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Mite Control and Sensory Evaluations of Dry-Cured Hams with Food-Grade Coatings

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Abstract: The ham mite, *Tyrophagus putrescentiae* (Schrank; Sarcoptiformes: Acaridae), is the predominant pest of dry-cured pork during aging. This research was conducted 1) to determine the minimal concentrations of propylene glycol necessary for food grade coatings to control mites; and 2) to determine if sensory differences could be detected in hams that were treated with food grade coatings in commercial facilities using difference from control sensory tests. Ham cubes coated with either xanthan gum + 15% propylene glycol or propylene glycol alginate + carrageenan + 7.5% propylene glycol were the lowest propylene glycol concentrations that were effective ($P < 0.05$) at controlling mite infestations under laboratory conditions. Whole hams from commercial plants that were dipped with coatings were slightly different ($P < 0.05$) from the non-dipped control hams with respect to flavor, texture and moistness in the first trial. However, hams sprayed with coatings, a lower-cost application than dipping, did not cause sensory differences ($P > 0.05$) when compared to the control with respect to flavor, texture, moistness, and weight loss in trial 2. This research indicated that dry-cured ham processors could potentially spray these coatings on dry-cured hams during aging to control mite infestations in their plants without negatively impacting the sensory quality of the hams.

Keywords: dry-cured ham, food-grade coatings, ham mite, propylene glycol, *Tyrophagus putrescentiae*
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Introduction

Dry-cured hams, referred to as southern country hams in the United States, are produced from the hind leg of a hog and cured by rubbing a dry salt curing mix on the surface of the hams, followed by salt equalization and aging (Marriott and Ockerman, 2004; Zhao et al., 2016). Unique characteristic flavors and aromas are developed during aging due to extensive lipolysis and proteolysis (Toldrá and Flores, 1998). The amount of time that hams are aged varies from 3 to 36 mo depending on the aging condition and the region (Toldrá, 2010). The ham mite, *Tyrophagus putrescentiae* (Schrank; Sarcoptiformes: Acaridae), also known as the mold, cheese or copra mite, infests stored food products, such as grains, whole wheat flour, soy flour, peanuts, cheese, nuts, copra (dried coconut), dried eggs, bacon, and dry-cured hams (Hughes, 1976; Van Hage-Hamstem and Johansson, 1992). Due to the high fat and protein composition, water activity and moldy surface, dry-cured hams have a high susceptibility to mite infestations starting at 4 to 6 mo into the aging process (García, 2004; Rentfrow et al., 2008). Dry-cured hams are aged in environments that facilitate mite reproduction and population growth (Sánchez-Ramos and Castañera, 2000; Rentfrow et al., 2012). The optimal growth conditions for ham mites include 23.2 ± 2.1°C and 71 ± 5.6% relative humidity (Sánchez-Ramos and Castañera,

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2005; Sánchez-Ramos et al., 2007; Aspaly et al., 2007; Qu et al., 2015), which are similar to the temperatures and relative humidities in dry-cured ham aging houses.

Methyl bromide is a fumigant pesticide that has been used globally to control pests in stored commodities and processing facilities (Fields and White, 2002). It also has been used as a quarantine treatment to prevent the movement of exotic pests across boarders since the 1930s (Fields and White, 2002). Methyl bromide is a stratospheric ozone layer depleting substance (Marriott and Schilling, 2004) and is being phased out of all industries by the United Nations through the Montreal Protocol, an international agreement ratified by more than 180 countries (Fields and White, 2002). As of 2008, 22 out of 35 dry-cured ham plants in the United States used methyl bromide fumigation to control ham mites (Rentfrow et al., 2008). The only 2016 critical use exemptions for methyl bromide by the U.S. Environment Protection Agency were the California strawberry fruit growers and dry-cured pork producers (EPA, 2015). However, it was determined in 2015 that methyl bromide stocks are available for use by the U.S. dry-cured pork industry and therefore there is not currently a need for a critical use exemption until existing stocks are depleted (EPA, 2015).

