE	23.3±1.27 ^{abB}	21.7±1.27 ^{aAB}	24.1±2.06 ^{baB}	23.7±1.85 ^{abB}
	OR	25.0±1.96 ^{abB}	23.0±1.38 ^{aB}	25.1±1.60 ^{bB}	23.9±1.02 ^{abB}
	MIX	23.5±1.93 ^B	23.2±1.26 ^B	24.1±0.61 ^{AB}	23.1±1.21 ^{AB}
MAP	C	20.9±0.47	21.8±0.63	21.1±0.46	21.7±2.77
	SE	20.4±1.46 ^a	22.2±0.86 ^b	21.5±0.57 ^{ab}	21.7±0.54 ^b
	OR	21.3±2.04	23.1±1.97	22.5±2.19	21.5±1.82
	MIX	21.4±2.69	23.0±2.20	21.7±1.53	21.3±1.29

C control, SE with sodium erythorbate, OR with rosemary oil extract, MIX with mixture of sodium erythorbate and rosemary oil extract

^{a,b} Values with different superscripts in a row differ significantly ($P<0.05$) ($n=6$)

^{A,B} Values with different superscripts in a column differ significantly ($P<0.05$) ($n=6$)

meatballs, but they did not prevent redness fading during storage. This trend is consistent with the results of Fernández-López et al. (2003) and Ahn et al. (2007) who reported that a^* values decreased during refrigerated storage of cooked pork and beef. In the present study, colour redness was more stable in samples with additives (SE, OR, MIX) stored under a gas mixture (20% CO₂/80% N₂) than in those stored under vacuum. This partially agrees with the findings of Rubio et al. (2008) who demonstrated that a^* values were more stable in meat products stored under modified atmosphere (20% CO₂/80% N₂) than in vacuum-packaged ones.

Due to the more intense colour of rosemary extract, turkey meatballs had lower L* and a^* values during storage which resulted in their darker colour. A possible browning reaction in rosemary could also contribute to the above colour change. According to Dogan and Dogan (2004), polyphenol oxidase enzymes, widespread in many plants, are responsible for browning. In the presence of oxygen these enzymes oxidise plant phenolic compounds to corresponding quinones, which then condense to form dark-coloured compounds.

The yellowness of vacuum-packaged turkey meatballs was affected by both additives and storage time (Table 3). The samples with additives (SE, OR, MIX) were characterized by higher b^* values than control (C) samples. The yellowness values of C, SE and OR samples showed an increasing tendency until 20 days of vacuum storage, and a decrease was observed at the end of storage. During vacuum storage, the b^* values of MIX samples did not change significantly ($P>0.05$). No significant ($P>0.05$) differences in yellowness were observed between MAP samples, and b^* values were affected only by the time of storage (Table 3). After 10 days of MA storage, the b^* values of SE samples increased significantly ($P<0.05$) and they remained at a similar level during further storage.

Microbiological quality

The results of microbial analysis of the turkey meatballs are shown in Table 4. Mesophilic bacteria counts were 10³–10⁴ cfu/g and 10³–10⁵ cfu/g in raw samples from

Table 4 Effect of thermal processing and storage on the microbiological load (log cfu/g) of turkey meatballs with different additives, vacuum and modified atmosphere packaging ($n=3$)

Microorganism	Type of samples	Raw	After thermal processing	After 15 days of storage	After 30 days of storage
Vacuum packaging- Experiment I					
Total mesophilic	C	1.8×10^4	2.4×10^3	1.0×10^3	1.5×10^3
	SE	7.8×10^3	2.0×10^2	1.0×10^2	2.0×10^3
	OR	5.0×10^3	1.8×10^2	90	4.8×10^2
	MIX	2.8×10^3	9.8×10^2	2.0×10^2	3.0×10^2
Total psychrotrophic	C	1.2×10^4	1.1×10^2	2.5×10^2	1.8×10^2
	SE	2.0×10^2	<100	<100	<10
	OR	9.8×10^2	<100	<100	<10
	MIX	6.0×10^2	<100	<100	<10
Fungi	C	30	<10	<10	<10
	SE	20	<10	<10	<10
	OR	20	<10	<10	<10
	MIX	10	<10	<10	<10
Coliforms	C	<10	<10	<10	<10
	SE	<10	<10	<10	<10
	OR	<10	<10	<10	<10
	MIX	<10	<10	<10	<10
Modified atmosphere packaging (20% CO ₂ /80% N ₂) – Experiment II					
Total mesophilic	C	1.0×10^5	1.0×10^3	3.0×10^4	1.0×10^6
	SE	2.0×10^4	1.2×10^2	30	9.2×10^2
	OR	9.4×10^3	3.0×10^2	30	7.6×10^3
	MIX	7.0×10^4	2.0×10^2	58	4.0×10^3
Total psychrotrophic	C	2.8×10^4	1.0×10^2	1.5×10^3	9.6×10^4
	SE	6.0×10^2	<10	<10	2.0×10^2
	OR	4.0×10^2	<10	<10	<10
	MIX	5.2×10^2	<10	<10	<10
Fungi	C	10	<10	<10	<10
	SE	20	<10	<10	<10
	OR	<10	<10	<10	<10
	MIX	20	<10	<10	<10
Coliforms	C	20	<10	<10	<10
	SE	30	<10	<10	<10
	OR	<10	<10	<10	<10
	MIX	20	<10	<10	<10

