Effect of grape seed extract combined with modified atmosphere packaging on the quality of roast chicken

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ABSTRACT The purpose of this study was to screen out the appropriate concentration of grape seed extract solution and study the effects of grape seed extract combined with modified atmosphere packaging on the physical and chemical properties of roasted chicken during storage at 4°C. Samples were stored in 3 different packages: A (air packaging), M (modified atmosphere packaging, CO_2/N_2 = 40%/60%), and P (0.5% grape seed extract solution treatment combined with modified atmosphere packaging, CO_2/N_2 = 40%/60%). Microbiological analysis, pH, headspace composition, color, and lipid oxidation of roasted chicken were measured. The results showed that 0.5% is the suitable concentration of grape seed extract preservative for the storage of modified atmosphere packaged roast chicken. Compared with normal packaging (A) and single modified atmosphere packaging (M), 0.5% grape seed extract solution combined with modified atmosphere packaging (P) could effectively reduce the growth rate of total aerobic bacteria, *Pseudomonas* spp., mold, and yeast in roast chicken during low-temperature storage, reduce the lipid oxidation rate in roast chicken, and maintain the color stability of the product. This result could help the roast poultry processing industry to find more efficient ways to store and sell products.

Key words: grape seed extract, modified atmosphere packaging, roast chicken, shelf life, microbiological analysis

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INTRODUCTION

Chicken, as a kind of high-nutrient and low-fat food, is second only to pork in terms of global meat consumption (FAS/USDA, 2019). As a chicken product with unique flavor, roast chicken is very popular among consumers. However, the shelf life of roast chicken has limited the sales range and product quality of roast chicken–processing enterprises. Especially, the food corruption caused by microorganisms and even food safety issues have been considered as the focus of roast poultry enterprises.

In recent years, natural substances extracted from animals, herbs, fruits, and other substances have become more popular. Natural extracts often have certain functionalities, such as polyphenols, which often have excellent antibacterial and antioxidant properties. Different from chemical synthetic preservatives, natural functional substances applied to foods can better meet the modern people's pursuit of more "healthy" foods (excluding conventional chemical preservatives) (Petrou et al., 2012). The grape seed extract, as a functional substance, is extracted from the wine grape seed. It mainly consists of proanthocyanidins and a small number of monomeric polyphenols such as gallic acid and catechin. Studies have shown that grape seed extract has excellent antibacterial and antioxidant properties and shows good inhibitory effects on *Pseudomonas*, *Staphylococcus aureus*, and *Salmonella* (Bagchi et al., 2000; Perumalla and Hettiarachchy, 2011; Moradi et al., 2012). Although grape seed extract is beneficial for the human body, large doses of natural functional substances impart a strong flavor to the food and mask the taste of the food itself, which affects the quality of the food (Chouliara et al., 2007). Therefore, the combination of lower concentrations of natural functional substances with other preservation technologies such as

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low temperature and modified atmosphere packaging (**MAP**) has gradually become a new choice for food companies to improve product quality and shelf life.

MAP is a kind of new and effective food preservation technology. The food is placed in a high-barrier box with the specific gas component (CO_2, O_2, N_2, and so forth) instead of air, which can inhibit the microbial growth and enzymatic reactions, thereby maintaining food quality and extending shelf life (Mcmillin, 2008; Cooksey, 2014). Owing to the different nature of chemical gases, researchers use different types and proportions of gas combinations to achieve different food preservation needs. For example, fresh red meat often requires a high-oxygen modified atmosphere package to maintain the presence of oxygenated myoglobin, thereby maintaining color stability (Gunilla, 2011). According to our research, 40% CO_2/60% N_2 MAP could effectively inhibit the growth of total viable counts (**TVC**), lactic acid bacteria (**LAB**), molds, and yeasts; reduce the lipid oxidation; and maintain the color stability of roast chicken meat (Guo et al., 2018). Therefore, the main purpose of this study was to evaluate the effect of grape seed extract solution combined with MAP on the quality and shelf life of roast chicken during storage at 4°C.

