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Application of Food-Grade Ingredients to Nets for Dry Cured Hams to Control Mite Infestations

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Abstract: Infestations of *Tyrophagus putrescentiae* (Schrank; Sarcoptiformes: Acaridae), known as the ham mite, may occur on dry cured hams during the aging process. The fumigant methyl bromide is currently used to control mite infestations, but it will eventually not be available for use since it contributes to the depletion of the ozone layer. The use of ham nets treated with xanthan gum, carrageenan, propylene glycol alginate, and propylene glycol food-grade ingredients on mite orientation to or oviposition on treated or untreated ham cubes, and mite reproduction and population growth over a 10-wk period was evaluated. Behavioral tests indicated that more than 95% of the mites oriented to the ham cubes that were wrapped in untreated nets when compared to treated nets and no eggs were laid on the latter. The reproduction assays demonstrated that there were fewer ($P < 0.05$) *T. putrescentiae* produced over a 2-wk period on ham cubes covered with both gum and propylene glycol treated nets, when compared to the untreated or gum-only treated nets over the 10-wk storage period of the experiment. Medium and high concentrations of propylene glycol treatments showed the lowest reproductive rates of mites. No more than 4 mites could be found on each of these treatments in comparison to 200 to 300 mites that were recorded on the untreated hams. This study demonstrated efficacy of using the nets treated with food-grade ingredients during ham aging to control mite infestations on a laboratory scale. Further research will be conducted to determine the effectiveness of the same treated nets on whole hams in commercial aging rooms.

Keywords: behavior, dry-cured ham, reproduction, *Tyrophagus putrescentiae*
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Introduction

Dry-cured ham is one of the most popular cured meat products in Spain, Germany, China, and the United States (Toldrá, 2008). Dry cured hams are susceptible to mite infestations due to their high fat and protein contents (Hughes, 1976; Lee et al., 2006; Macchioni et al., 2002), water activity, intense flavor, molds that grow on the meat surface (García, 2004), and the environmental temperature and humidity in the curing and aging room.

Tyrophagus putrescentiae (Schrank; Sarcoptiformes: Acaridae), known as the copra, mold mite, cheese mite or ham mite, may infest hams and feed directly on the dry-cured ham surface and the molds that grow on the hams (Cui, 2014). In addition, the presence of mold enhances mite growth and reproduction (Canfield and Wrenn, 2010; Hughes, 1976), and mites distribute molds on the ham surface because they carry viable fungus spores on their bodies and in their digestive tracts (Hoy, 2011). These *T. putrescentiae* infestations may decrease the quality of dry-cured hams (Townsend, 2007), and se-

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vere infestations lead to a powdery residue on the ham surface. In addition, *T. putrescentiae* may cause sensitization (Boquete et al., 2000; García, 2004), dermatitis (Quiñones Estévez, 2006; Vidal and Rial, 1998) and occupational asthma (Rodriguez del Rio et al., 2012) in people who work closely with mite-infested products.

Methyl bromide is an odorless, colorless gas that has been used effectively by food storage and processing facilities as a single space fumigant for more than 50 yr to control pests, including ham mites. However, the use of methyl bromide is in the process of being phased out, since it was listed as one of several substances that contribute to the depletion of ozone in the atmosphere in the Montreal Protocol (Fields and White, 2002). Although the United States dry-cured ham industry can use existing stocks of methyl bromide, no additional methyl bromide can be produced at this time (EPA, 2017). In addition, the cost for fumigations has increased by 10 fold from 2000 to 2015, which has contributed to decreased ham production.

Eventually, methyl bromide will likely not be an option for the dry-cured ham industry, which makes it necessary to research effective and economical alternatives to control mites. Alternatives that have been tested include chemical alternatives (Fields and White, 2002), food-safe compounds (Abbar et al., 2016a), the use of hot or cold temperature (Abbar et al., 2016b), and controlled atmosphere (Hasan et al., 2016). Sulfuryl fluoride was effective at controlling the adult stage of mites but was not effective at a concentration 3 times greater than the EPA label rate when applied at room temperature (Phillips et al., 2008). Phosphine fumigation was effective at controlling mites under laboratory conditions. However, phosphine use was not practical in commercial plants due to serious metal corrosion with costly damage from phosphine (Zhao et al., 2015). In Spain, coating the meat surface with lard or vegetable oil is part of the production process to help manage mite infestations (García, 2004). The application of lard to dry-cured ham cubes inhibited mite infestations on the laboratory benchtop, but may affect ham quality due to limited moisture and oxygen permeability (Zhao et al., 2016a).