Food grade coatings and edible films have been used on candies, fresh fruits, vegetables, and processed meat products to enhance appearance, texture, stability or quality and reduce water loss (Baldwin, 2007). Food grade coatings made with propylene glycol alginate, carrageenan, xanthan gum, water, and propylene glycol as the active ingredient were previously effective at controlling mites on ham cubes (Zhao et al., 2016; Abbar et al., 2016). Propylene glycol alginate (21CFR172.858), carrageenan (21CFR172.626), xanthan gum (21CFR172.695), and propylene glycol (21CFR184.1666) are generally recognized as safe compounds. The minimum effective concentration for propylene glycol was 10% for propylene glycol alginate and carrageenan and 20% for xanthan gum (Zhao et al., 2016). Similar coatings with 20 and 40% propylene glycol significantly reduced mite colonization and residency on treated whole hams (Abbar et al., 2016). If the propylene glycol concentration in these coatings could be decreased further, it would substantially reduce coating costs. However, no results have been reported on whether these coatings cause a perceivable difference between dry-cured hams that are not treated with coatings. Therefore, the first objective of this paper was to determine the lowest concentration of propylene glycol that controls mite growth on dry-cured ham cubes; the second objective was to apply the coatings in commercial ham aging facilities and evaluate the sensory differences between hams that were treated with coatings prior to aging and non-treated control hams by utilizing difference from control sensory tests.

Materials and Methods

Dry-cured hams in the mite reproduction assays were purchased from a commercial facility. For coating trials, dry-cured hams were provided by commercial plants. The Institutional Animal Care and Use Committee was not needed since this research was conducted on commercially available meat products.

Coating composition optimization

Materials. Propylene glycol (Essential Depot, Sebring, FL) was included at concentrations of 0, 10, 15, and 20% in coatings made with 1% Xanthan gum (TIC Gums, White Marsh, MD) in water. In addition, propylene glycol concentrations of 0, 2.5, 5, 7.5 and 10% were used in coatings made with 1% propylene glycol alginate (TIC Gums, White Marsh, MD) and 1% carrageenan (TIC Gums, White Marsh, MD). A coating with 10% propylene glycol with 0.5% propylene glycol alginate and 0.5% carrageenan was also evaluated to determine if a lower concentration of gum could be used in the formulation.

Ham cube preparation. Dry-cured hams that had been aged for approximately 90 d, weighing approximately 8 kg each, were purchased from a commercial dry-cured ham plant. Ham slices (2.5 cm thickness) were cut from each ham, and slices were cut to 2.5 × 2.5 × 2.5 cm^3 cubes. Xanthan gum coatings were solubilized at room temperature, PGA + CG coatings were solubilized with boiling water using a hot stir plate and then cooled to between 28 and 30°C (Zhao et al., 2016). Ham cubes (n = 5) were randomly selected and dipped directly into each treatment of the food grade coatings for 10 s with a cotton string and allowed to drip for one min to dry prior to wrapping in wax paper (Reynolds Consumer Products, LLC, Lake Forest, IL) and packaging in Zip-loc bags (Johnson & Son, Inc, Racine, WI). Bags were then packaged with icepacks and shipped overnight to Kansas State University (Manhattan, KS) and mite reproduction assays were conducted.

Mite reproduction assay. Mites were from a laboratory colony at Kansas State University that were reared using the methods described by Abbar et al. (2016). Twenty mixed sex adult *T. putrescentiae* (2 to 3 wk old from culture) with an average of 10 to 12 females were inoculated onto each cube in a randomized order. Each cube was placed in a glass mason jar (216 mL,

65mm diameter, 55 mm height; Ball Corp., Broomfield, CO) and incubated at 25 ± 1°C and 70% relative humidity for 14 d. Resulting populations of mobile adult and immature mites on the ham cubes were counted using a dissecting stereo-microscope (Olympus Model SZX10, Olympus Surgical and Industrial America INC, Orangeburg, NY) in a randomized order after 2 wk of incubation to determine how well coatings inhibited the 20 initial mites from reproducing.