ND none detected

C control, SE with sodium erythorbate, OR with rosemary oil extract, MIX with mixture of sodium erythorbate and rosemary oil extract

experiment I and experiment II, respectively. Thermal processing caused a reduction in the counts of these bacteria to 10^2 – 10^3 cfu/g. The counts of mesophilic bacteria did not change during vacuum storage of C and MIX samples. After 15 days of vacuum storage of SE samples, the counts of these bacteria did not change, but after 30 days of storage their population increased to 10^3 cfu/g. Samples treated with oil-soluble rosemary extract (OR) were characterized by the lowest count of mesophilic bacteria after 15 days of storage (90), which increased to 10^2 cfu/g after 30 days of storage. During MA storage, the counts of mesophilic bacteria increased gradually only in control (C) samples (to 10^6 cfu/g). The counts of mesophilic micro-organisms in samples with additives

(SE, OR, MIX) were below 100 cfu/g after 15 days of MA storage, and they increased to 10^2 – 10^3 cfu/g after 30 days of storage. Aerobic plate counts determined after 0, 15 and 30 days of storage of cooked turkey meatballs indicated their acceptable quality, since the limit of acceptability for poultry products is 10^7 cfu/g (Ntzimani et al. 2010). Notermans et al. (1993) reported a good correlation between shelf-life and the time taken for the mesophilic micro-organism count to reach 10^6 cfu/g. The present results show that turkey meatballs with additives (SE, OR, MIX) were characterized by lower counts of mesophilic bacteria during storage. An analysis performed after 15 days of storage revealed that modified atmosphere packaging was in this respect more effective than vacuum packaging

(except for OR samples). In control (C) turkey meatballs the count of mesophilic micro-organisms was lower in samples stored under vacuum than in those stored under modified atmosphere. García-Esteban et al. (2004) did not observe clear differences in the microbiological stability of dry-cured ham slices stored under vacuum and gas mixture (20% CO₂/80% N₂), although at 8 weeks mesophilic aerobic colonies slightly increased with regard to initial counts in vacuum-packaged samples whereas a decrease was found in samples packaged under 20% CO₂+80% N₂. According to Rubio et al. (2006), from the microbiological point of view gas mixture (20% CO₂/80% N₂) was more effective than vacuum packaging in extending the shelf-life of dry-cured “Cecina de Lone” slices.

Microbiological spoilage of raw and processed poultry products is caused largely by psychrotrophic bacteria (Ismail et al. 2000). The counts of psychrotrophic bacteria in raw turkey meatballs were 10⁴ cfu/g in control (C) samples and 10² cfu/g in samples with additives (SE, OR, MIX). As a result of cooking, the population size of psychrotrophic bacteria decreased to 10² in control samples, and it dropped below 100 cfu/g in samples with additives (SE, OR, MIX) assigned to VP and below 10 cfu/g in samples assigned to MAP. The count of psychrotrophic bacteria in control samples (C) remained at the same level during vacuum storage and showed a rising tendency during MA storage (to 10⁴ cfu/g). During vacuum storage all samples with additives (SE, OR, MIX) were characterized by low counts of psychrotrophic bacteria. In MA-packaged OR and MIX samples their count did not change during storage, and in SE samples it increased to 10² cfu/g after 30 days of storage.

The presence and numbers of yeasts and moulds in poultry meat and processed poultry products are important considerations while developing technologies to retard poultry meat spoilage. In the present experiments fungal and coliform contamination levels in raw turkey meatballs were not high (<100 cfu/g), and their population size decreased during thermal processing to <10 and no fungal and coliform growth was noted over refrigerated storage. Turkey meatballs were free of sulphate reducing *Clostridia* sp. (data not shown).

