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# Combined Effect of Electrical Stimulation and High-Oxygen Modified Atmosphere Packaging on the Sensorial Characteristics and Shelf-Life of Low-Fat Turkish Type Meatballs (Kofte)

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**Abstract:** Kofte is a common meat product consumed traditionally in Turkey. Electrical Stimulation (ES) and high-oxygen Modified Atmosphere Packaging (MAP) are used to improve the quality properties of meat and meat products. This study was aimed to investigate whether the beneficial effect of ES still continues in processed meat and to search the effect of MAP on the quality characteristics (microbial loads, pH, water activity, thiobarbituric acid reactive substances value, instrumental texture and color, sensory analysis) and shelf-life of low-fat Turkish type meatballs. For this purpose, electrically stimulated (500 V, 50 Hz, 60 and 120 sec) meats were used to prepare the meatballs which were packaged under high-oxygen modified atmosphere (70%, $O_2$/30%, $CO_2$) and meatballs were examined during storage (4°C). MAP resulted in increase in shelf-life of meatballs upon the 6th day and ES improved the quality criteria of meatballs by improving the sensorial properties.

**Key words:** Meatball, electrical stimulation, modified atmosphere packaging, shelf-life, sensorial characteristics

## INTRODUCTION

Turkish style meatballs (kofte) are produced mainly using ground meat (beef and/or lamb), fat (beef and/or lamb tallow fat), various spices and/or moistened bread and called by different names depending on the local area manufactured in Turkey (Adana kofte, Tekirdag kofte, Inegol kofte, etc.) (Serdaroglu and Degirmencioglu, 2004; Ulu, 2004).

The amount of fat in ground meat products plays an important role in determining the quality and the acceptability of the product. As fat level decreases in beef patties, tenderness, juiciness and flavor ratings decrease and shear force increases (Serdaroglu and Degirmencioglu, 2004; Ulu, 2006).

Electrical Stimulation (ES) is a procedure that depends on electric current passing through hot carcass immediately after slaughtering (Nazli *et al*., 2010). It is an innovation being used in the meat industry to increase tenderness of meat by contracting muscles and increasing the rate of glycogen usage (Pearce *et al*., 2009). ES eliminates the risk of cold shortening by accelerating rigor mortis and consequently improves the quality criteria such as color, texture and flavor (Nazli *et al*., 2010). Other benefits of ES include increased firmness of lean brighter lean color and earlier development of marbling (Savell *et al*., 1978). Moreover, it is reported that ES reduces the microbial count and increases the shelf-life of stored meat (Biswas *et al*., 2007).

Modern meat packaging techniques are intended to maintain microbial and sensorial qualities of the product (Hotchkiss, 1988). Modified Atmosphere Packaging (MAP) is nowadays a common means of retail sale display in supermarkets. The key to the success of this packaging method for fresh meat and meat products is its ability to extend the quality and shelf-life of the product by reducing microbial growth while maintaining the attractive oxymyoglobin bright-red color which is preferable for consumers (Parry, 1993; Church and Parson, 1995). There are several reports published according to the beneficial effects of MAP related with ground beef (Jayasingh *et al*., 2002; Seydim *et al*., 2006; Mancini *et al*., 2010; Suman *et al*., 2010) and now a days, high oxygen MAP (70-80%, $O_2$/20-30%, $CO_2$) is a widely used combination in industry to maintain an attractive color in meat products (Bingol and Ergun, 2011; Resconi *et al*., 2012).

This study was performed to investigate whether the beneficial effect of ES still continues in processed meat (kofte) and to search the effect of high-oxygen MAP on the sensorial characteristics and shelf-life of low-fat Turkish type meatballs.

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## MATERIALS AND METHODS

**Sampling of muscles:** For investigating the effects of ES, 24 beef at 3 years of age were processed by the approval of the Ethic Committee of the Istanbul University, Turkey (Approval number: 58/26.05.2011). After slaughtering, at approximately 30-45 min of the post-mortem period, one of the 1/2 carcasses were electrically stimulated with high voltage (17 impulses (1.8 sec duration each with a 1.8 sec interval between pulses) at 500 V (AC), 2.5 amps and 50 Hz for 60 and 120 sec applications) and the other one was kept as Non-Stimulated control (NES). During the first 24 h carcasses were held at the cold chain (4°C) and at the end of the 1st day samples were taken from the back (M. longissimus dorsi-LD) and thigh (M. Semimembranosus-SM) muscles of splitted carcasses. Muscle samples were examined according to their textural and sensorial characteristics (Nazli *et al*., 2010) at the 1st and 3rd day of the ripening period and overall scores were used for the designation of manufactured meatball groups.

**Manufacturing of meatballs:** Muscles were initially divided into 3 groups according to the treatmentapplied ($ES_{60}$, $ES_{120}$, NES) then they were separated into 2 sub-groups according to the muscle types (LD/SM) resulting finally in 6 sub-groups. Each sub-group was designed to have at least 3 similar sensorial characteristic beef meat for each repetition of manufacturing. Muscles were then finely ground through a 3.2 mm plate in a meat grinder (Biro Meat Grinder, Marblehead, OH, USA) and collected in a sterile container for the experimental meatball production. Meatballs were produced according to the following traditional recipe (Colak *et al*., 2008). Ground veal (84%) which contains 10% fat (low-fat) was mixed with ground black pepper (0.1%), cumin (0.4%), red pepper (2.0%), onion rind (3.0%), garlic clove rind (0.5%), salt (2.0%) and toasted bread crumbs (8.0%). The mix was kneaded for 30 min by hand (with sterile glove) to obtain a homogeneous dough then shaped by a filling machine into 2 cm diameter with a length of 8 cm and weight of 24-28 g. The experimental meatballs were manufactured at room temperature in triplicate for each group.