Application of food grade coatings to whole dry-cured hams

Materials. Food grade coatings that were developed by Zhao et al. (2016) were used to dip whole hams prior to aging. For the first trial, whole hams from each plant were dipped in either xanthan gum only, propylene glycol alginate + carrageenan only (PGA + CG only), xanthan + 20% propylene glycol (XG + 20% PG), propylene glycol alginate + carrageenan + 20% propylene glycol (PGA + CG + 20% PG), propylene glycol alginate + carrageenan + 40% propylene glycol (PGA + CG + 40% PG) or PGA + CG + 20% PG net only (net only). For the "net only" treatment, only the nets used by the processors were dipped in PGA + CG + 20% PG coating solution instead of the whole hams. Xanthan, PGA, and CG were used at 1% and control hams were not dipped and placed next to the coating dipped hams. Xanthan gum coatings were solubilized in room temperature water. Propylene glycol alginate + CG coatings were solubilized in PG and water was added into the mixture as the solution was heated to a boil. Propylene glycol alginate + CG based coatings were then cooled to 30 to 35°C (Zhao et al., 2016). Greater concentrations of PG were used in both plant trials in comparison to concentrations that were used in laboratory testing. We presumed that if high concentrations of PG did not cause noticeable sensory differences between control and treatment hams, then it is unlikely that lower concentrations would cause noticeable sensory differences. The first trial was conducted in the summer of 2014 in 3 commercial processing facilities in Tennessee and Virginia and in a simulated aging house at Mississippi State University for a total of 4 locations. In this initial trial, whole hams were dipped in coatings and aged for approximately 6 mo prior to sensory evaluation.

To reduce coating application cost and reduce sensory differences between hams, a paint gun with a high pressure spray nozzle (Wagner Flexio 590, Plymouth, MN) was used in the second trial to spray the coatings onto the whole hams. One liter of coating was used to coat 2 hams for each treatment. Based on the results from the first trial, the treatments in the second trial included the control, PGA + CG only, PGA + CG + 10% PG, PGA + CG + 20% PG, and XG + 20% PG. The second trial was conducted in the summer of 2015 in 3 different processing facilities in Tennessee and Virginia and the simulated aging house at Mississippi State University for a total of 4 locations. Propylene glycol alginate + CG + 20% PG and XG + 20% PG treated hams were evaluated for sensory differences, since greater concentrations of PG would potentially have a greater impact on sensory properties than lower concentrations, if any differences existed.

Whole hams and aging. The dry-cured hams that were used had finished the salting and equalization steps and were ready to be placed in the aging house. The hams were treated with coatings and then placed in the aging house with the other commercial hams that were produced that day. The aging environment varied within each processing facility with aging temperatures and relative humidities between 24 and 28°C and 60 to 80% relative humidity, respectively. The genetic breeds of the hogs used in each plant were different according to the processors, which included the breeds of Berkshire, Gloucester Old Spots, Red Wattle, Tamworth, Yorkshire, Hampshire, and Duroc cross, etc. Whole hams were aged for approximately 6 mo. After aging, each facility sent hams back to Mississippi State University for sensory evaluation. In addition, the weight of the hams in the second trial was recorded for moisture loss to verify that hams were losing enough moisture for the hams to be preserved.

Sensory evaluation-difference from control test. Difference from control tests were performed to determine if trained panelists could perceive a difference between control ham samples and coating-treated samples. Institutional Review Board (IRB) protocol number 11–230 was approved on 23 August 2011 for "Sensory quality and consumer acceptability of dry-cured ham exposed to processing aides designed to combat pest infestations". A continuous IRB protocol number 15–246 was approved on 29 July 2015 through 31 August 2018 for "Sensory quality and consumer acceptability of dry-cured ham exposed to food grade coatings, lactic acid fermentation, and other food safe methods for controlling pest infestations". Coatings on hams were washed off with tap water (20°C) at room temperature prior to slicing. Hams were sliced (1.3 cm thickness) in the meat laboratory at Mississippi State University using a band saw (Butcher Boy, Lasar Manufacturing Company, Inc., Los Angeles, CA). Slices were then vacuum packaged into vacuum bags (standard barrier, PVdC, 36 cm × 51 cm, WVTR ≈ 0.4 g/100 in2/24 h, Curwood, Inc., New London, WI) with a dual-chamber ULTRAVAC vacuum packaging