MATERIALS AND METHODS

Sample Preparation

One hundred and 44 fresh chicken legs (350 ± 30 g each) were obtained from a poultry-processing plant in the Liaoning Province, China. Before roasting at 180 ± 5°C for 60 min, raw chicken legs were marinated in a ready-made pickled liquid (2.5% salt and some spices) for 15 h during the storage at 4 ± 1°C. First, 63 chicken legs were selected for roasting. After cooling, the chicken legs were sprayed with 5 different concentrations (0, 0.2, 0.5, 0.8, and 1.0%) of grape seed extract solution (2 ml/leg), then they were modified atmosphere packaged (40% CO_2/60% N_2). Three roast chicken were randomly selected from each group for the detection of the total number of colonies every 7 D (0, 7, 14, 21, 28 D). According to the growth of total aerobic bacteria in roast chicken, the appropriate concentration of grape seed extract solution was selected for the next experiment. Then, 81 roast chicken legs were randomly assigned to 3 packaging methods: normal packaging (**A**), MAP (CO_2/N_2 = 40%/60%, **M**), 0.5% grape seed extract solution treat and MAP (CO_2/N_2 = 40%/60%, **P**). All roast chicken samples were kept at 4 ± 1°C (Compressor-Cooled Incubator ICP260, Memmert GmbH, Schwabach, Germany) for up to 30 D. The A group was treated by the polyethylene film with oxygen permeability of 14,483 $cm^3/(m^2$ day atm), CO_2 permeability of 63,683 $cm^3/(m^2$ day atm), and water vapor permeability of 54 $g/(m^2$ day atm). MAP treatment was packaged in 25-μm-thick, low-density polyethylene and polyamide barrier pouches (1 leg/pouch), with oxygen permeability of 24 $cm^3/(m^2$ day atm) at 0% RH and 23°C, CO_2 permeability of 78 $cm^3/(m^2$ day atm) at 0% RH and 23°C, and water vapor permeability of 44 $g/(m^2$ day) at 100% RH and 38°C. The volume ratio of gas to product was 2.54. Samples were evaluated at fixed time intervals. Namely, the physicochemical analysis was made at 0, 6, 12, 18, 24, and 30 D of storage, while microbiological indicators were analyzed at 0, 7, 14, 21, and 28 D (n = 3 per group for each sampling time), respectively.

Microbiological Analysis

Immediately after aseptically opening the packages containing roast chicken, the meat was mixed with skin from the upper side of the chicken breast and thighs. Weight for each sample was normalized to 25 g and placed in stomacher bags containing 225 mL of saline and then patted evenly. Afterward, TVCs were measured according to the China National Food Safety Standard Method-Food microbiological examination (GB 4789.2-2016). *Pseudomonas* spp. was determined according to SN/T4044-2014. LAB were determined according to the GB 4789.35-2016. Mold and yeast were determined according to the GB 4789.15-2010. TVC was enumerated in Plate Count Agar (PCA agar; LuQiao Co., Beijing, China), and LAB was enumerated in Man Rogosa Sharpe agar (MRS agar; HaiBo Co., Qingdao, China). PCA and MRS plates were incubated at 37°C for 48 h under normal and anaerobic environment, respectively. *Pseudomonas* spp. was determined in *Pseudomonas* selective medium (HaiBo Co., Qingdao, China) after incubation at 28°C for 44 h under normal conditions. Mold and yeast were determined in Rose Bengal Medium (Rose bengal agar; HaiBo Co., Qingdao, China) after incubation at 28°C for 5 D under normal conditions.

Physicochemical Analysis

pH Measurement The pH of the samples was analyzed according to the way described by Mcgeehin et al. (2001). Briefly, 1 g of roast chicken meat sample was mixed with 10 mL of ice-cold solution (pH 7.0) which contains 5 mmol/L sodium iodoacetate and 150 mmol/L potassium chloride. The mixtures were then homogenized (Ultra Turrax T25; IKA, Königswinter, Germany) at 6,000 rpm for 30 s (2 × 15 s with a 5-s interval). The pH values were measured using a microprocessor pH meter (Hanna HI9025c; Hanna Instruments, Amorim, Portugal).

Headspace Gas Measurement Changes in headspace gas of M2/M3/M4 packages were measured using an Oxybaby 6.0i gas analyzer (Witt-Gasetechnik GmbH & Co., KG, Witten, Germany) before opening the package and then expressed as the percentage of O_2 and CO_2, respectively. The background gas was N_2. The values were the average measurements of 3 boxes and analyzed once every 6 D.

Color Evaluation Surface color was measured immediately after opening package at each sampling day using a CR-400 colorimeter (Minolta, Osaka, Japan) with

illuminant D65, 10° observer, 11 mm aperture for illumination and 8 mm for measurement (Contini et al., 2014). The chromaticity coordinates recorded were L* (lightness), a* (redness), and b* (yellowness). Readings were the average of 3 roast chicken samples of each treatment. Before measurement, the instrument was calibrated using a whiteboard.