**Packaging of meatballs:** Meatballs were placed in low $O_2$ permeable (8-12 $cm^3/m^2$/24 h at STP) Polystyrene/Ethylvinylalcohol (EVOH)/polyethylene (PE) trays and were over-wrapped with oxygen permeable (6000-8000 $cm^3/m^2$/24 h at STP) polyvinyl-chloride film (Wrap Film Systems Ltd. Shropshire, UK) for aerobic packaging. The other part of meatballs were heat-sealed with a Multivac packaging unit (Multivac A300/16, Wolfertschwenden, Germany) within these trays using a low $O_2$ permeable (3 $cm^3/m^2$/24 h) lidding film (20 mm of a laminate orientated polypropylene and a co-extrusion layer (50 mm) of PE/EVOH/PE) for MAP using a gas mixture of 70% $O_2$/30% $CO_2$. Packages were stored at refrigerator temperature (4°C) for 9 days and examined at intervals of 0 (3 h after packaging) 3, 6 and 9 days of storage for microbiological, physicochemical and sensorial analysis.

**Gas analyses:** The headspace ratio of packages was approximately 1:2. Gas analyses of internal atmosphere were done in duplicate at day 0, 3, 6 and 9 throughout the storage periods. Gas analyses of $CO_2$, $O_2$ and $N_2$ within the packages were monitored by injecting 0.5 mL of gas removed from the headspace with a syringe (B-Braun, Germany) into a PDI gas chromatograph (PBI-Dansensor, Ringsted, Denmark) fitted with a thermal conductivity detector.

**Microbiological analyses:** About 25 g of meatball from each group was transferred to a sterile bag with 250 mL sterile peptone water (Oxoid, CM0009, Hampshire, UK) and was homogenized for 90 sec using a stomacher (LabBlender 400, Steward Lab., London, UK). Serial decimal dilutions were prepared using the same diluents. A 0.1 or 1 mL inoculum of appropriate dilutions was spread on Plate Count Agar (PCA, Oxoid, CM0325, Hampshire, UK); pour plates incubated at 35°C for 48 h for Total Aerobic Plate Counts (TAPC) and at 7°C for10 days for total psychrophilic bacteria (Harrigan, 1998).

Lactic Acid Bacteria (LAB) counts were determined by plating with overlay on de Man, Rogosa, Sharpe agar (MRS, Oxoid, CM0361) and incubating at 35°C for 48 h (Davidson and Cronin, 1973), *Pseudomonas* sp. were enumerated on Pseudomonas agar with Cetrimid, Fucidin, Cephaloridin supplement (PA with CFC, Oxoid, CM0559 and SR0103) on spread plates were incubated at 25-30°C for 48 h. Enterobacteriaceae were examined in Violet Red Bile Glucose agar (VRB, Oxoid, CM0485) by using pour plates with overlay added before incubation with incubation at 35°C for 24 h. Yeast and mould were defined on Dichloran Rose Bengal Chloramphenicol agar with Chloramphenicol Selective supplement (DRBC, Oxoid, CM0727 and SR0078). Spread plates were incubated at 25°C for 3-5 days (Harrigan, 1998). All microbiological tests were carried out in duplicate and the results expressed as log CFU/g.

**Physicochemical and sensorial analyses**

**Determination of pH:** The pH of meatballs was measured at 0, 3, 6 and 9 day of storage respectively using a portable pH-meter (WTW 340i, Weilheim, Germany) by calculating the mean of three measures in each sample (AOAC, 1990).

**Determination of water activity ($a_w$):** Water activity measurement was carried out using a water activity meter (Decagon AquaLab Series 4TE, USA) at room temperature (AOAC, 1990).

**Determination of Thiobarbituric Acid Reactive Substances (TBARS) value:** About 20 g of the meatball sample was mixed with 50 mL of 20% trichloroacetic acid in 2 M phosphoric acid solution at 4°C and it was homogenized by ultra-turrax (ART Miccra RT, Germany) for 1.5 min. It was diluted with deionised water to make 100 mL and then filtered 0.5 mL of the filtrate was mixed with 5 mL of freshly prepared 0.005 M thiobarbituric acid solution in a stopper fitted glass tube. It was mixed simply by inverting the tube several times and then kept in dark for 15 h at room temperature. Finally, the absorbance of the color developed was measured at 530 nm using UV visual spectrophotometer (Chebios Optimum-One, Germany). The TBARS value was calculated as following equation:

$$\text{TBARS value} = \left(\frac{\text{Absorbance-0.0121}}{0.1379}\right)\times \left(\frac{72.06}{94}\right)\text{mg MDA/kg meatball}$$

Results were calculated according the percentage of Malondialdehyde (MDA) which has a molecular weight of 72.06 (Shrestha and Min, 2006).

**Instrumental color measurement:** The averaged surface color of meatballs at five different locations on each sample were determined at each sampling day immediately after opening each package in terms of CIE L*, a*, b* values using color difference meter (Colorflex HunterLab Spectrophotometer, Reston, VA, USA). Color was evaluated using a diffuse illumination (D65 2° observer) with 8 mm viewing aperture and a 25 mm port size with the specular component excluded. All instrumental measurements were done before and after cooking in a kitchen type oven (Siemens, Germany) at 200°C for 10 min (AMSA, 1991).

**Instrumental texture measurement:** Four 2 cm diameter with a length of 8 cm meatball of each package were placed as raw and cooked in Instron Texture Analyzer Model 3343 device (UK) equipped with a Warner-Bratzler shear force system. Shear force was perpendicular to the length of meatballs and force required to shear was recorded in kilograms. For each sample, a mean value was calculated and used for statistical analysis (Nazli *et al*., 2010).