machine (Model UV2100, Koch Equipment, Kansas City, MO) at vacuum level of 99% and stored for 1 to 2 wk at 0 to 4°C prior to cooking. Refrigerated ham slices were equilibrated to room temperature prior to baking. Each ham slice was wrapped in aluminum foil and oven-baked at 177°C to an internal temperature of 71°C according to traditional cooking methods by Marriott and Ockerman (2004). The internal temperature was checked using an infrared thermometer (Horiba IT-330, Horiba Inc., Irvine, CA). Each ham slice was cut into square pieces with similar sizes (1.3 cm × 1.3 cm) from the same muscle (Fig. 1). Sensory sampling was mainly from muscle section 1, and 2 pieces were from section 2 or 3 when needed (Fig. 1). Upon serving, ham pieces were placed into 29.5 mL clear plastic containers that were coded with 3-digit random numbers. Each panelist was served samples from the same location on the same muscle for each treatment to avoid sensory variability between muscles. Panelists were trained for 2 wk with 6 sessions and 3 to 5 samples of coated hams and control hams per session to evaluate overall differences in flavor, texture, and moistness by 2 faculty members with experience conducting descriptive panels on dry-cured ham (Pham et al., 2008). A labeled control sample was provided as a reference along with the treated samples. A blind control with a 3-digit random number was included in each test as a baseline to account for natural random variation between samples. Trained panelists (n = 6 to 10, 12 panels per trial, an average of 100 overall ratings for each treatment for each descriptor), each with greater than 30 h of experience in tasting dry-cured ham, were asked to taste the labeled control first and then evaluate samples in a randomized order with 2 or 3 coated hams and blind control hams to rate how different the treatment samples were from the control with respect to flavor, texture, and moistness in 3 sessions each week. Water, apple juice, unsalted crackers, napkins, forks, and expectorant cups were provided to the panelists who were seated in separate booths during each panel. Panelists cleansed their palate with unsalted crackers, apple juice and water during a mandatory 20 s break between each sample. The scale for the difference from control test was: 1 = no difference, 2 = slight difference, 3 = moderate difference, 4 = large difference, 5 = very large difference (Meilgaard et al., 2007).

Prices of the coatings

Ingredient prices were provided by the supplier source based on the market in 2015. The prices of coatings (500 mL) for one ham were calculated based on these information. However, our research team was asked not to disclose the ingredient price information. There was only one source of price for each ingredient in the formulation, thus, no statistical analysis was needed.