Presumably, the additives and storage time affected the counts of mesophilic and psychrotrophic bacteria. Sodium erythorbate (SE), oil-soluble rosemary extract (OR) and their mixture (MIX) had an inhibitory effect on mesophilic bacteria during 15 days of modified atmosphere storage, while during vacuum storage this effect was exerted only by OR. All additives (SE, OR, MIX) inhibited the growth of psychrotrophic bacteria during the preparation (manufacturing) and vacuum and MA storage of turkey meatballs, although in samples stored under modified atmosphere sodium erythorbate (SE) prevented their growth for a

shorter time. These results seem to be in agreement with those reporting the antimicrobial properties of rosemary extract (Campo et al. 2000; Djenane et al. 2002; Fernández-López et al. 2005; Ntzimani et al. 2010) and sodium erythorbate (Barringer et al. 2005; Karpińska-Tymoszczyk 2006). Some researchers found that the most apolar phenolic compounds from rosemary extracts are presumably responsible of their antibacterial activity (Campo et al. 2000; Karamanoli et al. 2000). Schulz et al. (as cited Martínez et al. 2006) suggested that the antimicrobial activity of polyphenols may result from their interaction with bacterial enzymes and proteins.

Sensory quality

Flavour is one of the most important factors influencing the eating quality of meat and consumer decisions. The results of a sensory evaluation of turkey meatballs during storage under vacuum and modified atmosphere are shown in Tables 5 and 6. Initially (storage time zero) OR samples were characterized by lower intensity of meaty and typical of poultry meat flavours than the other samples, and their intensity did not change significantly ($P>0.05$) during vacuum and modified atmosphere storage. The intensity of these flavours in C, SE and MIX samples decreased significantly ($P<0.05$) during vacuum and modified atmosphere storage. The fatty flavour was perceived at a very low level in all investigated samples regardless of storage conditions. No significant ($P>0.05$) differences were observed between samples as the time of storage was prolonged. In both experiments the additives influenced the intensity of aromatic flavour. Immediately after heat treatment of meatballs destined for vacuum storage, significantly ($P<0.05$) higher intensity of this flavour was determined in samples containing oil-soluble rosemary extract (OR) and a mixture of oil-soluble rosemary extract and sodium erythorbate (MIX), compared with control (C) samples. Among samples destined for MAP storage, OR samples received higher scores for aromatic flavour in comparison with control samples. The intensity of aromatic flavour decreased significantly ($P<0.05$) in all samples during vacuum storage as well as in SE and OR samples stored under modified atmosphere conditions. OR samples were marked by higher intensity of this flavour than C, SE and MIX samples. Before packaging all samples showed similar intensity of typical of roasted meat flavour whose intensity decreased gradually during storage in vacuum-packaged C and OR samples and in MA-packaged C and SE samples. During storage, samples with oil-soluble rosemary extract (OR) and with a mixture of sodium erythorbate and oil-soluble rosemary extract (MIX) had a strong and slight rosemary flavour, respectively. In the present experiments, WOF appeared only in control (C)