Application of coatings that were composed of food-grade polysaccharides and propylene glycol to the dry cured ham cubes and slices was effective at controlling mites without affecting sensory quality in laboratory studies (Abbar et al., 2016a; Zhao et al., 2016b). Hams are typically aged by placing them in nets that are composed of natural and/or synthetic fibers and hanging them on racks. Application of ham nets treated with these mite-protective food-grade coatings controlled mites at the benchtop level (Campbell et al., 2016b). Therefore, the objective of this study was to determine the most effective formulations of food-grade chemicals for use in ham nets with respect to inhibiting mite contact and controlling mite reproduction over a 10-wk storage period.

Materials and Methods

Materials

Dry-cured hams (6 to 8 kg) aged for 4 to 6 mo were purchased from a commercial supplier. Ham nets were provided by Ennio International (Aurora, IL). Xanthan gum (XG), carrageenan (CG), and propylene glycol alginate (PGA) were provided by TIC Gums (Belcamp, MD). Food-grade propylene glycol (PG) was purchased from the Essential Depot (Sebring, FL).

Preparation of food ingredients infused nets

The solution of gum and PG was prepared as follows. Xanthan gum was first mixed with PG (low, medium, and high concentrations) and then the mixture was gradually poured into cold tap water and stirred until the mixture was clear. The combination of carrageenan and PGA was also first mixed with PG (low, medium, and high concentrations). The slurry was then mixed with warm water while stirring and heated to 90 to 100°C until the liquid turned from cloudy to clear. The specific methods under which the experimental nets were prepared are reported here as “low”, “medium”, and “high” concentrations of PG because the information is currently intellectual property with a patent pending.

The nets were cut, weighed, and then dipped in the coating solution. The nets were then pressed between 2 rollers in the netting machine (Midwest Metal Craft & Equipment Company, Winsor, MO) to minimize the amount of gum and PG that were used. The infused nets were weighed, and the netting solution that each foot of nets absorbed was calculated. The treated nets were then vacuum-packaged into vacuum bags (3 mil. standard barrier, nylon/PE Clarity Vacuum Pouches; Kansas City, MO) with a dual-chamber vacuum packaging machine (Model 2100, Koch Equipment LL., Kansas City, MO) at a full vacuum setting, and stored at room temperature prior to use.

Ham cubes

Whole hams were transversally cut into 2.5-cm or 1.3-cm thick pieces in the meat laboratory. Ham cubes were prepared and used for mite behavior (1.3 cm^3) and

mite reproduction assays (2.5 cm^3). The cubes were chosen from *biceps femoris*, *semitendinosus*, *adductor*, and *semimembranosus* muscles to avoid large variations among muscles. The ham cubes were wrapped in untreated nets, gum treated nets, or gum + PG treated nets.

Mite cultures

T. putrescentiae were reared in Dr. Phillips's laboratory in the Department of Entomology at Kansas State University as described by Abbar et al. (2016a). Prior to use, the mite containers were shipped overnight to Mississippi State University and stored in a latching storage box that contained soap water at the bottom and petroleum jelly smeared on the edges to prevent mites from escaping.

Two-choice behavior test of mites

The two-choice behavior test was conducted according to Abbar et al. (2016a) with some modifications. One 1.3-cm ham cube covered with the control (untreated) net and another 1.3-cm ham cube covered with a treated net were offered simultaneously to the mites inside a small arena (as shown in Fig. 1). The inside bottom of the plastic Petri dish (150 mm diameter × 15 mm depth) was covered with black construction paper that was cut to the same dimension as the Petri dish. Three specific round areas (C, M, and T) were assigned along a line passing through the center of the paper, with M (Mite) in the center, and C (control) and T (treatment) 10 mm away from each side wall of the Petri dish (Fig. 1). Two ham cubes from the same muscle section were selected and wrapped with control and treated nets, with 1 control cube placed in area C and 1 cube placed in area T. Five replications (5 pairs of cubes) were tested for each treatment. Among them, 2 pair of cubes were taken from the *biceps femoris* muscle, 1 pair from the *semitendinosus* muscle, and 2 pairs from the *adductor* and *semimembranosus* muscles. A total of 20 mixed sex adult mites were placed in the M area on the paper, and the Petri dish was placed in the dark in a growth chamber [23 ± 2°C and 80 ± 5% relative humidity (RH)]. A thin layer of petroleum jelly was applied on the inner upper 5 mm of the Petri dish to prevent mites from escaping. After 6 h of incubation, mites that were oriented to each of the net-wrapped ham cubes were counted. Orientation was indicated by the number of live mites on the control and treated ham cubes (Abbar et al., 2016a). An identical setup was prepared, and 20 mites were placed in the M area. The number of eggs laid on the cubes and nets were counted after 4 d of incubation. Oviposition was determined by counting eggs that were laid on the control and treated ham cubes.