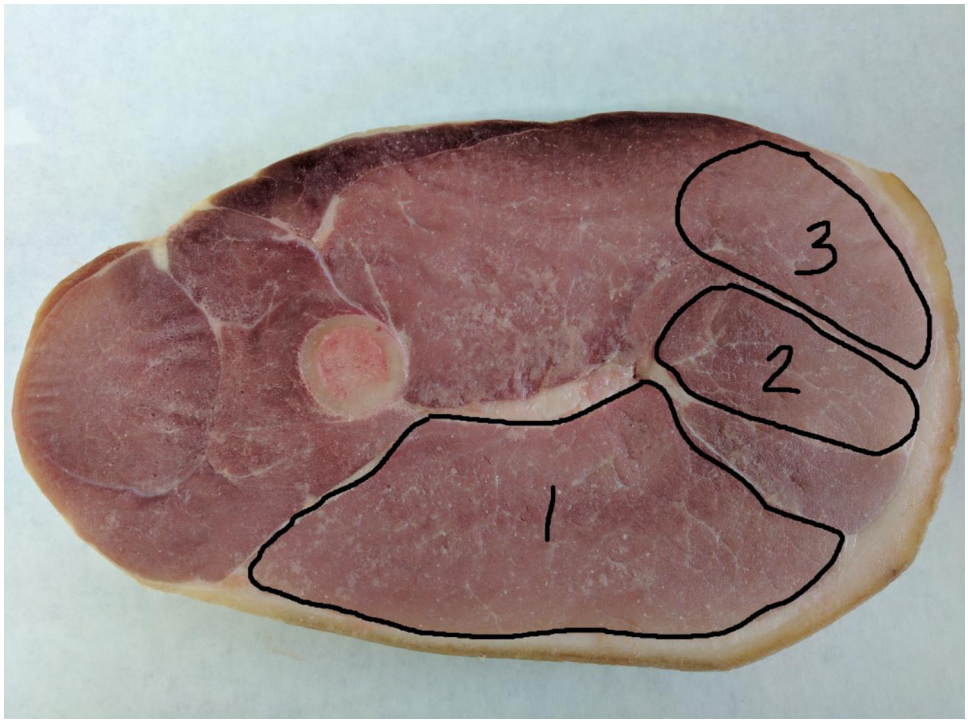

Figure 1. Photograph of a slice from an aged ham typical of those studied here, showing the 3 sampling areas for sensory evaluation: 1: M. Biceps femoris; 2: M. Semitendinosus; 3: part of M. Semimembranosus

Statistical analysis

A completely randomized design with 5 replications of each treatment (each cube as an experimental unit) was used to determine the effectiveness of PG concentrations in the coatings on controlling mite population growth on treated ham cubes. A randomized complete block design with location serving as a block was utilized for the 2 commercial trials to evaluate if trained panelists (n = 6 to 10, 12 panels per trial, an average of 100 overall ratings for each treatment for each descriptor) could detect a difference between coated and non-coated ham samples ($P < 0.05$). A randomized complete block design with location serving as a block was used for the weight loss of hams in the second trial. Statistical analyses were conducted using Compusense (Compusense 5.2 and Compusense Cloud, Guelph, CA) for collecting data and SAS statistical software (version 9.4, SAS Inst. Inc., Cary, NC). Procedure GLM was used to compare response variables among the different treatments. When differences ($P < 0.05$) occurred among treatments, Tukey's Honest Significance Difference Test ($P < 0.05$) was used to separate treatment means.

Table 1. Mean number of mites on inoculated ham cubes (20 mites/cube, n = 5) coated with propylene glycol alginate + carrageenan and xanthan gum at different percentage of propylene glycol after 2 wk incubation at 25°C and 70% relative humidity

Gum treatment[1,2]	PG	Mean no. of mites	SEM
Control	0%	517[a]	19
PGA (1%) + CG (1%)	0%	522[a]	
PGA (1%) + CG (1%)	2.5%	337[b]	
PGA (1%) + CG (1%)	5%	101[c]	
PGA (1%) + CG (1%)	7.5%	16[d]	
PGA (1%) + CG (1%)	10%	4[d]	
PGA (0.5%) + CG (0.5%)	10%	4[d]	
Control	0%	270[a]	20
XG (1%)	10%	80[b]	
XG (1%)	15%	15[c]	
XG (1%)	20%	5[c]	

[a–d]Means with same letter within the column for each gum (PGA + CG or XG) are not significantly different ($P > 0.05$) using Tukey's Honestly Significant Difference Test at 5% significance level.

[1]Control ham was not coated.

[2]PGA: propylene glycol alginate, CG: carrageenan, PG: propylene glycol, XG: xanthan gum.

Results and Discussion

Mite reproduction assay

No difference existed ($P > 0.05$) in number of mites between the control and 1% PGA + CG coating without PG added (Table 1). Adding 2.5% PG to PGA + CG resulted in fewer mites ($P < 0.05$) than the control and 1% (PGA + CG) treatments (Table 1). As PG concentration increased to 7.5%, mite counts decreased ($P < 0.05$). No difference existed in number of mites among the 7.5 and the 10% PG treatments regardless of concentration of PGA and CG. In addition, the 7.5 and 10% PG treatments had fewer mites than the initial inoculation level of 20 mites, suggesting that mites may not have produced in the jar and that some of the adults from the original inoculation had died. Propylene glycol alginate and CG should be included in the coating at 1% since the concentration was thicker and adhered better to the ham surface than the 0.5% treatment. The most cost-effective concentration for PG in PGA + CG coatings was 7.5% under laboratory conditions. The XG treatment with 10% PG had fewer mites than the XG treatment with 0% PG ($P < 0.05$; Table 1). In addition, XG with 15 and 20% PG had fewer mites ($P < 0.05$) than the XG + 10% PG treatment. The XG 15 and 20% PG treatments controlled mites since there were fewer mites than the initial 20 mites that were placed on the ham cubes. The most cost effective concentration of PG that controlled mites was 15% for xanthan gum coatings under laboratory conditions.