Lipid Oxidation Assay Lipid oxidation was determined by the thiobarbituric acid (**TBA**) method as described by Salih et al. (1987) with some modifications (Utrera et al., 2014). Slightly, samples (5 g) were homogenized with 25 mL of trichloroacetic acid (7.5%, w/v) in ice bath at 13,500 rpm for 30 s. The slurry was filtered and centrifuged (13,000 g for 10 min). Aliquots (2 mL) were then mixed with 2 mL of TBA (0.02 M) in a centrifuge tube and then boiled in a water bath (100°C) for 40 min. The absorbance was measured at 532 nm after cooling. The TBA-reactive substances content was calculated according to a standard curve of 1, 1, 3, 3-tetraethoxypropane solution. Results were expressed as mg malondialdehyde (**MDA**) per kg of sample.

Statistical Analysis

Three replicates were performed for the experiments, and the results of the analysis were expressed as mean ± standard deviation of 3/5 repetitions. Microbiological data were transformed into logarithms of the number of colony-forming units (CFU/g). A two-way ANOVA was performed to determine significant differences between the treatments using the SAS 9.2 statistical software (SAS Institute Inc., Cary, NC, 2003). The data of headspace gas measurement were analyzed by the one-way ANOVA. In all cases, the level of statistical significance was $P < 0.05$.

RESULTS AND DISCUSSION

Selection of Grape Seed Extract Solution Concentration

According to our previous study, the shelf life of CO_2/N_2 = 40%/60%-modified atmosphere packaged roast chicken is about 21 D (Guo et al., 2018). Therefore, the appropriate grape seed extract solution concentration was selected based on the TVC of the roast chicken stored in 21 D. Figure 1 shows the TVC in roast chicken stored in the modified atmosphere packaged at 4°C under treatment with different concentrations of grape seed extract solution. On the 21st day of storage, the total aerobic bacteria count of the control group (sterile water treatment) was 4.06 log CFU/g, which is similar to that of our previous study. The TVC in roast chicken meat of 0.5% grape seed extract solution treatment was 3.76 log CFU/g, which was significantly lower than that of the control group ($P < 0.05$). During the storage period, when the concentration of grape seed solution was within the range of 0 to 0.5%, the TVC in the roasted chicken decreased with the increase of the concentration of the grape seed extract solution. When the concentration of grape seed extract fresh-keeping solution was 0.5∼1.0%, the difference of TVC in roasted chicken was not significant ($P > 0.05$), indicating that the difference between inhibition effects was not significant. This result is the same as that of the study by Raeisi et al. (2015), who studied the effects of 0.5 and 1% grape seed extract coating treatment on the TVC of rainbow trout fillets during storage at 4°C. Therefore, from the perspective of bacteriostatic effect and cost reduction, 0.5% grape seed extract solution was selected for the next experiment.

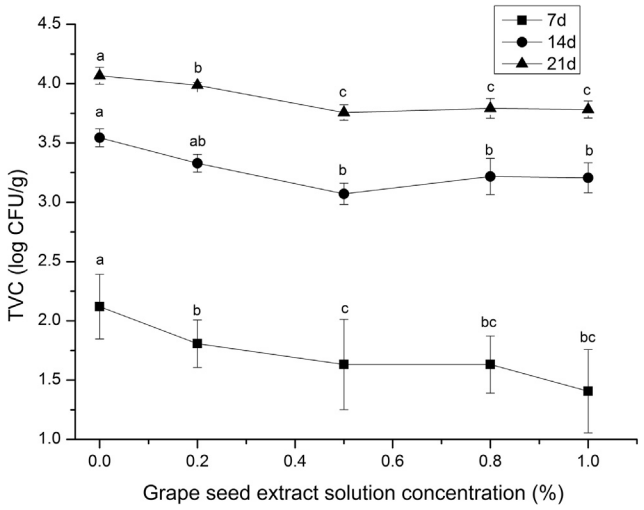

Figure 1. Effect of different concentrations of grape seed extract solution on the total viable counts (TVC) in roast chicken stored under modified atmosphere packing. Note: Error bars represent standard deviations of the mean (n = 3). Values with different letters were significantly different ($P < 0.05$).