Table 1: Definition of the attributes used in the sensory analysis of meatballs

| Attribute | Definition |
|---|---|
| Red-color | Clear, strong red color |
| Off-odor | Formation of undesirable odor |
| Hardness | The force required to bite through the sample |
| Tenderness | Time and numbers of chewing required to masticate the sample ready for swallowing |
| Fattiness | Fatty feeling in the mouth |
| Juiciness | Perception of water content in the sample after 3-4 chewing |
| Flavor intensity | Level of the overall flavor in the mouth |
| Flavor quality | Flavor experienced prior to swallowing |
| General appearance | Overall liking from the panelists |

**Sensory analysis:** Sensorial attributes were evaluated by eight well-experienced panelists, staff of Istanbul University, Food Hygiene and Technology Department (3 females and 5 males) who were selected for their sensory ability and earlie trained in descriptive analysis for meat and meat products (ISO 8586-1, 1993). The assessors were requested to score the intensity perceived for each sensory attribute (red-color, off-odor, hardness, tenderness, fattiness, juiciness, flavor intensity, flavor quality and general appearance acceptability) using an unstructured 10-point line scales (1: dislike extremely and 10: like extremely) (Cross *et al*., 1978).

The assessors were trained in two separate sessions approximately 2 h for the evaluation of selected attributes (Table 1). Training sessions were conducted to acquaint panelists with the products and attributes to be evaluated and were followed by an open-discussion session to familiarize panelists with the attributes and the scale to be used.

Samples chosen for sensory analyses were cooked in a kitchen type oven (Siemens, Germany) at 200°C until the internal temperature reached 80°C. Meatballs were stored in the oven at 60°C until they were served to panelists.

The panelists were seated in individual booths in a temperature-controlled and light-controlled room (fluorescent lighting of 2000 lx; Philips 40W Cool White) receiving a set of 12 samples (with 3 samples of in each plate, either for LD and/or SM) served in a complete randomized order. Each sample was labeled at random with a two-digit code number. Unsalted crackers and water were served to panelists to freshen their mouth between each sub-samples assessment (ISO 8586-1, 1993). Sensory panel was carried out triplicate in two sessions.

**Statistical analysis:** In order to determine the effects of ES and packaging, General Linear Model procedure (PROC GLM) of SPSS 16.0 program was used in the statistical analyzes of meatballs (SPSS, 2008). Least squares procedures were used to analyze data values including the fixed effects of ES, muscle types, storage

time, packaging and cooking conditions. The significant two-way interactions between these main effects and the effect of panelists for sensory characteristics were also added in the final mathematical model where significance of differences was defined as $p<0.05$.

## RESULTS AND DISCUSSION

**Headspace composition:** The actual headspace gas composition in the MAP was 70.1% $O_2$, 29.6% $CO_2$ and 0.3% residual air. A minimal shift was observed in headspace composition for ground beef under MAP condition >9 days' storage. Esmer *et al.* (2011) stated that the gas composition of each package of minced meat changed significantly within storage period ($p = 0.05$) as $O_2$ concentration decreased and $CO_2$ concentration increased in the packages starting from the 1st day of storage, similarly with the present study. They indicated also that this change was more evident in air packaged samples than MAP samples which contain less $O_2$ concentrations. Additionally, O'Grady *et al.* (2000) determined that relative changes in gaseous atmospheres within MA-packages were higher at a lower oxygen level. This attitude is well-known by the non-static gaseous environment within a MA-package which may be related to the microbial growth, the permeability of packaging material and respiration of the product or the gas absorption by the food (Esmer *et al.*, 2011).

**pH:** The average initial pH of all meatball samples was 5.9 while it was 6.12 at the end of the storage. There was a significant difference between the groups at the 1st day of storage ($p<0.05$) but no difference was observed in other storage times and muscle types ($p>0.05$). The statistically difference was more significant on the packaging types throughout the storage time ($p<0.001$, Table 2).

Jayasingh *et al.* (2002) stated that high-oxygen (80% $O_2$/20% $CO_2$) and air packaged ground beef had significant pH differences, especially after 10 days of storage at 2°C decreasing from 5.7-5.3 for air and 5.8-5.7 for MAP. However, Suman *et al.* (2010) indicated that storage time and packaging had no effect on pH of ground beef stored at 2°C. These findings are in agreement with Mancini *et al.* (2010) who reported that the mean pH of ground beef patties packaged in air and high-oxygen were 5.72 and 5.62, respectively. Temelli *et al.* (2011) observed that pH values of MA-packaged Inegol kofte decreased during storage contrary to ambient packaging in agreement with Colak *et al.* (2008).

**Water activity ($a_w$):** The initial and final $a_w$ capacities of meatballs were 0.958 and 0.936, respectively. The differences between the groups occurred at the end of the storage ($p<0.01$) but no significant difference were determined according the muscle types of the samples ($p>0.05$). The statistically significant difference was observed depending on package and stimulation types during the storage ($p<0.05$).