In previous research, incorporation of 20, 30, 40 and 50% PG in PGA + CG and XG coatings were effective at controlling mites (Zhao et al., 2016). Plasma-treated fibers with chitosan/Ag^+ coating were toxic to synanthropic mites including *T. putrescentiae* (Rahel et al., 2012). Chitosan alone was not able to achieve a high level of acaricidal activity. However, chitosan was used as a delivery method for Ag^+ (strong toxicity to mites) to inhibit the population growth of *T. putrescentiae* (Rahel et al., 2012). $AgNO_3$ and Ag_2O are both toxic and not food grade. It is therefore not practical for them to be used on hams. Propylene glycol is generally considered safe and used in the food industry for multiple purposes such as an anticaking agent, antioxidant, flavor agent, emulsifier, etc. (21CFR184.1666). Propylene glycol alginate + CG serves a similar function to chitosan in that it delivers PG, the active ingredient in the coating.

Polysaccharides have been widely studied and used in the food industry as antimicrobial coatings for food packaging including fish and meat products as well as fruits and vegetables (Sánchez-Ortega et al., 2014; Valdés et al., 2017). Alginates used in coatings with sodium lactate (2.4%) and sodium diacetate (0.25%) suppressed the growth of *Listeria monocytogenes* on cold-smoked salmon slices and fillets during 30 days of storage at 4°C (Neetoo et al., 2010). The PGA (1%) + CG (1%) gum

only and xanthan gum (1%) treatments demonstrated some inhibitory effects on mite growth as compared to the control ham cubes (Zhao et al., 2016). However, gums alone were not effective at controlling mite growth, and including propylene glycol as the active ingredient was necessary (Zhao et al., 2016; Abbar et al., 2016). Mite orientation experiments conducted by Abbar et al. (2016) revealed that *T. putrescentiae* would avoid staying on or near PG-treated ham pieces, and laid very few to no eggs on treated hams, although the mechanism for this inhibitory effect remains to be unknown. Propylene glycol has antimicrobial properties against *Candida albicans*, *Staphylococcus aureus*, *Staphylococcus epidermidis*, *Streptococcus pyogenes* A, *Streptococcus mitis,* and *E. coli* within 20 h (Kinnunen and Koskela, 1991). A study of mite residency test on whole hams treated with PG coatings indicated that both 20 and 40% PG with PGA + CG treated hams had less than 10 mites ($P < 0.05$) after 6 wk following the inoculation of 900 mites on the whole hams (Abbar et al., 2016). This confirms that mites behaviorally avoid these coatings due to an inhibitory effect caused by PG. In summary, these results indicated 7.5% PG or greater for PGA + CG and 15% PG or greater for xanthan gum might be effective at controlling mites on whole hams in processing plants.

Sensory evaluation on the whole hams applied with food grade coatings

Difference from control test-trial 1 in 2014. Hams coated with PGA + CG + 20% PG and XG only were not different ($P > 0.05$) from the blind control hams with respect to flavor (Table 2). There were slight differences ($P < 0.05$) in the hams treated with PGA + CG + 40% PG, net only, PGA + CG only, and XG + 20% PG in comparison to the blind control hams. Even though there was a difference between these treated hams and the control hams, the highest mean rating was 2.7, which indicates a slight to moderate difference. Panelists commented that treated hams were saltier, smokier, and had stronger dry-cured flavor than the control hams. In addition, the block (plant) effect was highly variable ($P < 0.05$), since each plant has different processing methods, aging conditions, ham origins, and ham size.

Panelists did not detect a difference ($P > 0.05$) in texture between the coated hams and control hams with the exception of the PGA + CG + 40% PG treatment, which was rated moderately different from the control in comparison to the blind control, which was rated slightly different ($P < 0.05$) from the control (Table 2).

