The effects of egg albumin incorporation on quality attributes of pale, soft, exudative (PSE-like) turkey rolls

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Abstract Pale, soft, exudative (PSE-like) poultry phenomenon has been a growing problem in meat industry in terms of quality and economic losses, thus data is required to evaluate PSE raw material in product formulations. The aim of our study was to investigate the effects of egg albumin (EA) utilization on quality characteristics of PSE-like turkey rolls. Turkey *Pectoralis major* muscles were exposed to either 40 °C to stimulate typical processing causing PSE or 0 °C to reduce PSE and keep the muscles “normal”. Turkey rolls were prepared in nine different formulations; using 100% normal (N), 50% normal + 50% PSE (NP) or 100% PSE meat (P). Treatments also included 0, 1 or 2% EA. Addition of EA increased protein content of all samples. L*, a* and b* values were affected by PSE level. Increased levels of PSE caused decreased processing yields, while EA incorporation increased processing yield of the samples. Addition of 1% EA increased water-holding capacity (WHC) of the samples, while higher level of EA (2%) caused decrement in the same. Addition of either 1% or 2% EA was effective in reducing purge loss in P samples. Texture profile analysis showed that EA addition rather had considerable effects on N samples. Sensory scores showed that 1% EA utilization has the potential to increase mostly the mouthfeel of PSE-like products. Results showed that EA could be used as a promising ingredient that improved overall quality of PSE-like turkey rolls.

Keywords Pale · Soft · Exudative · Poultry · Turkey roll · Egg albumin

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Introduction

Global poultry meat production and consumption has been continuously increasing as a consequence of novel trends and technological progress. Although there has been a considerable improvement in poultry meat industry, pale, soft, exudative (PSE-like) poultry phenomenon, which is characterized by low water-holding capacity, soft texture and light color, has been causing quality problems (Petracci et al. 2009). Despite the unknown ultimate cause of this problem, it seem to be genetic, environmental, or a combination of both and the problem has been associated with ante-mortem and post-mortem stressors including heat stress, pre-slaughter handling practices and carcass chilling regimens (Owens et al. 2009).

Post-mortem temperature was found to be an important processing factor affecting rigor development and overall meat quality. A number of studies reported that high post-mortem temperature-treated muscles showed similar characteristics to PSE muscles in turkey (McKee and Sams 1998; Molette et al. 2003; Zhu et al. 2013; Öztürk and Serdaroğlu 2015), in broiler (Zhu et al. 2011) and in pork (Liu et al. 2014). As a result of rapid post-mortem metabolism, a rapid decrease in pH and accumulation of lactic acid occur in muscles. The consequent low pH (<5.8) combined with high breast muscle temperature (>35 °C), typically causes protein denaturation leading to soft and discolored PSE meat with reduced protein functionality (Alvarado and Sams 2002; Sosnicki et al. 1998).

PSE poultry meat is a significant quality problem leading to dissatisfaction for both producer and consumers. This problem occurs in both fresh meat and meat product causing quality and economic losses. It has been estimated that PSE meat represents 5–40% of meat that is produced in the poultry industry (Owens et al. 2009). As the

production of further processed cooked turkey products such as formed breast loaves and rolls is increased, the PSE problem becomes more apparent (Owens et al. 2000). Meat products manufactured with PSE raw material represent a pale, undesired color and increases the amount of purge in cook-in bags, which results in reduced cook yield, a soft-mushy and/or cracked texture and poor sliceability as a result of protein denaturation and poor meat binding (Alvarado and Sams 2004; Daigle et al. 2005; Schilling et al. 2005).

According to Barbut (2009), incorporation of non-meat ingredients in product formulations is one the most useful strategies to deal with PSE meat and compensate for the lower protein functionality and water-holding capacity. These kind of ingredients range from starch, used to increase water-holding capacity, to proteins or gums that can independently form a gel and thus improve texture, and enzymes such as transglutaminase that can induce protein–protein interactions. Carrageenan, soy protein concentrate and turkey collagen (Daigle et al. 2005) and turkey collagen alone (Schilling et al. 2004) have been utilized in PSE-like turkey; chicken collagen in PSE-like broiler (Schilling et al. 2005); carrageenan (Huang et al. 1997) and modified food starch (Motzer et al. 1998) have been utilized in PSE-like pork product formulations.

Egg albumin (EA) is known as one of the functional non-meat protein ingredients that imparts multiple characteristics such as gelling, binding, emulsification and improves overall textural quality in and restructured meat products (Carballo et al. 1995; Lu and Chen 1999; Pietrasik 2003; Teye et al. 2012). EA has good potential to improve value of low-quality PSE meat due to its higher capacity to retain water and bind meat pieces. To the best of our knowledge, no study has been reported any data regarding EA utilization in PSE-like turkey rolls. Therefore, there is a need for further information regarding the quality of PSE-like turkey products as affected by EA.

The objectives of our present work includes: (1) utilization of PSE-like turkey breast meat obtained with high post-mortem temperature application in formulation of turkey rolls (2) investigation of the quality characteristics of PSE-like turkey rolls in terms of chemical composition, physical, visual, textural, sensory attributes and oxidative stability (3) seeking the possibility of improving the value of low-quality PSE poultry products with a non-meat protein agent (EA).