Microbiological Analysis

Changes in TVC, Pseudomonas spp. count, LAB count, and yeast and mold count are shown in Figure 2A–D, respectively. As shown in Figure 2A, initially, TVC of the sample was 1.06 log CFU/g, indicating that the roast chicken was not seriously polluted during production, cooling, and packaging. With prolonged storage time, the TVC in the roast chickens of different treatment groups gradually increased, but there was a significant difference in the growth rate of TVC between different treatments ($P < 0.05$). The TVC in the A treatment increased rapidly, reaching 5.55 log CFU/g on the 14th day of storage, while the TVC of M treatment and P treatment was 3.56 log CFU/g and 3.14 log CFU/g, respectively. On the 21st day of storage, the TVC in the roast chicken of the grape seed extract solution treatment was 3.79 log CFU/g in 21 D, which was significantly lower than that in the MAP group (4.05 log CFU/g). The results of this study indicate that grape seed extract solution spray treatment combined with MAP could significantly inhibit the growth of TVC in roast chicken, and its inhibition effect was higher than that of single MAP. This result is consistent with reports by Carpenter et al. (2007), who studied the effect of MAP combined with grape seed extract on the TVC of raw pork

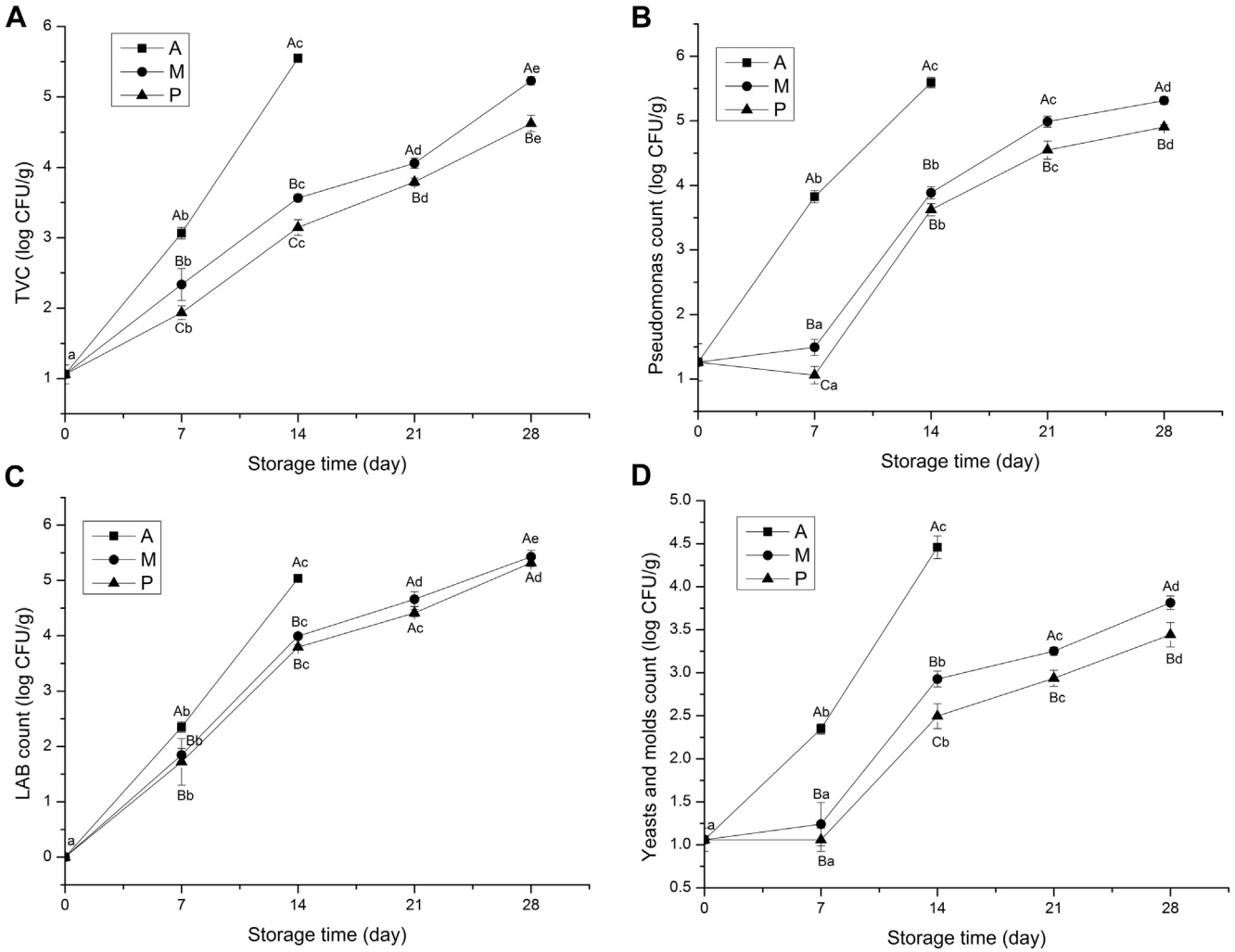

Figure 2. Effects storage time and packaging method on (log CFU/g) total viable counts (TVC) (A), *Pseudomonas* spp. (B), lactic acid bacteria (LAB) (C), molds and yeasts (D) during storage at 4°C. Note: A, roast chicken meat under air-packaging; M, roast chicken samples sealed in modified atmosphere packaging (MAP) with CO_2/N_2 (40%/60%); P, roast chicken samples sealed in MAP (CO_2/N_2 = 40%/60%) with 0.5% grape seed extract solution. Error bars represent standard deviations of the mean (n = 3). Values with different uppercase letters within the same sampling day were significantly different, and values with different lowercase letters in superscripts, within different storage time, were significantly different ($P < 0.05$).

loaves during storage. Studies have shown that the antibacterial properties of grape seed extract are mainly derived from the Proanthocyanidins (Rhodes et al., 2006). As for the specific bacteriostatic mechanism, further research is needed.

Pseudomonas spp., as a spoilage organism, is commonly found in meat products. As shown in Figure 2B, *Pseudomonas* spp. in the roast chicken was 1.26 log CFU/g at the initial stage of storage. On the seventh day of storage, the number of *Pseudomonas* spp. in the normal packaged roast chicken was significantly increased, and the number of *Pseudomonas* spp. in the MAP treatment group was significantly higher than that in the grape seed extract solution treatment group ($P < 0.05$). However, there was no significant difference in the number of *Pseudomonas* spp. in roast chicken between the 2 types of MAP groups compared with that on day 0. This indicates that the combination of low temperature and MAP can fully inhibit the growth of *Pseudomonas* spp. in roast chicken 7 D before storage, while the grape seed extract preservation treatment enhances the inhibitory effect. The number of *Pseudomonas* spp. in roast chicken in the A