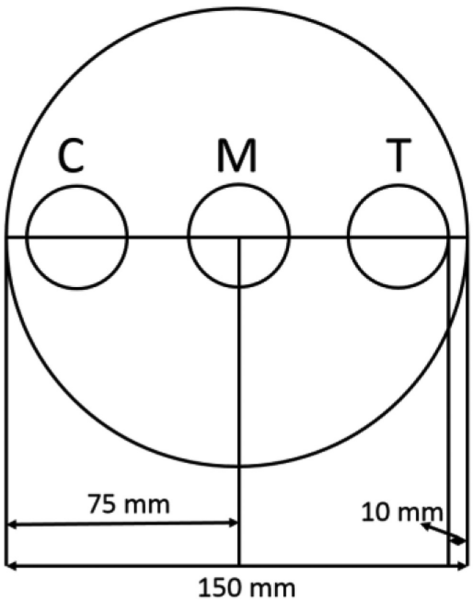

Figure 1. Mite 2-choice behavior assay. Mites were released at circle M (Mites), and the ham cubes wrapped in untreated and treated nets were placed in circles C (Control) and T (Treatment), respectively.

Mite reproduction assay

The 2.5-cm ham cubes were removed from ham muscles and assigned to and packaged with either control or treated nets. Five replications were tested for each treatment. Two cubes were taken from the *biceps femoris* muscle, 1 from the *semitendinosus* muscle, and 2 from the *adductor* and *semimembranosus* muscles. Ham cubes wrapped in nets were then placed in ventilated glass Mason jars (216 mL, 65 mm diameter, 55 mm height; Ball Corp., Broomfield, CO). The bottoms of the jars were covered with black construction paper and the tops were covered with filter paper (Whatman No. 1, 90 mm diameter; GE Healthcare, UK) that was sealed with the jar ring.

Two sets of mite infestation studies were conducted. One experiment included XG + PG treated nets, and the other set consisted of CG + PGA + PG treated nets. For each set of experiments, 3 groups of samples were prepared. Twenty mixed sex adult mites were introduced to ham cubes of each group on the first day (first group), and at 4 wk (second group) and 8 wk (third group) of storage, respectively. This was done to evaluate the long-term effectiveness of treated nets at controlling mite survival and reproduction. This experiment was conducted twice. The first batch was exposed to a relative humidity of 70 ± 5% for the first 4 wk with an increase to 80 ± 5% from wk 5 to wk 8 at 23 ± 2°C. For the second replication, ham cubes and nets were exposed to a relative humidity

of 80 ± 5% at 23 ± 2°C. Two weeks after inoculation, the ham cube, net, and paper were separated in a Petri dish (90 mm diameter × 15 mm depth) that was placed in a large Petri dish (150 mm diameter × 15 mm depth) that held 90% ethanol. The mites that were present on ham cubes, nets, black papers, and jars were counted separately under a microscope. Between samples, the Petri dishes that held samples were sprayed with 90% ethanol and wiped thoroughly.

Statistical analyses

Significance of mite preference for a given ham combination (control vs. treated) in the 2-choice behavioral test were calculated by a paired, 2-sided Student's *t* test using Microsoft Excel 2007, assuming unequal variances.

A randomized complete block design with 2 replications (batch) was used to determine the effect of different treatments on mite reproduction on ham cubes over 2 wk in glass jars. The blocking factor was included to account for slightly variable relative humidity throughout the study. When significant differences ($P < 0.05$) occurred among treatments, Tukey's Honestly Significant Difference Test ($P < 0.05$) was used to separate treatment means.

Results

Two-choice behavior assays

Fewer mites ($P < 0.01$) were found on the treated samples, in comparison to the control after 6 h in the Petri dish arena (Table 1), indicating that *T. putrescentiae* oriented to and remained on the control ham cube that was wrapped in the untreated nets over those cubes treated with low or medium levels of PG whether in XG or CA + PGA. In addition, there were no mites found on any of the netted ham cubes at 6 h that were wrapped in nets with either XG or CG + PGA that included the high concentration of PG. For the XG + PG group, only 2 and 1 mite(s) were found on all the ham cubes treated with low and medium PG, respectively; no mites were found on the high PG treatment. Similarly, for the CA + PGA + PG group, only 3 and 1 mite(s) chose to remain on the ham cubes treated with low and medium PG, respectively. On average, 8 to 12 mites oriented to the ham cubes that were wrapped in the control nets, out of the 20 original mites that were used for inoculation. The total number of mites found on the pair of control and treated ham cubes was less than the number of mites introduced, which indicated that some mites did not stay on the ham samples. Since the Petri dish stage was an open area, there were mites under the black paper and mites that climbed up the Petri dish wall and became stuck in the petroleum jelly.