Hams coated with PGA + CG + 20% PG were not different ($P > 0.05$) from the blind control hams with respect to moistness (Table 2). Propylene glycol alginate + CG + 40% PG (2.5), net only (2.3) and PGA + CG only (2.2) treated hams were slightly different ($P < 0.05$) from the blind control, which was rated 1.6. Panelists commented that hams from these 3 treatments were more moist. Even though, there were slight differences in the above 3 treatments, the highest rating was 2.5, which is half way between a slight and moderate difference. Xanthan only and XG + 20% PG treated hams did not differ from the control hams with respect to moistness ($P > 0.05$). When developing these coatings, maintaining moisture permeability was crucial since the United States Department of Agriculture requires a dry-cured ham to lose at least 18% of weight from original weight (USDA, 1999). The preliminary weight loss study by Zhao et al. (2016) on coated whole hams indicated a difference of weight loss within 1% between non-coated and control hams during 2 mo of aging.

Table 2. Difference-from-control sensory test results by trained panelists ($n = 6$ to 10, 12 panels per trial, an average of 100 overall ratings for each treatment for each descriptor) of whole hams (sliced into 1.3 cm thickness) treated by dipping with different food grade coatings after approximately 6 mo of aging from 4 plants in 2014

Treatment[1]	Flavor[2]	Texture	Moistness
Blind Control	1.8^{c}	1.7^{b}	1.6^{d}
PGA + CG + 20%PG	2.3^{abc}	1.9^{b}	1.8^{cd}
PGA + CG + 40%PG	2.5^{ab}	2.8^{a}	2.5^{a}
net only	2.4^{ab}	2.4^{ab}	2.3^{ab}
PGA + CG only	2.7^{a}	2.3^{ab}	2.2^{abc}
XG only	2.1^{bc}	2.1^{ab}	1.9^{bcd}
XG + 20%PG	2.4^{ab}	2.2^{ab}	1.9^{bcd}
SEM	0.039	0.053	0.039

[a–d]Means with same letter within each column are not significantly different ($P > 0.05$) using Tukey's Honest Significant Difference Test at 5% significance level.

[1]PGA: propylene glycol alginate, CG: carrageenan, PG: propylene glycol, XG: xanthan.

[2]Scale for sensory evaluation against the labeled control: 1-no difference, 2-slight difference, 3-moderate difference, 4-large difference, 5-very large difference.

Difference from control test-trial 2 in 2015. Since there were slight sensory differences between some of the treatments and the control in the dipping trial, an additional trial was conducted by spraying coatings on hams in an attempt to lower costs and minimize sensory differences that occurred in Trial 1. Spraying hams led to thinner and more uniform films. Therefore, less coatings were used in the process. There were no differences ($P > 0.05$) in ham flavor, texture, and moistness

between treated hams and the control (Table 3). All hams including the blind control were rated as slightly different from the labeled control hams. Zhao et al. (2016) treated 1.3 cm thick ham slices with 100% PG and food grade coatings, and there was no difference among the control and coated ham slices when coated for 2 wk. The results of this trial, using treated hams that were then aged 6 mo, confirmed the results from the study by Zhao et al. (2016). When the dipping method was used, there were some differences between treatments and the control. However, in trial 2, spraying was used and treated hams did not differ from the control hams with respect to flavor, texture, and moistness. This may be attributed to the spray imparting a thinner coating on the hams with a more consistent coating thickness (Ramos et al., 2012) and controlled delivery of PG, and this may have minimized differences detected by panelists. Thus, the coatings could potentially be applied to hams as a processing aide by spraying to help prevent mite infestations in dry-cured ham processing facilities without negatively impacting sensory properties.

Weight loss. No differences ($P > 0.05$) existed in the coated hams in comparison to the control hams with respect to weight loss (Table 4). The water vapor permeability was determined for these coatings by Zhao et al. (2016). A mix of kappa and iota carrageenan was used in the PGA + CG coating. Research by Alves et al. (2006) demonstrated that when kappa-carrageenan concentration was increased in a blend of kappa-carrageenan and pectin, the permeability to gases (O_2 and CO_2) and water vapor also increased. Generally, when plasticizers (e.g., PG) are added to polysaccharide coatings, the permeability to gas and water vapor is increased (Alves et al., 2010; Skurtys et al., 2010), which supports the results on the lack of difference in weight loss in the current study. Zhao et al. (2016) evaluated moisture loss of hams coated with various food coatings including 100% PG and 2% CG + 50% PG. In that study, hams treated with 2% CG + 50% PG lost 6.4% of weight while the control lost 7.4% of weight after 48 d of storage (Zhao et al., 2016). The weight loss in this study was measured on 4-mo old commercial hams. Therefore, each ham would have already lost 18% of its original weight prior to the receipt of the hams. In the current study, weight loss was not different ($P > 0.05$) from the treated hams, but there was variability ($P < 0.05$) among plants (blocking factor) with respect to weight loss, since initial ham weight prior to coating varied in each plant. The hams that were used in both trials had finished curing, and would have already lost greater than 10% of their weight. Therefore, all hams lost greater than 18% of moisture during the combination of curing and aging.