treatment reached 5.59 log CFU/g on the 14th day, and the number of *Pseudomonas* spp. in the M and P treatment was 5.31 log CFU/g and 4.90 log CFU/g on the 28th day, respectively. This result indicates that grape seed extract treatment can effectively inhibit the growth of *Pseudomonas* spp. in roast chicken. This result is similar to that of the report by Raeisi et al. (2015) who studied that 0.5% grape seed extract coating treatment could inhibit the growth rate of *Pseudomonas* spp. in rainbow trout fillets during storage at 4°C.

Figure 2C shows the growth of LAB in roasted chicken under different treatments. On day 0, the number of LAB in roast chicken was below the detection limit. This was mainly because LAB are facultative anaerobic bacteria, which are found in an aerobic environment during the process from roasting to packaging, and there is fewer LAB in contact. On the 14th day, the number of LAB in the roast chicken of the A group reached 5.04 log CFU/g, which was significantly higher than the

number of LAB in the M group and the P group ($P < 0.05$). On the 21st day, the number of LAB in the roast chicken in the M group was 5.41 log CFU/g. Compared with A treatment, M treatment could significantly inhibit the growth of LAB in roast chicken. However, owing to the facultative anaerobic growth characteristics of LAB, its inhibitory effect on LAB was less than that on total aerobic bacteria and *Pseudomonas* spp. During the storage period, no significant difference was found between the number of LAB in groups M and P, which might be mainly because of the resistance of the LAB to the antibacterial effect of grape seed extract (Sara, 2004). Aminzare et al. (2018) studied the effects of grape seed extract on the physical and chemical properties of cooked sausages during storage. The results showed that the addition of 0.02∼0.16% grape seed extract could not inhibit the growth of LAB in cooked sausages. Raeisi et al. (2015) explored the effects of essential oils and grape seed extracts on the shelf life of rainbow trout fillets. The results showed that the addition of a single 0.5% grape seed extract did not inhibit the growth of LAB in fish meat. These reports are consistent with our research.

As shown in Figure 2D, the initial yeast and mold count of different treatment groups displayed different growth trends from the same starting point: 1.06 log CFU/g (day 0). The MAP treatment and 0.5% grape seed extract treatments significantly inhibited yeast and mold in roast chicken samples during storage at 4°C. On the 14th day of storage, the mold and yeast count in the A group reached 4.46 log CFU/g. The mold and yeast count in group M and group P was 3.81 log CFU/g and 3.44 log CFU/g on the 28th day of storage, respectively. This showed that the MAP could effectively inhibit the growth of mold, and the grape seed extract solution treatment combined with the MAP could further enhance the inhibition effect. The results of this study are similar to those of the study by Singh et al. (2018), in which 0.2% grape seed extract could significantly reduce the growth rate of mold and yeast in water beef slices. Wang et al. (2015) also reported the inhibitory effect of grape seed extract on the growth of mold and yeast in cured bacon.