Materials and methods

Raw material

In our previous research that we objected to generate PSE-like turkey *Pectoralis major* muscles by the effect of high

post-mortem temperature, we indicated that high post-mortem temperature treatment induced development of PSE characteristics in turkey breast. 40 °C post-mortem treated muscles showed rapid pH fall, high L^* values, and decreased technological quality in terms of drip loss, cook loss and thawing loss compared to 0 °C treated ones (Öztürk and Serdaroğlu 2015). Based on these data, in the present study the muscles exposed to 40 °C were assumed as PSE raw material (P), while the muscles treated at 0 °C were assumed as normal raw material (N). Immediately after slaughter, 40 mature male turkeys (Hybrid Converter, between 16 and 18 kg) were selected on slaughter line of a local slaughterhouse, which had 6.0–6.3 pH and 42.1–43.1 °C internal muscle temperature. As soon as *P. major* muscles were removed manually from each turkey carcass, they were packed individually in sealed polyethylene bags and submitted to 0 °C or 40 °C of water-bath (NÜVE BM 15/30, Turkey) temperatures and kept for 2.5 h for N and P groups, respectively. In P samples, ultimate pH (pH_u) was 5.65, L^* value was 53.47 and drip loss was 5.64%, while in N samples pH_u was 5.92, L^* value was 49.34 and drip loss was 2.49%, in accordance with our previous results (Öztürk and Serdaroğlu 2015).

Egg albumin (EA) was supplied from Pulviver (Belgium) as albumin from hen egg white, lyophilized powder (according to the specifications of the supplier, it was consisted of min. 80% crude protein, max. 8% moisture, max. 0.2% fat and max. 0.1% reducing sugar). Sodium chloride (NaCl), sodium tripolyphosphate (STPP) and sodium nitrite ($NaNO_2$) were kindly donated by Pacovis Food Co. (Turkey).

Experimental design

Post-mortem treated turkey breast muscle groups (normal and PSE) were divided into three groups as follows: 100% PSE (P), 50% normal + 50% PSE (NP) and 100% normal (N). Treatment combinations consisted of 0, 1 or 2% EA. The experimental design of the study is presented in Table 1.

Production of restructured turkey rolls

For preparation of turkey roll mix, the breast muscles (N, P, N + P) were cut into 2.5 cm by 2.5 cm cubes. For control treatments (E0), the cubes were placed in a vacuum tumbler, 10% distilled water, 1.5% NaCl, 0.5% STPP and 0.015% $NaNO_2$ were added and tumbling was applied with a vacuum tumbler (Suhner, Wastro MGH-20, Germany) at 4 °C and 30 rpm for 30 min. For treatments with EA (E1, E2) 1% or 2% EA was added together with the other additives as a dry powder. After the tumbling process, the mixture was stuffed into synthetic cellulose casings (D:

Table 1 Experimental design of the study

Meat quality	Egg albumin (%)	Turkey roll formulations	Abbreviation
Normal	0	100% normal meat + 0% EA	N-E0
	1	100% normal meat + 1% EA	N-E1
	2	100% normal meat + 2% EA	N-E2
Normal + PSE	0	50% normal + 50% PSE meat + 0% EA	NP-E0
	1	50% normal + 50% PSE meat + 1% EA	NP-E1
	2	50% normal + 50% PSE meat + 2% EA	NP-E2
PSE	0	100% PSE meat + 0% EA	P-E0
	1	100% PSE meat + 1% EA	P-E1
	2	100% PSE meat + 2% EA	P-E2

100 mm) using a hydraulic stuffer (Bemak Machine Co., Turkey), the rolls were smoked in a smoking chamber (Gıdatek Machine Co., Turkey) at 78 °C for 45 min. The rolls were then cooked in a steam cabin (Gıdatek Machine Co., Turkey) at 85 °C for 30 min, until the internal temperature of 72–75 °C was reached. After heat treatment, the rolls were rapidly showered with cold water and cooled to room temperature. The casings were removed and the rolls were sliced into 2 cm thickness. The slices were individually vacuum-packed and stored at +4 °C for 5 months for analysis. 0th month analyses were performed within 24 h after production.

Methods

Chemical composition and energy value

Total moisture (Method 950.46), protein (Method 2011.04) and ash content (Method 923.03) of turkey rolls were determined according to AOAC (2012). Total fat content was analyzed according to Flynn and Bramblett (1975). Energy value was calculated as total calorie estimates (kcal) from the chemical composition on the basis of 100 g sample using Atwater values for fat (9 kcal/g) and protein (4.02 kcal/g). Analysis were carried out in triplicate.

pH

pH was measured in triplicate from three different points, using a probe-type pH-meter (WTW pH 330i/SET, Germany).

Color

The surface color of the rolls was measured in triplicate using a portable colorimeter (CR-200, Konica Minolta, Japan) with D65 illuminant setting and 10° standard observer. Color was measured on four different points of

the slices and expressed according to CIE system as L* (lightness), a* (redness), b* (yellowness).