Table 3. Difference-from-control sensory test results by trained panelists ($n = 6$ to 10, 12 panels per trial, an average of 100 overall ratings for each treatment for each descriptor) of whole hams (sliced into 1.3 cm thickness) treated by spraying with different food grade coatings at 4 plants after approximately 6 mo of aging in 2015

Treatment[1]	Flavor[2]	Texture	Moistness
Blind Control	1.9	2.1	1.9
XG + 20% PG	2.0	2.3	2.1
PGA + CG + 20% PG	2.2	2.0	1.9
SEM	0.065	0.065	0.042

[1]PGA: propylene glycol alginate, CG: carrageenan, PG: propylene glycol, XG: xanthan gum.

[2]Scale for sensory evaluation against the labeled control: 1-no difference, 2-slight difference, 3-moderate difference, 4-large difference, 5-very large difference.

Table 4. Weight loss of control hams and coated hams after aging approximately 6 mo in 4 plants (2 hams/plant, $n = 8$ each treatment)

Treatment[1]	Weight loss, %
Control	16.4
XG + 20% PG	16.7
PGA + CG + 10% PG	18.1
PGA + CG + 20% PG	16.8
PGA + CG only	16.1
SEM	0.40

[1]PGA: propylene glycol alginate, CG: carrageenan, PG: propylene glycol, XG: xanthan gum.

Cost analysis of food grade coatings

One ham required approximately 500 mL of a given food grade coating solution in our scenario for use of these coatings to protect hams from mites. Based on the market price of the ingredients in 2015 (Table 5), the price for 1% PGA and 1% CG coatings ranges from approximately \$0.82 to \$2.64 per ham when 10 to 50% PG was used in the coating. The price for 1% xanthan gum coatings varied between approximately \$0.54 and \$2.35 per ham from 10 to 50% PG in the coating. However, these are retail prices and production would be much less expensive for a company that already produces or sells propylene glycol. According to some processors' price for methyl bromide, it is about \$10 or greater per kg, which can be as much as \$3 or more per ham by the time the ham has aged for 18 mo to 2 yr (Edwards, personal communication, 2016). In addition, dry-cured ham processors may not have access to methyl bromide once the existing stocks are depleted if there is not an opportunity

Table 5. Cost for coating one ham (500 ml food grade coating solution)[1]

PG percentage	Price[2] for 1% PGA + 1% CG coatings	Price for 1% XG coatings
10%	$0.82	$0.53
20%	$1.28	$0.99
30%	$1.73	$1.45
40%	$2.19	$1.90
50%	$2.64	$2.35

[1]PG: propylene glycol, PGA: propylene glycol alginate, CG, carrageenan, XG: xanthan gum.

[2]Price may vary depending on market cost of ingredients, cost was calculated from the supplier's information.

for the dry-cured ham industry to apply for a critical use exemption for methyl bromide. Optimization of the coating costs would be necessary to help the dry-cured ham processors reduce production costs and maintain viability.

Conclusion

Propylene glycol alginate and carrageenan based coatings with 7.5% PG and xanthan gum with 15% PG were effective at controlling mite infestations under laboratory conditions. Dipping hams in coatings led to slight differences in flavor, texture and moistness of dry-cured hams. However, the hams that were sprayed with coatings did not differ with respect to flavor, texture, and moistness from the control hams. This implies that dry-cured ham processing facilities could potentially spray these coatings on dry-cured hams to prevent mite infestations in their plants without affecting the sensory quality of the hams. Further research will include incorporating coatings into ham nets to determine their efficacy at controlling mite infestations and their impact on sensory quality.

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