Table 5 Sensory attributes of vacuum-packaged turkey meatballs

Flavour/Sort of samples	Storage time [days]						
	0	5	10	15	20	25	30
Meaty							
C	4.0±0.00 ^{cB}	4.2±0.29 ^{cB}	4.0±0.00 ^{cB}	4.0±0.00 ^{cB}	3.7±0.29 ^{bB}	3.0±0.00 ^{abA}	2.7±0.58 ^{aA}
SE	4.0±0.00 ^{bB}	4.0±0.00 ^{bB}	4.0±0.00 ^{bB}	4.0±0.00 ^{bB}	4.0±0.00 ^{bB}	4.0±0.00 ^{bB}	3.7±0.29 ^{abB}
OR	3.3±0.29 ^A	3.2±0.29 ^A	3.0±0.00 ^A	3.0±0.00 ^A	3.0±0.00 ^A	3.0±0.00 ^A	3.0±0.00 ^{AB}
MIX	4.0±0.00 ^{bB}	3.8±0.29 ^{bB}	4.0±0.00 ^{bB}	4.0±0.00 ^{bB}	4.0±0.00 ^{bB}	4.0±0.00 ^{bB}	3.3±0.29 ^{abAB}
Typical of poultry meat							
C	5.0±0.00 ^b	4.3±0.29 ^{abAB}	4.3±0.29 ^{abB}	4.3±0.29 ^{abB}	4.0±0.50 ^{ab}	3.3±0.58 ^{abAB}	3.3±0.58 ^a
SE	5.0±0.00 ^b	4.3±0.29 ^{abAB}	4.3±0.29 ^{abB}	4.2±0.29 ^{abAB}	4.2±0.29 ^a	4.2±0.29 ^{abB}	3.7±0.58 ^a
OR	4.0±0.00	3.8±0.29 ^A	3.3±0.58 ^A	3.3±0.58 ^A	3.3±0.58	3.2±0.29 ^A	3.7±0.29
MIX	5.0±0.00 ^c	4.5±0.00 ^{bB}	4.2±0.29 ^{abAB}	4.2±0.29 ^{abAB}	4.0±0.00 ^a	4.0±0.00 ^{abAB}	4.0±0.00 ^a
Fatty							
C	0.7±0.58	0.7±0.58	0.7±0.58	0.7±0.58	1.0±0.00	1.0±0.00	1.0±0.00
SE	0.7±0.58	0.7±0.58	0.7±0.58	0.7±0.58	1.0±0.00	1.0±0.00	1.0±0.00
OR	0.7±0.58	0.7±0.58	0.7±0.58	0.7±0.58	1.0±0.00	1.0±0.00	1.0±0.00
MIX	0.7±0.58	0.7±0.58	1.0±0.00	1.0±0.00	1.0±0.00	1.0±0.00	1.0±0.00
Aromatic							
C	3.5±0.00 ^{bA}	3.0±0.00 ^{abA}	3.2±0.29 ^{abA}	3.2±0.29 ^{abA}	3.2±0.29 ^{abA}	2.7±0.58 ^{abA}	2.3±0.58 ^{aA}
SE	3.8±0.29 ^{bAB}	3.0±0.00 ^{abA}	3.8±0.29 ^{bB}	3.3±0.29 ^{abA}	3.2±0.29 ^{abA}	3.0±0.00 ^{abA}	2.7±0.58 ^{aA}
OR	4.5±0.00 ^{bC}	4.5±0.00 ^{bB}	4.5±0.00 ^{bC}	4.0±0.00 ^{ab}	4.0±0.00 ^{ab}	4.0±0.00 ^{ab}	4.0±0.00 ^{ab}
MIX	4.2±0.29 ^{cBC}	4.0±0.00 ^{cB}	4.0±0.00 ^{cBC}	3.3±0.29 ^{bA}	3.5±0.00 ^{bAB}	3.0±0.00 ^{aA}	3.0±0.00 ^{abAB}
Typical of roasted meat							
C	3.5±0.00 ^c	3.5±0.00 ^c	3.0±0.00 ^{bcA}	3.0±0.00 ^{bcA}	3.0±0.00 ^{bcA}	2.7±0.58 ^{abA}	2.2±0.29 ^{aA}
SE	3.5±0.00	3.3±0.29	3.0±0.00 ^A	3.0±0.00 ^A	3.0±0.00 ^A	3.2±0.28 ^B	3.3±0.29 ^B
OR	3.7±0.29 ^b	3.3±0.29 ^{ab}	3.0±0.00 ^{aA}	3.0±0.00 ^{aA}	3.0±0.00 ^{aA}	3.0±0.00 ^{abAB}	2.8±0.29 ^{abAB}
MIX	3.8±0.29	3.8±0.29	3.7±0.29 ^B	3.7±0.58 ^B	3.7±0.29 ^B	3.7±0.29 ^B	3.5±0.50 ^B
Spices							
C	NE	NE	NE	NE	NE	NE	NE
SE	NE	NE	NE	NE	NE	NE	NE
OR	4.0±0.00 ^B	3.7±0.00 ^B	4.0±0.00 ^B	3.8±0.29 ^B	3.7±0.29 ^B	4.0±0.00 ^B	4.0±0.00 ^B
MIX	2.0±0.00 ^A	2.0±0.00 ^A	2.0±0.00 ^A	2.0±0.00 ^A	2.0±0.00 ^A	1.7±0.58 ^A	1.7±0.58 ^A
WOF							
C	0.0	0.0	0.0	1.0±0.00	2.0±0.00	2.3±0.58	2.7±0.58
SE	0.0	0.0	0.0	0.0	1.0±0.00	1.0±0.00	1.0±0.00
OR	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MIX	0.0	0.0	0.0	0.0	0.0	0.0	0.0