Processing yield (PY)

Processing yield (PY) of the samples was determined from three different portions of turkey rolls as a percentage of the pre-cooked weight (Bloukas et al. 1997). Raw portions were weighed after casing process (W_1) and re-weighed after heat treatment and cooling processes (W_2). PY was calculated using the equation below:

$$PY\% = (W_2/W_1) \times 100$$

Water-holding capacity (WHC)

Water-holding capacity (WHC) was determined in triplicate according to Hughes et al. (1997). 10 g turkey roll batter was weighed (W_1), placed into glass jars and heated in 90 °C water bath for 10 min. After cooling, the samples were centrifuged at 1400 rpm for 15 min and weighed again (W_2). WHC was calculated from the equation below:

$$WHC\% = 1 - T/M \times 100 = 1 - (W_1 - W_2)/M \times 100$$

T : water loss after heating and centrifugation, M : total moisture content of the sample.

Purge loss

Purge loss (PL) of vacuum packed slices during 5 months-storage period was analyzed from total weight loss of the samples (Bloukas et al. 1997). Each sample was analyzed in triplicate at each storage time. Initial sample weight was recorded before packaging (W_1). At the end of each month, the package was opened, the sample was wiped with paper towel to remove the exudate and re-weighed (W_2). PL was calculated using the equation below:

$$PL\% = (W_1 - W_2)/W_1 \times 100$$

Thiobarbituric acid-reactive substances (TBA-RS)

Thiobarbituric acid-reactive substances (TBA-RS) value was analyzed spectrophotometrically according to Tarladgis et al. (1960), as modified by Shahidi et al. (1985) to determine oxidative deterioration of the samples during 5 months storage. TBA values were calculated by multiplying the absorbance in a K value of 7.8 and expressed as mg malonaldehyde/kg sample. Each sample was analyzed in triplicate at each storage time.

Texture profile analysis

Texture profile analysis (TPA) was performed in triplicate using a texture analyzer (TA-XT2, Stable Micro Systems, Haslemere, UK). Five samples (2.5 cm × 2 cm × 2 cm) were taken from each treatment group by using a probe. Samples were compressed to 50% of its original height with a crosshead speed of 5 mm/s and 50 kg load cell. A pre-test speed of 2 mm/s and post-test speed of 0.5 mm/s were applied. The parameters calculated from the force and time curves were hardness (maximum force required for the initial compression as N), cohesiveness (ratio of active work done under the second compression curve to that done under the first compression curve as dimensionless), springiness (distance of the sample recovers after the first compression as mm), gumminess (the strength of internal bonds making up the body of the sample as N) and chewiness (the required work to masticate the sample as N × mm). Also, the samples were cut to size of 1.0 cm × 2.0 cm × 0.5 cm for shear force analysis performed with Warner–Bratzler shear apparatus with a cross-head speed of 2 mm/s and a 25 kg load-cell. Pre-test and post-test speeds were 2 and 0.5 mm/s, respectively.

Sensory evaluation

Sensory evaluation of the turkey rolls was performed with 25 volunteered panelists at Ege University Food Engineering Department Organoleptic Test Laboratory. Totally nine different samples were randomly coded and served cold to panelists. Samples were subjected to sensory evaluation for appearance, color, juiciness, tenderness, flavor, and overall acceptability. Water and bread were served for cleaning the mouth between samples. A nine-point hedonic scale (9 = like extremely, 8 = like very much, 7 = like moderately, 6 = like slightly, 5 = neither like or dislike, 4 = dislike slightly, 3 = dislike moderately, 2 = dislike very much, 1 = dislike extremely) was used for evaluation (Stone and Sidel 2004).

Statistical analysis

The entire meat system production procedure was replicated twice. One-way analysis of variance (ANOVA) was used to evaluate the statistical significance ($P < 0.05$) among formulations and two-way ANOVA as a function of storage using the SPSS for Windows statistical package program version 21.0 (IBM, USA). The data was analyzed using general linear model (GLM), in which formulation groups and storage time were assigned as fixed effects and replications as a random effect. The means were obtained from the triplicates and comparison was performed with least squares differences (LSD). Significant differences among means were determined by Duncan's multiple range test. For analysis of processing yield, water-holding capacity and color, ANOVA for Response Surface Quadratic or 2FI Model was performed using Design-Expert statistical software package version 7.0 (Stat-Ease Inc., USA) to evaluate the effects of PSE meat and EA concentration.

Results and discussion

Chemical composition, energy value and pH

Chemical composition, energy and pH values of turkey rolls are presented in Table 2. Moisture values of the samples were between 56.17 and 62.60%, where E0 samples had similar moisture to each other, indicating that PSE meat level did not have any significant effect on moisture content of the final product. Added EA in the formulations tend to decrease moisture content of the products, probably due to the increase in dry matter, however the effects were found insignificant. Addition of EA significantly increased protein content of the samples ($P < 0.05$), which were between 30.18 and 36.90%. Increase in the total protein content was probably due to EA composition (high protein content). It is known that non-meat protein binders present a good potential to increase nutritional value of meat products, while they are able to improve binding and texture. EA could be noted as one of these ingredients as it ensured the protein enhancement. Similarly, Teye et al. (2012) reported higher protein contents in frankfurters produced with either fresh or dried EA. Slight differences were recorded in total fat and ash values, which were between 1.54–3.57% and 3.03–3.51%, respectively. Although Teye et al. (2012) emphasized that EA could act as a diluent to reduce the fat content; our results showed that EA did not show any considerable effect on fat retention and total fat content of the samples, this could be a consequence of low fat content of the breast muscle and no added fat to the formulation. In N group, energy value