Physicochemical Change

pH Value Table 1 shows the pH changes of the 3 groups of samples during storage at 4°C. The initial pH values of the A, M, and P samples were 6.80, 6.88, and 6.72, respectively. On the 18th day, the final pH of the packaged sample of the A group was 6.82, and the pH of the M group and P group on the 30th day was 6.78 and 6.85, respectively. There was no significant difference in pH values between the A and P samples throughout the storage period. The pH of the M group samples decreased somewhat during the storage period, but the overall difference was not significant. Changes in meat pH are influenced by a variety of factors. Studies have shown that CO_2 could dissolve in water in MAP producing carbonic acid which decreases the pH of the product

Table 1. The changes in pH with the time of storage at 4°C using different packaging methods.

	pH		
Storage time (days)	A	M	P
0	6.80 ± 0.09	6.88 ± 0.03[a]	6.72 ± 0.08
6	6.70 ± 0.02	6.84 ± 0.11[a,b]	6.80 ± 0.15
12	6.88 ± 0.11	6.95 ± 0.09[a]	6.95 ± 0.10
18	6.82 ± 0.01	6.74 ± 0.01[a,b]	6.89 ± 0.02
24	ND	6.66 ± 0.04[b]	6.77 ± 0.07
30	ND	6.78 ± 0.07[a,b]	6.85 ± 0.01
		P values	
Treatment		< 0.05	
Storage time		< 0.001	
Treatment × storage time		< 0.01	

[a,b]Values with different letters were significantly different ($P < 0.05$).

A, roast chicken meat under air-packaging; M, roast chicken samples sealed in MAP with CO_2/N_2 (40%/60%); P, roast chicken samples sealed in MAP (CO_2/N_2 = 40%/60%) with 0.5% grape seed extract solution. Error bars represent standard deviations of the mean (n = 3).

Abbreviation: MAP, modified atmosphere packaging; ND, not detected.

(Leygonie et al., 2011). Changes in the number of microorganisms such as LAB that produces acidic or alkaline substances also affect pH changes. In addition, the buffering capacity of the meat tissue itself also reduces the degree of pH change (Al-Nehlawi et al., 2013). Most of the microbes in roast chicken are killed by high-temperature roasting. Therefore, microbial contamination in roast chicken was mainly concentrated on roast chicken skin, which greatly reduced the influence of microbial growth and reproduction on the pH value of roast chicken. The pH value of the MAP treatment group sample decreased slowly after 18 D. This might be due to the dramatic increase in the number of certain acidogenic microorganisms such as LAB in the later period. The pH of the sample treated with 0.5% grape seed extract solution was not significantly reduced, which might be due to the addition of natural functional substances to cause a certain change in the microbial species in the roast chicken. This result is consistent with the findings of the study by Brannan (2010), in which GSE had no effects on the moisture content or pH of the chicken pie during storage. This result is also similar to the report by Zhai et al. (2017), who studied the pH changes during the storage of MAP salted ducks.

Headspace Gas Change Figure 3 shows the change in CO_2 content in the boxes of the M and P groups during storage. The CO_2 content in the M and P groups rapidly decreased by about 10% in the 6 D and then showed a stable trend within 18 D of storage. This was possibly because carbon dioxide is easily soluble in water and fat. Studies have shown that this change is most intense in the first 24 h in the storage (Al-Nehlawi et al., 2013). After storage for 18 D to 24 D, the carbon dioxide content in the boxes of M and P groups decreased significantly, reaching 28.18 and 26.34%, respectively. In our previous study, the CO_2 content in the 40% CO_2/60% N_2 MAP also showed a significant decrease on the 20th day of storage (Guo et al., 2018). This might be due to the action of certain microorganisms in the modified