**Microbiological examination:** Microbial changes of meatballs packaged under different conditions (air and MAP) during refrigerator storage at 4°C are shown in Fig. 1. The effects of ES and packaging on TAPC of meatballs were found to be statistically different ($p<0.001$). When meat which were subjected for meatballs manufacturing were treated with different periods of ES, the increase on the initial counts of TAPC in NES group was from 6.636-7.404 log CFU $g^{-1}$ while $ES_{60}$ and $ES_{120}$ groups were ranged from 6.631-7.367 log CFU $g^{-1}$ and from 6.589-7.365 log CFU $g^{-1}$, respectively. MAP extended the shelf-life of the product and brought out approximately 1 log lower count of microorganism

Table 2: Means and standard errors of pH values of meatballs stored at 4°C

| | Storage time (days) | | | |
|---|---|---|---|---|
| Factors | 0 | 3 | 6 | 9 |
| Groups | * | NS | NS | NS |
| NES | 5.925±0.007[a] | 6.006±0.006 | 6.103±0.007 | 6.203±0.006 |
| $ES_{60}$ | 5.898±0.007[b] | 5.996±0.006 | 6.102±0.007 | 6.210±0.006 |
| $ES_{120}$ | 5.902±0.007[b] | 6.016±0.006 | 6.118±0.007 | 6.223±0.006 |
| Muscle type | NS | NS | NS | NS |
| LD | 5.911±0.005 | 5.999±0.005 | 6.107±0.006 | 6.216±0.005 |
| SM | 5.906±0.005 | 6.013±0.005 | 6.108±0.006 | 6.208±0.005 |
| Packaging methods | *** | *** | *** | *** |
| MAP | 5.856±0.005[b] | 5.923±0.005[b] | 6.016±0.006[b] | 6.134±0.005[b] |
| Air | 5.961±0.005[a] | 6.089±0.005[a] | 6.200±0.006[a] | 6.289±0.005[a] |
| Group x muscle type | *** | ** | * | NS |
| Group x packaging methods | NS | NS | NS | NS |
| Muscle type x packaging methods | NS | NS | NS | NS |
| Group x cooking methods | - | - | - | - |
| Muscle type x cooking methods | - | - | - | - |
| Packaging methods x cooking methods | - | - | - | - |
| Overall mean | 5.908±0.004 | 6.006±0.003 | 6.108±0.004 | 6.212±0.004 |

[a-c]Mean values within the same column with different superscript small letters are different; *$p<0.05$, **$p<0.01$, ***$p<0.001$, NS: Not Significant $p>0.05$, LD: M. Longissimus Dorsi and SM: M. Semimembranosus

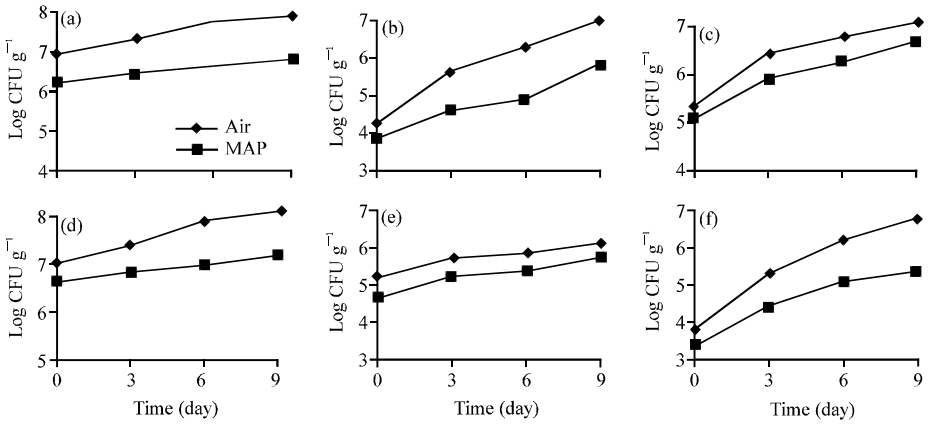


Fig. 1: Changes in total aerobic plate counts; a) Lactic acid bacteria; b) *Pseudomonas* sp.; c) Psychrophilic bacteria; d) Enterobacteriacea; e) Yeast and mould; f) counts of meatballs packaged under different conditions (air and MAP) during storage time at 4°C

Table 3: Means and standard errors of Total Aerobic Plate Counts (TAPC) of meatballs stored at 4°C (Log CFU/g)

| | Storage time (days) | | | |
|---|---|---|---|---|
| Factors | 0 | 3 | 6 | 9 |
| Groups | *** | *** | *** | *** |
| NES | 6.636±0.018$^{a}$ | 6.940± 0.019$^{a}$ | 7.211±0.016$^{a}$ | 7.404±0.013$^{a}$ |
| ES60 | 6.631±0.018$^{b}$ | 6.924± 0.019$^{b}$ | 7.207±0.016$^{a}$ | 7.367±0.013$^{b}$ |
| ES120 | 6.589±0.018$^{c}$ | 6.844± 0.019$^{c}$ | 7.174±0.016$^{b}$ | 7.365±0.013$^{b}$ |
| Muscle type | NS | NS | NS | NS |
| LD | 6.617±0.027 | 6.909±0.027 | 7.196±0.025 | 7.375±0.023 |
| SM | 6.621±0.027 | 6.896±0.027 | 7.199±0.025 | 7.383±0.023 |
| Packaging methods | *** | *** | *** | *** |
| MAP | 6.263±0.017 | 6.466±0.017 | 6.602±0.015 | 6.840±0.013 |
| Air | 6.975±0.017 | 7.340±0.017 | 7.793±0.015 | 7.918±0.013 |
| Group x muscle type | NS | NS | NS | NS |
| Group x packaging methods | NS | ** | *** | * |
| Muscle type x packaging methods | ** | NS | NS | * |
| Overall mean | 6.619±0.015 | 6.903±0.015 | 7.198±0.014 | 7.379±0.012 |

$^{a-c}$Mean values within the same column with different superscript small letters are different; *p<0.05; **p<0.01; ***p<0.001; NS: Not Significant p>0.05; LD: M. Longissimus Dorsi; SM: M. Semimembranosus