was significantly increased with 2% EA addition ($P < 0.05$), while the differences in NP and P groups were insignificant. pH values of the samples were between 6.47 and 6.55. Although PSE raw meat had characteristic low pH value, the values were almost similar in final products of P and N groups, probably due to the effect of heat treatment and additives used during production. Utilization of EA did not show a considerable effect on pH value of the final products. That was probably due to the amount of EA added to the formulations which was insufficient to provide a change in pH values. Teye et al. (2012) reported that frankfurters produced with 5–10% fresh or dried EA had significantly lower pH than control products. In their study, the main reason for this situation was using STPP in the control sample formulations that have direct influence on pH increase. Thus, it was a noticeable point that utilization of phosphates was a preventive factor for maintaining the pH values at desired levels in PSE meat product formulations.

Color

Meat color is the most important visual attribute for customer satisfaction since any discoloration has negative influence on customer choice. Pale color of PSE meat is considerable as a low-quality indicator and can be attributed to the denaturation of sarcoplasmic proteins. The effect of PSE and EA level on L^* , a^* and b^* values of turkey rolls could be seen in Fig. 1a–c, respectively. Analysis of variance indicated that the regression model for color parameters were significant. L^* values were in the range of 68.75–73.13, significantly affected by PSE level ($P < 0.05$). The results showed that increased

concentrations of PSE meat increased L^* values regardless of EA level. This could be due to extremely high L^* values of raw material. Similar studies reported increased L^* values in PSE-like turkey (Daigle et al. 2005; Schilling et al. 2004), broiler (Schilling et al. 2005) and pork (Motzer et al. 1998) products. Although addition of both 1 and 2% EA in P samples provided slight decreases in L^* values, it could be concluded that EA could help in masking pale color of PSE-like turkey products when used in combination with some supportive additives. Similarly, a^* (7.83–9.97) values were significantly affected by PSE meat concentration ($P < 0.05$), where decreased values were recorded in samples containing increased amounts of PSE. Motzer et al. (1998) reported that in pork hams, redness, which is mainly correlated with cured color, is not greatly affected by PSE incorporation. Therefore, the differences in a^* values of the rolls in our study could be attributed to the production methods and additives used in the formulations. b^* values of the samples were between 9.16 and 13.98, and showed increment with increased levels of PSE ($P < 0.05$), regardless of EA level. Daigle et al. (2005) stated that increased yellowness in PSE-like turkey rolls could be attributed to the use of pale raw material. Since EA addition did not show considerable changes in color attributes of PSE turkey rolls, it could be concluded that color additives in combination with EA could be adjuvant to improve visual quality of PSE-like poultry products.

Processing yield

Since meat is a high-cost raw material, the economic losses occurring during processing, especially when using low-quality raw material like PSE, are important and could be

Table 2 Chemical composition (moisture, protein, fat, ash), energy value and pH of turkey roll treatments

Treatment groups ^a	Moisture (%)	Protein (%)	Fat (%)	Ash (%)	Energy value (kcal/100 g)	pH
N-E0	60.83 ± 2.43 ^{ab}	30.54 ± 0.62 ^c	2.15 ± 0.53 ^{ab}	3.51 ± 0.49 ^a	142.16 ± 7.22 ^b	6.51 ± 0.01 ^{ab}
N-E1	62.60 ± 2.27 ^a	31.98 ± 1.71 ^c	1.73 ± 0.11 ^{ab}	3.03 ± 0.12 ^b	144.11 ± 6.09 ^b	6.55 ± 0.00 ^a
N-E2	57.04 ± 2.94 ^{bc}	36.67 ± 1.60 ^a	2.51 ± 0.34 ^{ab}	3.13 ± 0.11 ^{ab}	170.02 ± 16.60 ^a	6.47 ± 0.04 ^b
NP-E0	60.58 ± 1.75 ^{ab}	30.60 ± 1.18 ^c	1.79 ± 0.03 ^{ab}	3.06 ± 0.12 ^b	139.174 ± 5.02 ^b	6.50 ± 0.01 ^{ab}
NP-E1	60.17 ± 1.97 ^{ab}	33.07 ± 0.12 ^{bc}	2.72 ± 0.25 ^{ab}	3.23 ± 0.10 ^{ab}	157.46 ± 11.63 ^{ab}	6.55 ± 0.02 ^a
NP-E2	57.85 ± 0.62 ^{bc}	35.66 ± 1.82 ^{ab}	1.54 ± 0.61 ^b	3.14 ± 0.04 ^{ab}	157.24 ± 10.30 ^{ab}	6.51 ± 0.02 ^{ab}
P-E0	60.28 ± 0.97 ^{ab}	30.18 ± 1.00 ^c	3.57 ± 0.96 ^a	3.41 ± 0.33 ^{ab}	153.42 ± 18.08 ^{ab}	6.50 ± 0.03 ^{ab}
P-E1	57.92 ± 2.54 ^{bc}	35.07 ± 3.24 ^{ab}	2.35 ± 0.92 ^{ab}	3.14 ± 0.17 ^{ab}	162.10 ± 4.95 ^{ab}	6.52 ± 0.02 ^{ab}
P-E2	56.17 ± 1.64 ^b	36.90 ± 1.71 ^a	2.34 ± 0.96 ^{ab}	3.08 ± 0.08 ^{ab}	169.43 ± 16.82 ^a	6.48 ± 0.04 ^b