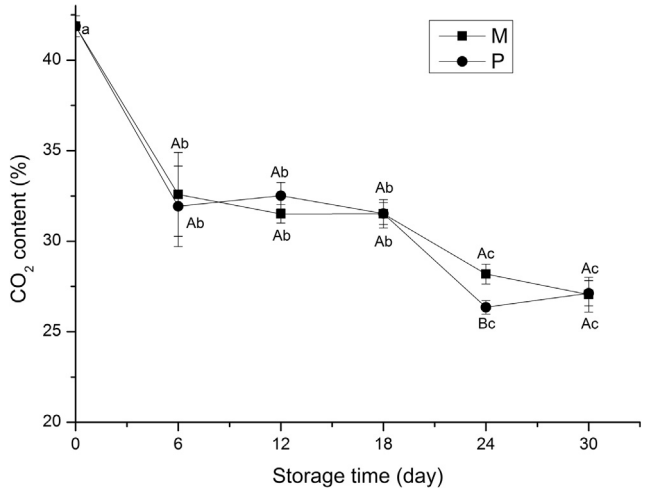

Figure 3. Effect of storage time on carbon dioxide content in CO_2/N_2 packaged at 4°C. Note: M, roast chicken samples sealed in modified atmosphere packaging (MAP) with CO_2/N_2 (40%/60%); P, roast chicken samples sealed in MAP (CO_2/N_2 = 40%/60%) with 0.5% grape seed extract solution. Error bars represent standard deviations of the mean (n = 3). Values with different uppercase letters within the same sampling day were significantly different, and values with different lowercase letters in superscripts, within different storage time, were significantly different ($P < 0.05$).

atmosphere of packaged roast chicken. However, the specific mechanism needs further research.

Color Evaluation Color is an important factor that directly affects consumers' purchase of roasted poultry products, especially the redness value (a*) of the product. Table 2 reflects the effect of different treatment groups on the color of roast chicken. As can be seen from Table 2, the initial redness values of the samples of groups A, M, and P were 19.16, 19.71, and 21.41, respectively. Within 18 D of storage, 0.5% grape seed extract–sprayed roast chicken redness value was higher than that of the A group, which might be mainly due to the redness of the solution, which increased the redness of the roast chicken. The study of Brannan (2009) has shown that 0.1% grape seed extract added to chicken pie could significantly increase the redness value of the product. However, there was no significant difference between the color of roast chickens in the M and P groups, which indicates that the effect of increasing the redness value of the roast chicken with the grape seed extract solution is limited. This might be mainly due to the lower concentration of the solution and the way that the spray is processed. As shown in Table 3, the initial redness values of the samples of groups A, M, and P were 40.72, 40.92, and 42.91, respectively. There was no significant difference in L* between the 3 treatment groups throughout the storage period. The L* value of roast chickens in the A and M treatment groups increased within 6 to 12 D, probably due to the condensation of water on the surface of the roast chicken resulting from the low temperature and high humidity storage environment. The L* value of the roast chicken in the P treatment did not change significantly during the whole storage period ($P > 0.05$), which might be due to the increase of the initial L* value of the roast chicken by the spraying treatment of the grape seed extract solution. The results of this study are consistent with reports by Contini et al. (2014) regarding the effect of citrus extract active packaging on the L* value of cooked turkey.

Lipid Oxidation The measurement results of lipid oxidation were expressed by the number of MDA mg/kg of meat, as shown in Table 4. The initial lipid oxidation value of the sample was 1.53∼1.84 mg/kg. The content of MDA in the 3 treatments showed an upward trend. The content of MDA in group A was significantly higher than that in the other groups ($P < 0.05$). On the 18th day of storage, the MDA content in the roast chickens of the A, M, and P treatment groups was 4.55, 2.44, and 2.16 mg/kg, respectively, and the difference of MDA content between the M group and the P group was not significant

Table 2. Effects storage time and packaging method on redness during storage at 4°C.

	a*		
Storage time (D)	A	M	P
0	19.16 ± 1.03^{A}	19.71 ± 0.92^{A,B}	21.41 ± 0.89^{B}
6	19.28 ± 0.57	20.73 ± 1.21	20.13 ± 0.54
12	20.12 ± 0.96^{A}	20.98 ± 0.98^{A,B}	22.05 ± 1.62^{B}
18	19.79 ± 0.68^{A}	20.98 ± 0.75^{B}	22.20 ± 1.27^{B}
24	ND	20.47 ± 1.07	20.03 ± 0.62
30	ND	20.91 ± 0.66	20.41 ± 0.43
		P values	
Treatment		< 0.0001	
Storage time		< 0.0001	
Treatment × Storage time		< 0.01	

^{A,B}Values with different uppercase letters within the same sampling day were significantly different ($P < 0.05$).

A, roast chicken meat under air-packaging; M, roast chicken samples sealed in MAP with CO_2/N_2 (40%/60%); P, roast chicken samples sealed in MAP (CO_2/N_2 = 40%/60%) with 0.5% grape seed extract solution. Error bars represent standard deviations of the mean (n = 3).

Abbreviation: MAP, modified atmosphere packaging; ND, not detected.