(p<0.001, Table 3). The initial counts of TAPC averaged 6.263 log CFU $g^{-1}$ in MAP samples while 6.975 log CFU $g^{-1}$ in air packaged meatballs with a final TAPC of 6.840 and 7.918 log CFU $g^{-1}$, respectively. Microbial changes in other analyzed bacteria were similar to TAPC with approximately 0.5-1 log lower count of microorganism (p<0.001) for whole storage time. MAP performed better than air packaged ones with an initial microbial count of 5.06±0.2 log CFU $g^{-1}$ for total psychrophilic bacteria, 3.88±0.3 log CFU $g^{-1}$ for LAB, 5.06±0.4 log CFU $g^{-1}$ for *Pseudomonas* sp., 4.61±0.2 log CFU $g^{-1}$ for Enterobacteriaceae and 3.39±0.3 log CFU $g^{-1}$ for yeast and moulds and a final microbial count of 7.20±0.2, 5.86±0.3, 6.68±0.4, 5.71±0.2 and 5.35±0.3 log CFU $g^{-1}$, respectively. Briefly, MAP resulted in increase in shelf-life of meatballs upon the 6th day of storage and ES improved slightly the microbiological quality of meatballs compared to air packaging. TAPC of air samples reached >7 log 10 CFU $g^{-1}$ which is considered a spoilage level for this type of product as from the 3th day of storage, similarly to the statement of Colak *et al.* (2008).

Increased shelf life has been reported by several researchers (Bingol and Ergun, 2011; Ercolini *et al.*, 2006; Esmer *et al.*, 2011; Kennedy *et al.*, 2004; Koutsoumanis *et al.*, 2008; Ozturk *et al.*, 2010; Yilmaz and Demirci, 2010; Temelli *et al.*, 2011) for meat and meat products packaged under different modified atmospheres. Although, Jayasingh *et al.* (2002) observed no significant differences in TAPC between the air packaged and MAP (80%, $O_2$/20%, $CO_2$) samples of ground beef. They emphasized that TAPC of ground beef in both treatments remained below spoilage levels during 10 days of storage at 2°C. Seydim *et al.* (2006) indicated that the initial TAPC for ground ostrich meat was slightly higher than that of typical ground beef and added that days of storage at 4°C was a factor (p≤0.001) for each bacterial group examined where the significant difference was more evident in

*Pseudomonas* sp. with <0.5 log10 CFU $g^{-1}$ lower counts in MAP than air packaging. Esmer *et al.* (2011) emphasized that microbial loads in aerobic packaging of ground meat showed higher viable counts than those of MAP. They determined that *Pseudomonas* sp. particularly were the dominant population in the 1st 3 days of storage for aerobic packaging followed by LAB and Enterobacteriaceae. They also highlighted that packaging under modified atmosphere delayed and restricted the growth of these microorganisms similarly to the present study.

**Lipid oxidation:** ES resulted higher lipid oxidation than Not Stimulated One (NES). MAP did not extend the shelf-life of meatballs compared to air packaged samples in terms of TBARS values. TBARS values of all air packaged samples remained lower than MA-packaged samples during the entire storage time (Table 4). Similarly, Mancini *et al.* (2010) reported that high-oxygen and air packaged patties had more lipid oxidation than other packages for 4 days of storage at 2°C. Patties packaged in air had lower TBARS values (0.31 mg MDA $kg^{-1}$) compared with high-oxygen packaged ground beef patties. Jayasingh *et al.* (2002) indicated that after 6 days of storage, MAP samples had much higher mean TBARS number (1.8 mg MDA $kg^{-1}$) than air packaged (0.6 mg MDA $kg^{-1}$) ground beef. Thus, high-oxygen atmosphere packaging was associated with increased TBARS value during storage in agreement with the present study.

Seydim *et al.* (2006) determined that storage time was a significant factor for TBARS value increase regardless of the packaging effect. Meat packaged in air had lower mean TBARS values during the 9 days of storage as compared to meat in $O_2$ packages (>20 mg MDA $kg^{-1}$). These results agree with statements of Ordonez and Ledward (1977) who stated that the concentration of $O_2$ in the package atmosphere is the determining factor for the rate of lipid oxidation. Likewise, Esmer *et al.* (2011) found that the gas composition of package was not statistically significant ($p>0.05$) for oxidative stability, whereas the storage time was significant ($p\leq0.05$). Oxidative stability decreased for whole storage period by increasing TBARS values of minced beef. They underlined also that the TBARS values of MAP ($O_2/CO_2/N_2$:70/30/0) samples were virtually higher than aerobic packaging throughout the entire storage period.

**Textural properties:** Textural properties of the raw and cooked meatballs are shown in Table 5. ES had a greater effect on the tenderness of both raw and cooked meatballs. The textural scores of all meatballs which were manufactured to electrically stimulated meat were lower than NES samples ($p<0.05$) and then were more tender. During the entire storage time, LD samples performed lower textural scores and were more tender than SM samples ($p<0.001$). Air packaging of meatballs caused tenderness compared to MA-packaging after 3rd day of storage ($p<0.001$). These could be due to the effect of spoilage on meatballs sourced of microbial growth in all packages. Raw and cooked meatballs had a highly significant ($p<0.001$) difference during the entire storage time but no significance was observed in the interactions between meatball groups and cooking type ($p>0.05$). These findings show the effectiveness of ES even in cooked product.

Ulu (2006) stated that cooking led to an increase in hardness, cohesiveness, gumminess and chewiness of meatballs but had a small effect on springiness. Also, cooking led to decrease in adhesiveness of meatballs. Ulu (2004) added that storage conditions had not significant ($p>0.05$) effect on the cohesiveness and springiness of meatballs.