Data are presented as the mean values of replications ± standard deviation. abcd: Means with the different letter in the same column are significantly different ($P < 0.05$)

^a N-E0 (100% normal meat + 0% EA), N-E1 (100% normal meat + 1% EA), N-E2 (100% normal meat + 2% EA), NP-E0 (50% normal meat + 50% PSE meat + 0% EA), NP-E1 (50% normal meat + 50% PSE meat + 1% EA), NP-E2 (50% normal meat + 50% PSE meat + 2% EA), P-E0 (100% PSE meat + 0% EA), P-E1 (100% PSE meat + 1% EA) and P-E2 (100% PSE meat + 2% EA)

Fig. 1 Effects of PSE meat (%) and EA (%) levels on colour parameters (L^* , a^* , b^*), processing yield (PY) and water-holding capacity (WHC) of turkey rolls. **a** L^* values of turkey rolls, response surface 2FI model $F = 4.85$, $p = 0.0394$ (significant), $r^2 = 0.6750$, Coefficient estimate for intercept $CE = 71.03$ and standard error $SE = 0.25$. **b** a^* values of turkey rolls, response surface 2FI model $F = 6.71$, $p = 0.0292$ (significant), $r^2 = 0.4269$, coefficient estimate for intercept $CE = 91.6$ and standard error $SE = 0.14$. **c** b^* values of turkey rolls, response surface 2FI model $F = 5.08$, $p = 0.0354$

(significant), $r^2 = 0.6853$, coefficient estimate for intercept $CE = 12.28$ and standard error $SE = 0.33$. **d** PY of turkey rolls, response surface quadratic model $F = 84.40$, $p < 0.0001$ (significant), lack of fit = 0.0850 (not significant), $r^2 = 0.9837$, coefficient estimate for intercept $CE = 59.54$ and standard error $SE = 0.30$. **e** WHC of turkey rolls, response surface quadratic model $F = 9.65$, $p = 0.0074$ (significant), lack of fit = 0.4373 (not significant), $r^2 = 0.7069$, coefficient estimate for intercept $CE = 99.29$ and standard error $SE = 0.059$

attributed to the decreases in product weight. The effect of PSE and EA level on processing yield of turkey rolls is presented in Fig. 1d. Analysis of variance for quadratic model showed that both PSE and EA level have significant effects on processing yield of samples ($P < 0.05$).

Increased levels of PSE meat caused decreased processing yields, which could be associated with decreased water-holding capacity of the raw material. Previously, Kuo and Chu (2003) reported decrement in processing yield of PSE pork sausages. EA incorporation significantly increased

processing yield of the samples ($P < 0.05$). Therefore, it could be concluded that addition of EA could improve binding properties in PSE-like turkey products by means of increasing protein concentration and gel formation. Since PSE-like raw material has decreased ability to hold and bind water inside the structure, EA utilization could be suggested to compensate for low product yield. Motzer et al. (1998) found that in PSE pork hams, modified starches and κ -carrageenan have an ability to increase processing yield, while isolated soy protein did not show a significant effect. In PSE-like turkey rolls, incorporation of collagen increased processing yield as increasing cooking yields (Schilling et al. 2004). These differences could be ascribed to the type of the meat and/or type of the product which could influence the binding properties.

Water-holding capacity

Water-holding capacity (WHC), which is defined as the ability of meat to retain moisture, is an important quality attributes affecting textural and sensory quality. In PSE syndrome, denaturation of myosin and shrinkage of myosin heads resulted in more fluid being expelled between fibers and fiber bundles leading to decline in WHC (Offer 1991). The effect of PSE and EA level on WHC of turkey rolls is shown in Fig. 1e. Analysis of variance for the model showed that WHC was significantly affected by EA utilization ($P < 0.05$). However, no significant effects was observed for PSE level. This lack of differences in WHC values depending on meat type could probably be due to early water release of the raw materials before production and only a small amount of water addition to formulations, besides the applications such as heat treatment and use of STPP increasing WHC in meat matrix. Similar results were reported in a study where WHC of normal and PSE-like turkey rolls did not show any change by collagen incorporation (Schilling et al. 2004). Thus, it could be concluded that compared to restructured poultry products, WHC could be a more prior function in fresh or emulsified ones, since more water was required to be bound in the structure. Evaluating the effect of EA addition, it was seen that addition of EA significantly increased WHC of the samples ($P < 0.05$). Egg proteins could increase WHC acting in the formation of protein network (Pietrasik 2003). Thus, EA may increase WHC by synergistically working with meat proteins to bind water in the matrix. However, increased levels of EA may cause decrement in WHC. Similar results were reported by Teye et al. (2012), who found that in frankfurters made with fresh or dried EA appeared to have reduced cooking losses of the products, but the losses increased with an increase in EA inclusions. Authors stated that an increase in albumin inclusion resulted in formation of egg-lumps, which did not bind the meat pieces, but were