Table 3. Effects storage time and packaging method on lightness during storage at 4°C.

	L*		
Storage time (D)	A	M	P
0	40.72 ± 2.19^{a}	40.92 ± 1.25^{a}	42.91 ± 1.11
6	43.93 ± 1.87^{b}	41.63 ± 2.07^{a}	43.95 ± 1.18
12	45.84 ± 0.84^{b}	45.36 ± 2.18^{b,c}	43.30 ± 1.87
18	42.57 ± 1.49^{a,b}	41.38 ± 0.77^{a}	44.33 ± 0.72
24	ND	43.97 ± 1.32^{a,c}	43.78 ± 0.96
30	ND	43.78 ± 2.53^{a,c}	43.00 ± 0.94
		P values	
Treatment		> 0.05	
Storage time		< 0.0001	
Treatment × storage time		< 0.0001	

$^{a\text{-}c}$Values with different lowercase letters in superscripts, within different storage time, were significantly different ($P < 0.05$).

A, roast chicken meat under air-packaging; M, roast chicken samples sealed in MAP with CO_2/N_2 (40%/60%); P, roast chicken samples sealed in MAP (CO_2/N_2 = 40%/60%) with 0.5% grape seed extract solution. Error bars represent standard deviations of the mean (n = 3).

Abbreviation: MAP, modified atmosphere packaging; ND, not detected.

($P > 0.05$). The results showed that anaerobic packaging inhibited the lipid oxidation of roast chicken, and the inhibition effect of grape seed extract spray treatment combined with MAP was better. Conchillo et al. (2003) studied the combined effects of different cooking methods (grilling and baking) and packaging conditions on lipid oxidation of chicken breast, indicating that the anaerobic environment significantly inhibited the lipid oxidation rate of chicken. Mielnik et al. (2006) reported that 1.6 g/kg grape seed extract could effectively inhibit lipid oxidation of cooked turkey meat during cold storage, which is similar to our research. The study showed that GSE was an effective antioxidant in ground chicken thigh meat for inhibiting TBA-reactive substances formation, which was beneficial for mitigating the prooxidative effects of NaCl (Brannan, 2010). This is very advantageous for the storage of roast chicken products that need to be marinated with saline solution before roasting.

CONCLUSIONS

The experimental results showed that 0.5% was the suitable concentration of grape seed extract preservative for the storage of modified atmosphere packaged roast chicken. The 0.5% grape seed extract solution could effectively decrease the growth rate of total aerobic bacteria, *Pseudomonas* spp., mold, and yeast in roast chicken during low-temperature storage, reduce the fat oxidation rate in roast chicken, and maintain the color stability of the product. Compared with normal packaging (A) and single MAP (M), the storage method of grape seed extract solution combined with MAP (P) could effectively extend the shelf life of roast chicken

Table 4. Effects of storage time and packaging method on lipid oxidation (mg/kg) in roast chicken meat at 4°C.

	MDA (mg/kg)		
Storage time (D)	A	M	P
0	1.72 ± 0.06^{a}	1.84 ± 0.42^{a}	1.53 ± 0.19^{a}
6	3.44 ± 0.15^{A,b}	2.07 ± 0.08^{B,ab}	1.54 ± 0.11^{C,a}
12	3.55 ± 0.20^{A,b}	2.12 ± 0.28^{B,ab}	1.70 ± 0.28^{B,ab}
18	4.55 ± 0.67^{A,c}	2.44 ± 0.50^{B,b}	2.16 ± 0.19^{B,bc}
24	ND	2.72 ± 0.19^{A,bc}	2.21 ± 0.20^{B,bc}
30	ND	3.11 ± 0.13^{A,c}	2.29 ± 0.12^{B,c}
		P values	
Treatment		< 0.0001	
Storage time		< 0.0001	
Treatment × storage time		< 0.0001	

$^{A\text{-}C}$Values with different uppercase letters within the same sampling day were significantly different, and $^{a\text{-}c}$values with different lowercase letters in superscripts, within different storage time, were significantly different ($P < 0.05$).

A, roast chicken meat under air-packaging; M, roast chicken samples sealed in MAP with CO_2/N_2 (40%/60%); P, roast chicken samples sealed in MAP (CO_2/N_2 = 40%/60%) with 0.5% grape seed extract solution. Error bars represent standard deviations of the mean (n = 3).

Abbreviations: MAP, modified atmosphere packaging; MDA, malondialdehyde; ND, not detected.

and could store roast chicken products for more than 21 D. This result will help the roast poultry–processing industry to find more efficient ways to store and sell products.

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