Table 4: Means and standard errors of TBARS values of meatballs stored at 4°C (mg MDA $kg^{-1}$ meatball)

| | Storage time (days) | | | |
|---|---|---|---|---|
| Factors | 0 | 3 | 6 | 9 |
| Groups | *** | *** | *** | *** |
| NES | 0.643±0.003$^{b}$ | 0.691±0.003$^{b}$ | 0.959±0.003$^{b}$ | 1.120±0.003$^{b}$ |
| ES60 | 0.651±0.003$^{b}$ | 0.699±0.003$^{b}$ | 0.962±0.003$^{b}$ | 1.129±0.003$^{b}$ |
| ES120 | 0.669±0.003$^{a}$ | 0.728±0.003$^{a}$ | 0.990±0.003$^{a}$ | 1.165±0.003$^{a}$ |
| Muscle type | NS | * | *** | *** |
| LD | 0.652±0.002 | 0.703±0.002$^{b}$ | 0.963±0.003$^{b}$ | 1.128±0.003$^{b}$ |
| SM | 0.657±0.002 | 0.710±0.002$^{a}$ | 0.977±0.003$^{a}$ | 1.148±0.003$^{a}$ |
| Packaging Methods | *** | *** | *** | *** |
| MAP | 0.548±0.002$^{a}$ | 0.683±0.002$^{a}$ | 0.962±0.003$^{a}$ | 1.327±0.005$^{a}$ |
| Air | 0.461±0.002$^{b}$ | 0.529±0.002$^{b}$ | 0.778±0.003$^{b}$ | 0.839±0.005$^{b}$ |
| Group x muscle type | NS | * | ** | ** |
| Group x packaging methods | * | *** | *** | *** |
| Muscle type x packaging methods | ** | ** | NS | * |
| Overall mean | 0.655±0.002 | 0.706±0.002 | 0.970±0.002 | 1.138±0.002 |

$^{a-c}$Mean values within the same column with different superscript small letters are different; *p<0.05, **p<0.01, ***p<0.001, NS: Not Significant p>0.05, LD: M. Longissimus dorsi and SM: M. Semimembranosus

Table 5: Means and standard errors of textural properties of meatballs stored at 4°C (kg/cm$^2$)

| | Storage time (days) | | | |
|---|---|---|---|---|
| Factors | 0 | 3 | 6 | 9 |
| Groups | *** | * | NS | *** |
| NES | 3.628±0.039$^a$ | 2.995±0.056$^a$ | 2.601±0.039 | 2.306±0.036$^a$ |
| ES60 | 3.515±0.039$^b$ | 2.802±0.056$^b$ | 2.587±0.039 | 2.112±0.036$^b$ |
| ES120 | 3.500±0.039$^b$ | 2.802±0.056$^b$ | 2.518±0.039 | 2.054±0.036$^b$ |
| Muscle type | *** | *** | *** | *** |
| LD | 3.279±0.032$^b$ | 2.673±0.046$^b$ | 2.344±0.032$^b$ | 1.963±0.029$^b$ |
| SM | 3.576±0.032$^a$ | 3.072±0.046$^a$ | 2.794±0.032$^a$ | 2.351±0.029$^a$ |
| Packaging methods | NS | *** | *** | *** |
| MAP | 3.469±0.032 | 3.088±0.046$^a$ | 2.761±0.032$^a$ | 2.438±0.029$^a$ |
| Air | 3.387±0.032 | 2.656±0.046$^b$ | 2.377±0.032$^b$ | 1.876±0.029$^b$ |
| Cooking methods | *** | *** | *** | *** |
| Raw | 4.064±0.032$^b$ | 3.240±0.046$^b$ | 2.861±0.032$^b$ | 2.396±0.029$^b$ |
| Cooked | 6.992±0.032$^a$ | 6.504±0.046$^a$ | 6.276±0.032$^a$ | 5.918±0.029$^a$ |
| Group x muscle type | *** | ** | *** | NS |
| Group x packaging methods | *** | ** | NS | NS |
| Muscle type x packaging methods | * | * | * | *** |
| Group x cooking methods | NS | NS | NS | NS |
| Muscle type x cooking methods | *** | *** | *** | *** |
| Packaging methods x cooking methods | * | ** | *** | *** |
| Overall mean | 3.548±0.022 | 2.872±0.032 | 2.569±0.023 | 2.157±0.021 |

$^{a-c}$Mean values within the same column with different superscript small letters are different; *p<0.05; **p<0.01; ***p<0.001; NS: Not Significant p>0.05; LD: M. Longissimus dorsi and SM: M. Semimembranosus

**Surface color measurements:** The instrumental color of raw and cooked meatballs under different package is given in Table 6. ES samples were lighter and redder than NES samples (p<0.001). Results of statistical analyses indicated that in samples CIE L*, a*, b* values were significantly (p<0.05) affected by packaging. Redness of meatballs decreased in MAP but was better than air packaged samples during whole storage time whereas lightness and yellowness were observed in air packaging. Moreover, values for L*, a* and b* in LD samples were higher compared to SM meatballs (p<0.05) for all storage time.

Jayasingh *et al*. (2002) stated that ground beef patties stored in MAP had higher (p<0.05) redness (a*) value on day 1 but a* values were not different from air packaged on day 6 and 10. They indicated also that patties in MAP had higher lightness (L*) and yellowness (b*) values than air packaged samples on 1-10 day storage contrary to the present study. Thus, they determined that ground beef in both treatments (80%, $O_2$/20%, $CO_2$ and air) produced patties with bright red color through 10 days of storage at 2°C. Suman *et al*. (2010) stated also that ground beef patties in high-oxygen MAP had higher lightness, redness and yellowness values than air packaged samples for 4 days of storage at 2°C. Seydim *et al*. (2006) explained that during storage, L* values changed slightly within packaging atmospheres generally between day 0 and 3 whereas among packaging atmospheres significant differences existed. Mancini *et al*. (2010) emphasized that a* values for patties in high-oxygen increased (p<0.05) between day 0 and 2 of storage while air packaged patties displayed no change (p>0.05). Esmer *et al*. (2011) determined that the effect of gas compositions on L* value of minced meat was not statistically significant (p>0.05) whereas L* values were significantly affected by the storage time (p≤0.01). They remarked also that varying concentrations of $CO_2$ or $O_2$ gases in MAP applications did not affect the lightness of minced beef while L* values showed a varying trend, irrespective of packaging treatments. However, they stated that both gas composition and storage time had a significant effect on the redness of minced beef (p≤0.01) with an early discoloration in air packaged samples than MAP ones. They indicated also that b* value of minced meat changed significantly with the gas compositions of MAP and the storage time (p≤0.01) and decreased throughout the whole storage period but remained lower than air packaged samples.