separated from the structure, resulting in a poor particle-binding of products. In this context, excessive amounts of EA utilization should be avoided to prevent the decrease in WHC. Carballo et al. (1995) stated that in pork emulsions, although EA did not change water and fat binding, the effect of EA was related to myofibrillar protein functionality: this binding effect would mostly show itself in case of using meat protein which has low-functionality. From this point of view, it could be concluded that more favorable results could be obtained by addition of EA in products produced with PSE-like meat, compared to products formulated with normal meat.

Purge loss

Purge loss is an important visual quality problem in packed meat and meat products. Lower water-holding capacity in PSE meat led to higher drip and purge losses which tended to accumulate in the packaging material during storage. Purge loss of turkey rolls is presented in Fig. 2a. Since purge loss typically increased with storage time depending on the loss of protein functionality, in our study during 5 months of storage period purge losses of all the samples were increased compared to initial values as expected ($P < 0.05$). At all evaluation periods, P-E0 samples had the highest purge loss ($P < 0.05$), not surprisingly due to loss of ability of PSE material to entrap fluid inside the matrix. Addition of either 1% or 2% EA was significantly effective in reducing purge loss in P samples ($P < 0.05$). In N and NP samples, the effect of EA utilization was not significant. Therefore, it was found that more promising impacts could be achieved by addition of EA in products produced with PSE-like raw material, compared to products produce with normal meat. Therefore, EA could be stated as a promising ingredient in PSE-type meat products that imparted protein–protein and protein–water interactions in meat matrix, thus supplied a stable structure and reduced purge. Since EA has an ability to improve binding of meat pieces, it presented a potential to overcome poor water retention of PSE-meat. Although no study has reported EA addition in PSE meat products, Pietrasik (2003) reported reduced purge loss in beef gels produced with 2% EA. In studies with PSE meat, 1.5% collagen addition in PSE-like turkey and broiler rolls managed to overcome excess purge (Schilling et al. 2004, 2005). Another study reported reduced purge loss in PSE-like turkey rolls produced with 1.5% collagen, 1.5% soy protein or 0.3% carrageenan (Daigle et al. 2005).

TBA-RS

TBA-RS value is used as an indicator of secondary products formed in fatty acid oxidation chain reactions. TBA-RS values measured in turkey rolls during storage are

Fig. 2 Purge loss (%) and sensory scores of turkey rolls. **a** Purge loss (%) of the samples during 5-months of storage. **b** Appearance, color and flavor of the samples. **c** Tenderness, juiciness and overall acceptability of the samples

presented in Table 3. No significant differences were recorded as affected by meat quality and EA addition, except slight deviations. The values of 0th month did not differ from each other, ranging between 0.01 and 0.05 mg malonaldehyde/kg. During the storage period, no extreme increases were recorded in samples. In 5th month, the individual values in N, NP and P groups did not differ from each other, which were between 0.14 and 0.33 mg malonaldehyde/kg. Previously O'Neill et al. (2003) stated that PSE meats could be more sensitive to lipid oxidation.

However, our results were contrary to this, since no differences were obtained in different meat quality groups. This could arise from many reasons delaying oxidation rate, like low fat content of the formulations, antioxidant effect provided by sodium nitrite and sodium phosphate, phenolic compounds formed in smoking, storage in vacuum packs at low temperatures. Similarly, Kuo and Chu (2003) and Everts et al. (2010) did not find any significant differences in TBA values of normal and PSE pork products. Recently it has been mentioned that some peptides presented in egg show antioxidant effects (Liu et al. 2015). However, in this study no significant differences were recorded in TBA-RS values with added EA. This could be probably due to inadequate amounts of EA used in formulations to ensure antioxidant effect. Further research should be performed to identify the antioxidant role of EA in meat matrix.

Texture profile analysis

PSE poultry meat is characterized by a soft, almost mushy texture. Products manufactured with 100% PSE meat presented low binding strength, textural cracking and poor sliceability due to loss of protein functionality. The results of texture profile analysis (TPA) of the samples are presented in Table 4. Hardness, cohesiveness, elasticity, gumminess and chewiness were significantly different in N and P groups ($P < 0.05$). The lowest hardness and cohesiveness were recorded in N samples ($P < 0.05$). Both 1 and 2% EA were effective in increasing hardness and cohesiveness in N samples ($P < 0.05$), while in NP and P samples the impact was not considerable. Similarly, elasticity and gumminess were the lowest in N samples and increased with added EA ($P < 0.05$). EA did not show any significant effect on elasticity and gumminess of NP and P groups. The lowest chewiness was recorded in N samples, with increased values with either 1% or 2% EA ($P < 0.05$). In NP group, 2% EA addition caused a significant increment ($P < 0.05$) in chewiness, while no significant difference was recorded in P samples. N-E0 samples had the lowest shear force and 2% EA addition increased the value significantly ($P < 0.05$). EA did not have any significant effect on NP samples, whilst in P samples, either 1% or 2% added EA increased shear force ($P < 0.05$). The results showed that EA addition mostly had significant effects in N samples, instead of P samples. This result could be due to lack of protein functionality of PSE raw material, inhibiting the network formation and interactions between meat and egg proteins. In a previous study with beef gels, 2% EA was mentioned to increase gel strength, especially when used with microbial transglutaminase and carrageenan (Pietrasik 2003). Carballo et al. (1995) reported improved hardness and chewiness in Bologna sausages