NE not estimated

C control, SE with sodium erythorbate, OR with rosemary oil extract, MIX with mixture of sodium erythorbate and rosemary oil extract

^{a,b,c} Values with different superscripts in a row differ significantly ($P<0.05$) ($n=10$)^{A,B,C} Values with different superscripts in a column differ significantly ($P<0.05$) ($n=10$)

samples and in samples with sodium erythorbate (SE). It was detected at a later stage of storage under MA, compared with vacuum storage. Its intensity in samples with sodium erythorbate (SE) was described as hardly noticeable. In control (C) samples WOF was hardly noticeable after 15 days of vacuum storage and after 20 days of MA storage. WOF intensity increased during

subsequent storage periods, and after 30 days of vacuum and MA storage it was moderately and slightly noticeable, respectively. Oil-soluble rosemary extract (OR) and a mixture of sodium erythorbate and oil-soluble rosemary extract (MIX) were effective in slowing down WOF development. The addition of sodium erythorbate (SE) alone retarded WOF occurrence.

Table 6 Sensory attributes of modified atmosphere-packaged turkey meatballs

Flavour/Sort of samples	Storage time [days]						
	0	5	10	15	20	25	30
Meaty							
Control	4.3±0.29 ^{cB}	4.3±0.29 ^{cB}	4.2±0.29 ^c	4.0±0.00 ^{bcB}	4.0±0.00 ^{bcB}	3.3±0.58 ^{ab}	3.0±0.00 ^a
SE	4.0±0.00 ^{bAB}	4.0±0.00 ^{bAB}	4.0±0.00 ^b	4.0±0.00 ^{bbB}	4.0±0.00 ^{bbB}	3.3±0.58 ^a	3.0±0.00 ^a
OR	3.7±0.29 ^A	3.3±0.58 ^A	3.5±0.50	3.2±0.29 ^{aA}	3.0±0.00 ^A	3.0±0.00	3.0±0.00
MIX	4.0±0.00 ^{cAB}	4.0±0.00 ^{cAB}	4.0±0.00 ^c	4.0±0.00 ^{cB}	3.5±0.00 ^{bbB}	3.2±0.28 ^a	3.0±0.00 ^a
Typical of poultry meat							
Control	4.3±0.29 ^{cB}	4.3±0.29 ^{cB}	4.3±0.29 ^{cB}	4.2±0.29 ^{bcB}	4.2±0.29 ^{bcC}	3.3±0.58 ^{ab}	3.0±0.00 ^a
SE	4.3±0.29 ^{cB}	4.2±0.29 ^{bcAB}	4.2±0.29 ^{bcB}	4.2±0.29 ^{bcB}	4.0±0.00 ^{bcBC}	3.3±0.58 ^{ab}	3.0±0.00 ^a
OR	3.5±0.00 ^A	3.3±0.58 ^A	3.3±0.29 ^A	3.2±0.29 ^A	3.2±0.29 ^A	3.2±0.29	3.0±0.00
MIX	4.3±0.29 ^{cB}	4.2±0.29 ^{cAB}	4.2±0.29 ^{cB}	4.0±0.00 ^{bcB}	3.7±0.29 ^{abcAB}	3.3±0.29 ^{ab}	3.2±0.29 ^a
Fatty							
Control	0.7±0.58	1.0±0.00	1.0±0.00	0.7±0.58	1.0±0.00	0.7±0.58	1.0±0.00
SE	0.7±0.58	0.7±0.58	0.7±0.58	0.7±0.58	1.0±0.00	1.0±0.00	1.0±0.00
OR	0.7±0.58	0.7±0.58	0.7±0.58	0.7±0.58	1.0±0.00	1.0±0.00	1.0±0.00
MIX	0.7±0.58	0.7±0.58	0.7±0.58	0.7±0.58	1.0±0.00	1.0±0.00	1.0±0.00
Aromatic							
Control	3.3±0.00 ^A	3.0±0.00 ^A	3.0±0.00 ^A	3.0±0.00 ^A	2.8±0.29	2.5±0.50	2.5±0.50
SE	3.8±0.00 ^{cAB}	3.8±0.29 ^{cB}	3.3±0.29 ^{bcA}	3.2±0.29 ^{bcA}	3.2±0.29 ^{bc}	3.0±0.00 ^{ab}	2.3±0.29 ^a
OR	4.5±0.29 ^{bbB}	4.2±0.29 ^{abB}	4.0±0.00 ^{abB}	4.0±0.00 ^{abB}	3.7±0.29 ^{ab}	3.3±0.58 ^a	3.3±0.29 ^a
MIX	4.0±0.00 ^{AB}	4.0±0.00 ^B	4.0±0.00 ^B	4.0±0.00 ^B	3.0±1.00	3.0±1.00	3.0±1.00
Typical of roasted meat							
Control	4.0±0.00 ^c	3.8±0.29 ^c	3.8±0.29 ^{cB}	3.8±0.29 ^c	3.7±0.29 ^{bc}	3.0±0.00 ^{ab}	2.5±0.50 ^{aA}
SE	4.0±0.00 ^c	4.0±0.00 ^c	3.7±0.29 ^{bAB}	3.3±0.58 ^{bc}	3.3±0.29 ^{bc}	3.0±0.00 ^{ab}	2.3±0.58 ^{aA}
OR	3.5±0.50	3.5±0.50	3.2±0.29 ^A	3.3±0.29	3.3±0.58	3.3±0.58	2.7±0.29 ^{AB}
MIX	4.0±0.00	4.0±0.00	4.0±0.00 ^B	4.0±0.00	3.3±0.58	3.3±0.58	3.3±0.29 ^B
Spices							
Control	NE	NE	NE	NE	NE	NE	NE
SE	NE	NE	NE	NE	NE	NE	NE
OR	3.8±0.29 ^{bbB}	4.0±0.00 ^{bbB}	4.0±0.00 ^{bbB}	4.0±0.00 ^{bbB}	4.0±0.00 ^{bbB}	3.3±0.28 ^{abB}	3.0±0.00 ^{abB}
MIX	2.0±0.00 ^A	2.0±0.00 ^A	2.0±0.00 ^A	2.0±0.00 ^A	2.0±0.00 ^A	1.7±0.58 ^A	1.7±0.58 ^A
WOF							
Control	0.0	0.0	0.0	0.0	1.0±0.00	2.0±0.00	2.0±0.00
SE	0.0	0.0	0.0	0.0	0.0	0.0	1.0±0.00
OR	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MIX	0.0	0.0	0.0	0.0	0.0	0.0	0.0