**Sensorial evaluation:** The results of the sensorial evaluation of electrical stimulated and MA-packaged meatballs were generally acceptable until the 6th day of storage (Fig. 2). MA-packaging meatballs received generally higher scores than air packaged ones in terms of sensorial attributes. The flavor, appearance, color and odor of ES samples received higher scores than NES ones (p<0.001) while packaging conditions did not strongly effect the hardness, tenderness and juiciness of meatball samples (p<0.05). Furthermore, LD samples were more favorable than SM meatballs. Meatballs in high-oxygen MAP maintained a bright-red color for 9 days while acceptable scores were obtained up to 6 days of storage

Table 6: Means and standard errors of color properties (CIE L*, a*, b* values) of meatballs stored at 4°C

| | Storage time (days) | | | | | |
|---|---|---|---|---|---|---|
| | 0 | | | 3 | | |
| Factors | L* | a* | b* | L* | a* | b* |
| Groups | *** | *** | * | *** | *** | *** |
| NES | 28.08±0.22$^{b}$ | 7.08±0.07$^{c}$ | 11.57±0.18$^{a}$ | 29.65±0.18$^{b}$ | 5.94±0.07$^{b}$ | 12.80±0.13$^{a}$ |
| ES60 | 28.47±0.22$^{b}$ | 7.69±0.07$^{b}$ | 11.17±0.18$^{ab}$ | 29.97±0.18$^{a}$ | 6.34±0.07$^{a}$ | 11.85±0.13$^{b}$ |
| ES120 | 30.51±0.22$^{a}$ | 7.90±0.07$^{a}$ | 10.92±0.18$^{b}$ | 31.57±0.18$^{a}$ | 6.45±0.07$^{a}$ | 11.75±0.13$^{b}$ |
| Muscle type | * | NS | *** | *** | *** | *** |
| LD | 29.32±0.18$^{a}$ | 7.57±0.06 | 12.14±0.14$^{a}$ | 30.83±0.15$^{a}$ | 6.43±0.06$^{a}$ | 13.00±0.10$^{a}$ |
| SM | 28.72±0.18$^{b}$ | 7.54±0.06 | 10.30±0.14$^{b}$ | 29.97±0.15$^{b}$ | 6.06±0.06$^{b}$ | 11.26±0.10$^{b}$ |
| Packaging methods | *** | *** | NS | *** | *** | * |
| MAP | 28.13±0.18$^{b}$ | 7.72±0.06$^{a}$ | 11.06±0.14 | 29.78±0.15$^{b}$ | 6.46±0.06$^{a}$ | 11.98±0.10$^{b}$ |
| Air | 29.91±0.18$^{a}$ | 7.39±0.06$^{b}$ | 11.38±0.14 | 31.02±0.15$^{a}$ | 6.03±0.06$^{b}$ | 12.29±0.10$^{a}$ |
| Cooking methods | *** | *** | *** | *** | *** | *** |
| Raw | 33.59±0.18$^{a}$ | 8.62±0.06$^{a}$ | 14.18±0.14$^{a}$ | 35.70±0.15$^{a}$ | 7.30±0.06$^{a}$ | 15.33±0.10$^{a}$ |
| Cooked | 24.46±0.18$^{b}$ | 6.49±0.06$^{b}$ | 8.26±0.14$^{b}$ | 25.09±0.15$^{b}$ | 5.19±0.06$^{b}$ | 8.94±0.10$^{b}$ |
| Group x muscle type | *** | *** | *** | NS | *** | *** |
| Group x packaging methods | *** | NS | NS | *** | NS | NS |
| Muscle type x packaging methods | NS | NS | NS | NS | NS | NS |
| Group x cooking methods | NS | *** | NS | ** | NS | * |
| Muscle type x cooking methods | * | NS | NS | *** | NS | NS |
| Packaging methods x cooking methods | ** | ** | * | *** | *** | NS |
| Overall mean | 29.02±0.12 | 7.56±0.04 | 11.22±0.10 | 30.40±0.10 | 6.24±0.04 | 12.13±0.07 |
| | Storage time (days) | | | | | |
| | 6 | | | 9 | | |
| Factors | L* | a* | b* | L* | a* | b* |
| Groups | *** | *** | *** | *** | *** | NS |
| NES | 31.14±0.19$^{b}$ | 4.76±0.09$^{b}$ | 13.31±0.13$^{a}$ | 32.63±0.22$^{b}$ | 4.06±0.08$^{b}$ | 14.08±0.15 |
| ES60 | 31.40±0.19$^{b}$ | 5.25±0.09$^{a}$ | 12.77±0.13$^{b}$ | 32.90±0.22$^{b}$ | 4.56±0.08$^{a}$ | 13.88±0.15 |
| ES120 | 32.72±0.19$^{a}$ | 5.28±0.09$^{a}$ | 12.59±0.13$^{b}$ | 34.37±0.22$^{a}$ | 4.57±0.08$^{a}$ | 13.70±0.15 |
| Muscle type | NS | ** | *** | NS | NS | *** |
| LD | 31.91±0.15 | 5.26±0.07$^{a}$ | 13.83±0.11$^{a}$ | 33.42±0.18 | 4.48±0.06 | 14.74±0.12$^{a}$ |
| SM | 31.59±0.15 | 4.93±0.07$^{b}$ | 11.96±0.11$^{b}$ | 33.18±0.18 | 4.31±0.06 | 13.03±0.12$^{b}$ |
| Packaging methods | *** | * | NS | *** | ** | *** |
| MAP | 31.05±0.15$^{b}$ | 5.21±0.07$^{a}$ | 12.74±0.11 | 32.64±0.18$^{b}$ | 4.53±0.06$^{a}$ | 13.53±0.12$^{b}$ |
| Air | 32.45±0.15$^{a}$ | 4.99±0.07$^{b}$ | 13.04±0.11 | 33.69±0.18$^{a}$ | 4.27±0.06$^{b}$ | 14.24±0.12$^{a}$ |
| Cooking methods | *** | *** | *** | *** | *** | *** |
| Raw | 37.27±0.15$^{a}$ | 5.82±0.07$^{a}$ | 16.19±0.11$^{a}$ | 39.31±0.18$^{a}$ | 4.81±0.06$^{a}$ | 17.63±0.12$^{a}$ |
| Cooked | 26.23±0.15$^{b}$ | 4.38±0.07$^{b}$ | 9.59±0.11$^{b}$ | 27.29±0.18$^{b}$ | 3.98±0.06$^{b}$ | 10.14±0.12$^{b}$ |
| Group x muscle type | NS | *** | *** | NS | *** | *** |
| Groupx x packaging methods | *** | NS | NS | *** | NS | NS |
| Muscle type x packaging methods | NS | NS | NS | NS | NS | *** |
| Group x cooking methods | *** | *** | * | * | *** | NS |
| Muscle type x cooking methods | *** | NS | NS | NS | NS | NS |
| Packaging methods x cooking methods | *** | NS | NS | *** | NS | NS |
| Overall mean | 31.75±0.11 | 5.10±0.05 | 12.89±0.07 | 33.30±0.12 | 4.40±0.04 | 13.89±0.08 |