Table 3 TBA-RS values of turkey rolls (mg malonaldehyde/kg) during 5 months of storage

Treatment groups ^a	Storage period (month)					
	0	1	2	3	4	5
N-E0	0.03 ± 0.01 ^{abY}	0.13 ± 0.00 ^{bcX}	0.19 ± 0.03 ^{abX}	0.20 ± 0.02 ^{bcX}	0.19 ± 0.01 ^{bX}	0.19 ± 0.09 ^{abX}
N-E1	0.02 ± 0.01 ^{bW}	0.39 ± 0.01 ^{aX}	0.20 ± 0.02 ^{abYZ}	0.09 ± 0.05 ^{dZW}	0.08 ± 0.04 ^{bZW}	0.23 ± 0.07 ^{abY}
N-E2	0.05 ± 0.0 ^{abY}	0.19 ± 0.02 ^{abcXY}	0.15 ± 0.03 ^{abXY}	0.31 ± 0.01 ^{aX}	0.34 ± 0.09 ^{aX}	0.33 ± 0.08 ^{aX}
NP-E0	0.02 ± 0.03 ^{bZ}	0.10 ± 0.00 ^{bcXYZ}	0.05 ± 0.05 ^{bYZ}	0.14 ± 0.03 ^{bcdXY}	0.15 ± 0.03 ^{bXY}	0.20 ± 0.06 ^{abX}
NP-E1	0.06 ± 0.04 ^{aW}	0.33 ± 0.03 ^{abX}	0.12 ± 0.05 ^{bZW}	0.17 ± 0.01 ^{bcdYZ}	0.13 ± 0.04 ^{bZW}	0.22 ± 0.06 ^{abY}
NP-E2	0.04 ± 0.01 ^{abY}	0.12 ± 0.02 ^{bcY}	0.50 ± 0.03 ^{aX}	0.18 ± 0.01 ^{bcdXY}	0.19 ± 0.03 ^{bXY}	0.28 ± 0.08 ^{abXY}
P-E0	0.02 ± 0.02 ^{bZ}	0.28 ± 0.02 ^{abXY}	0.33 ± 0.31 ^{abX}	0.10 ± 0.03 ^{cdYZ}	0.11 ± 0.03 ^{bYZ}	0.18 ± 0.07 ^{abXYZ}
P-E1	0.02 ± 0.01 ^{bY}	0.33 ± 0.05 ^{abX}	0.19 ± 0.02 ^{abXY}	0.13 ± 0.01 ^{bcdXY}	0.12 ± 0.01 ^{bXY}	0.14 ± 0.03 ^{bXY}
P-E2	0.01 ± 0.01 ^{bZ}	0.01 ± 0.00 ^{cZ}	0.12 ± 0.05 ^{bY}	0.23 ± 0.02 ^{abX}	0.20 ± 0.08 ^{bXY}	0.27 ± 0.09 ^{abX}

Data are presented as the mean values of 3 replications ± standard deviation. abcd: Means with the different letter in the same column are significantly different ($P < 0.05$). XYZ: Means with the different letter in the same row are significantly different ($P < 0.05$)

^a N-E0 (100% normal meat + 0% EA), N-E1 (100% normal meat + 1% EA), N-E2 (100% normal meat + 2% EA), NP-E0 (50% normal meat + 50% PSE meat + 0% EA), NP-E1 (50% normal meat + 50% PSE meat + 1% EA), NP-E2 (50% normal meat + 50% PSE meat + 2% EA), P-E0 (100% PSE meat + 0% EA), P-E1 (100% PSE meat + 1% EA) and P-E2 (100% PSE meat + 2% EA)