NE not estimated

C control, SE with sodium erythorbate, OR with rosemary oil extract, MIX with mixture of sodium erythorbate and rosemary oil extract

^{a,b,c} Values with different superscripts in a row differ significantly ($P<0.05$) ($n=10$)^{A,B} Values with different superscripts in a column differ significantly ($P<0.05$) ($n=10$)

The present study shows that the addition of oil-soluble rosemary extract (OR), alone and with sodium erythorbate (MIX), influenced the flavour attributes of turkey meatballs and contributed to their better quality during storage. These results agree with the findings of other authors. Liu et al. (2009) showed that fresh chicken sausages containing rosemary tended to have higher aroma scores, and that the

additive retarded the development of off-odour produced by fat oxidation. According to Fernández-López et al. (2005), the application of rosemary extract could be useful in controlling rancidification and off-flavours in meat products. Ntzimani et al. 2010 demonstrated that the addition of rosemary preserved the taste and odour of cooked chicken fillets during vacuum storage.

In the present work samples stored under gas mixture (20%CO₂/80% N₂) were characterized by a better sensory quality than vacuum-packaged ones. 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% CO₂/70% N₂). Rubio et al. (2006) found that vacuum-packaged cured beef slices had a better sensory quality and could be stored over a longer period of time than gas-packaged (20%CO₂/80% N₂) slices.

Conclusion

This study concluded that natural oil-soluble rosemary extract, applied alone or with sodium erythorbate, was more effective in inhibiting lipid oxidation in turkey meatballs than sodium erythorbate. Smaller changes in lipid oxidation were noted during vacuum storage. All additives stabilized the redness of turkey meatballs stored under modified atmosphere and showed antimicrobial activity, which was more pronounced in MA-packaged samples than in vacuum-packaged ones. Turkey meatballs with oil-soluble rosemary extract and with a mixture of sodium erythorbate and oil-soluble rosemary extract were characterized by a better sensory quality than control samples and samples with sodium erythorbate. Samples stored under gas mixture (20% CO₂/80% N₂) showed a better sensory quality than vacuum-packaged ones. As indicated by the present results, oil-soluble rosemary extract clearly provides an alternative to synthetic antioxidants to extend the shelf-life of cooked turkey meatballs.

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