$^{a-c}$Mean values within the same column with different superscript small letters are different; *p<0.05; **p<0.01; ***p<0.001; NS: Not Significant p>0.05; LD: M. Longissimus dorsi; SM: M. Semimembranosus

storage for flavor and odor. The off-flavor of >6 days MAP samples was due to oxidative rancidity in the high oxygen MAP as indicated by the high TBARS values of these samples and the off-odor after 6 days was associated with the increase in the total viable bacteria attained to meat spoilage.

Jayasingh *et al*. (2002) determined that there was no significant difference in sensory scores for flavor between MAP and air packaged samples on day 1 but the flavor score of MAP samples decreased to slightly dislike level by day 6 while the flavor score of air packaged samples was slightly like >10 days of storage. Thus, the 10 days old MAP samples were considered the least desirable of all the samples and in addition to this, the 6 and 10 days old MAP samples received significantly lower scores ($p<0.05$) than air packaged ones for texture, juiciness and overall acceptability. Furthermore, Mancini *et al.* (2010) indicated that there was significant interaction ($p<0.05$) for visual surface color of ground beef patties stored at 2°C. Patties packaged in high-oxygen MAP were redder compared to air packaged ones at the end of the storage.

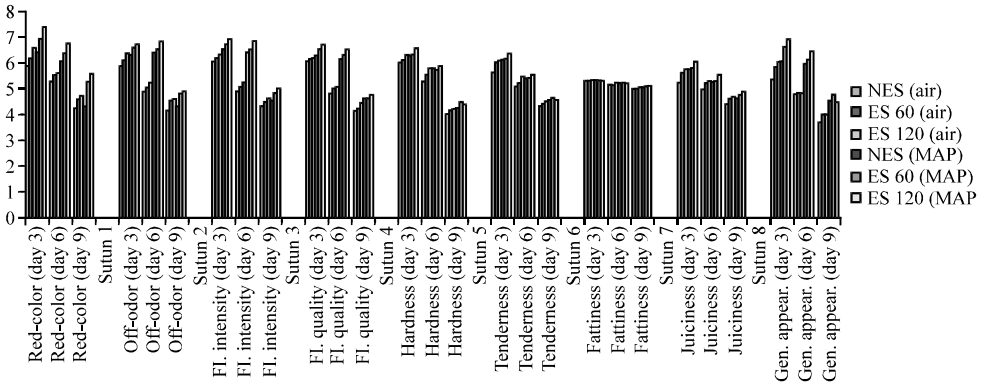


Fig. 2: Sensory evaluation (red-color, off-odor, hardness, tenderness, fattiness, juiciness, flavor intensity, flavor quality and general appearance acceptability) of meatballs packaged under different conditions (air and MAP) during storage time at 4°C

## CONCLUSION

ES and MAP are used in meat industry to improve the quality criteria and shelf-life of the products. Meat processors prefer to use high-oxygen MAP in order to maintain bright red color of the product. MA-packaging resulted in increase in shelf-life of meatballs comparing to air packages but lipid oxidation appeared likely to be the limiting factor for MA-packaged samples. Use of high-oxygen MAP extended the shelf-life of meatballs upon the 6th day. ES improved the sensorial quality of meatballs and LD muscle's meatballs were defined more tender, lighter and redder than SM meatballs. Thus, it indicates that the beneficial effect of ES still continuous in processed meat such as low-fat meatballs. Furthermore, high-oxygen MAP was effective in maintaining a desirable red color for 9 days of refrigerated storage. However, the color of MAP samples was significantly redder than ground meat from air ones, a significant development of rancid off-flavor was detected in MAP by the end of the storage. Therefore, it was concluded that the meatballs have just saleable quality until the 6th day.

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