Table 4 Texture profile analysis (TPA) of turkey rolls

Treatment groups ^a	Hardness (N)	Cohesiveness	Springiness (mm)	Gumminess (N)	Chewiness (N × mm)	Shear force (N)
N-E0	86.15 ± 8.50 ^c	57.17 ± 6.12 ^c	0.51 ± 0.01 ^d	86.15 ± 6.25 ^c	27.21 ± 4.34 ^d	39.17 ± 5.72 ^d
N-E1	113.08 ± 7.24 ^b	81.93 ± 5.22 ^{ab}	0.70 ± 0.03 ^a	113.08 ± 7.24 ^b	65.89 ± 4.34 ^{bc}	48.37 ± 2.52 ^{cd}
N-E2	131.30 ± 2.46 ^a	85.39 ± 9.39 ^a	0.68 ± 0.04 ^{ab}	131.30 ± 2.46 ^a	105.50 ± 5.15 ^a	57.20 ± 5.58 ^{bc}
NP-E0	104.36 ± 2.09 ^b	72.83 ± 2.61 ^b	0.63 ± 0.00 ^{bc}	104.36 ± 2.09 ^b	54.15 ± 0.69 ^c	42.61 ± 0.49 ^{cd}
NP-E1	106.94 ± 4.45 ^b	81.88 ± 5.95 ^{ab}	0.66 ± 0.00 ^{abc}	106.94 ± 4.45 ^b	63.68 ± 8.87 ^{bc}	51.28 ± 8.41 ^{cd}
NP-E2	117.17 ± 2.83 ^b	82.27 ± 4.21 ^{ab}	0.67 ± 0.00 ^{abc}	117.17 ± 2.83 ^b	69.13 ± 3.98 ^b	52.48 ± 8.52 ^{cd}
P-E0	103.94 ± 8.86 ^b	78.73 ± 6.95 ^{ab}	0.64 ± 0.03 ^{bc}	103.94 ± 7.86 ^b	63.50 ± 9.09 ^{bc}	49.01 ± 4.67 ^{cd}
P-E1	104.50 ± 3.10 ^b	81.62 ± 7.82 ^{ab}	0.62 ± 0.00 ^c	104.5 ± 3.10 ^b	64.36 ± 5.76 ^{bc}	71.58 ± 7.95 ^b
P-E2	116.68 ± 2.56 ^b	87.78 ± 3.58 ^a	0.63 ± 0.03 ^{bc}	116.68 ± 2.56 ^b	73.14 ± 7.22 ^b	90.77 ± 6.95 ^a

Data are presented as the mean values of replications ± standard deviation. abcd: Means with the different letter in the same column are significantly different ($P < 0.05$)

^a N-E0 (100% normal meat + 0% EA), N-E1 (100% normal meat + 1% EA), N-E2 (100% normal meat + 2% EA), NP-E0 (50% normal meat + 50% PSE meat + 0% EA), NP-E1 (50% normal meat + 50% PSE meat + 1% EA), NP-E2 (50% normal meat + 50% PSE meat + 2% EA), P-E0 (100% PSE meat + 0% EA), P-E1 (100% PSE meat + 1% EA) and P-E2 (100% PSE meat + 2% EA)

with added EA. In broiler breasts, EA incorporation increased Warner–Bratzler shear force (Lu and Chen 1999). In studies with PSE meat, some results were obtained as follows: No differences were recorded in hardness, elasticity, cohesiveness and chewiness of PSE and normal broiler sausages, while soy protein and phosphate addition increased hardness and chewiness (Kissel et al. 2009). Motzer et al. (1998) reported that modified starch addition led decrement in hardness, cohesiveness and chewiness of 100% PSE pork ham. In PSE-like turkey rolls, binding strength was increased by addition of soy protein and collagen (Daigle et al. 2005). From the results,

it could be suggested to use EA in combination with different proteins, starches or gums to improve binding, network formation and texture.

Sensory evaluation

PSE meat and meat products are stated to have low sensory acceptability scores in terms of appearance, color, texture and flavor. Lower sensory test results were recorded in PSE-type pork products (Kuo and Chu 2003; Everts et al. 2010). It is important to manage and add value to PSE meat products by using potential ingredients. The scores obtained from

sensory test of the turkey rolls are illustrated in Fig. 2b, c. The results showed that except slight differences, generally the sensory attributes of the treatments were similar to each other. The highest appearance score was recorded in N-E0 group, where in N and P groups 2% EA usage lead decreases in scores ($P < 0.05$). Generally color scores did not differ from each other. This result could be associated with desired cured pigment formation by sodium nitrite addition, which could have an off-color masking effect in P groups. No significant differences were recorded in flavor and tenderness scores between treatments. Although Keeton (2001) stated that high inclusion level of egg white could result in an egg flavor within the finished product, in our study no remarkable changes were recorded with increased EA concentrations. Teye et al. (2012) stated that the drying of the albumen might have resulted in the loss of egg flavor from it, and consequently the insignificant differences in the egg flavor intensity of the dried albumin products. Consequently, regarding also visual quality, it could be suggested not to use excess amounts of EA in meat product formulations to protect appearance and flavor. Juiciness scores were increased in P samples with added EA ($P < 0.05$), but were similar to each other in N and NP samples. Thus, EA could be noted to have a good potential in improving mouthfeel and chewing parameters in PSE-like products. Overall acceptability scores were similar in all of the treatments. Thus, sensory scores showed that 1% EA utilization has the potential to increase mostly the mouthfeel of PSE-like products, while in normal and PSE-like products, it may maintain other sensory quality attributes without changing appearance and flavor.

Conclusion

Our study indicated that EA incorporation presents a favorable opportunity to add value to PSE-like turkey meat products in terms of total protein content, color, processing yield, water retention, purge loss and sensory properties. However, it could be suggested to utilize EA with combination of other non-meat binders, such as different proteins, starches, enzymes or gums, to improve overall quality of poultry products. Since PSE meat phenomenon is a growing problem in poultry meat industry, further studies should be performed to evaluate this kind of meat in different product formulations.

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