Adults of *T. putrescentiae* preferred ($P < 0.05$) to lay eggs on ham cubes in the control nets in comparison to ham cubes in treatment nets. Evaluation of the egg placement by mites after 4 d revealed that all eggs in the arena were laid on control cubes and none were found on the treated cubes, regardless of PG levels. Between 110 and 230 eggs were laid on the control cubes, and no eggs were laid on any treated ham cubes over the 4 d period regardless of the type of gum treatment used or the PG concentration that were used (Table 1). In addition, after 4 d, only one moving mite was found on 1 ham cube wrapped in CG + PGA + low PG treated net among all samples observed for oviposition, which suggests that nearly all mites given 4 d for orientation (compared to 6 h in the orientation trial) preferred to settle on untreated cubes where females laid all their eggs.

Reproduction assays

Regardless of the netting duration (first day, 4 or 8 wk) prior to mite inoculation, the number of *T.*

Table 1. Mean numbers (SD) of mites (orientation) and eggs (oviposition) of *T. putrescentiae* on small dry-cured ham cubes wrapped in untreated control and treated nets in a laboratory 2-choice behavior bioassay ($n = 5$)[1]

	Orientation-mites after 6 h			Oviposition-eggs after 4 d		
Treatment[2]	Treated	Control	Probability difference	Treated	Control	Probability difference
XG + low PG	0.4 (0.9)	11.0 (2.5)	0.00033	0	129 (36)	0.00133
XG + medium PG	0.2 (0.4)	9.0 (2.1)	0.00055	0	225 (83)	0.00373
XG + high PG	0	9.8 (2.3)	0.00066	0	162 (62)	0.00426
CG + PGA + low PG	0.6 (0.9)	11.8 (3.1)	0.00080	0	150 (64)	0.00625
CG + PGA + medium PG	0.2 (0.4)	10.0 (2.1)	0.00035	0	114 (56)	0.01044
CG + PGA + high PG	0	8.0 (2.6)	0.00250	0	154 (71)	0.00849

[1]Pairwise comparison of treated and control orientation and oviposition data followed by a 2-sample Student's *t* test, assuming unequal variances.

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

putrescentiae produced in the assays was less ($P < 0.05$) on ham cubes with nets that were treated with gum and PG after 2 wk of culture when compared to any of the treatments lacking PG. These treatments include no net on the cube, untreated nets, and nets treated with gums (Tables 2 and 3).

Though no difference ($P > 0.05$) existed in mite numbers on ham cubes regardless of PG concentration, the medium PG and high PG treatments only had approximately 4 live mites on the cubes in comparison to the initial inoculating level of 20 mites, or in comparison to between 280 and 480 mites on the non-PG treated ham cubes. Control hams without nets had the highest number of mites (195 to 483 on average) followed by the ones wrapped in gum-treated (95 to 513 on average) and untreated nets (76 to 288 on average), respectively. No difference was found ($P > 0.05$) between the ham samples with or without gum-treated nets with respect to mite numbers after 2 wk of incubation, with the exception of the third batch of the 8-wk old XG-treated sample set in which XG-treated samples contained fewer mites than ham cubes without nets or with untreated nets. In addition, no differences ($P > 0.05$) were observed between XG and CG + PGA treated nets of the same concentration of PG regarding mite population on net-treated hams.

Molds appeared on most of the ham cubes (without nets, with untreated nets, or with gum treated nets in both batches of experiments). Molds were also found on several ham cubes wrapped in XG + low/medium PG treated nets, and 2 ham cubes that were wrapped in CG + PGA + low PG treated nets. No molds were found on any of ham cubes wrapped in nets with XG + high PG or CG + PGA + medium/high concentrations of PG in either batch.

Discussion

The behavioral choice test is a commonly used experimental design in animal ecology and behavior studies (Raffa et al., 2002). In the present study, PG and gum were infused into net fibers to produce wraps that were applied on ham cubes. When 2 food choices were provided simultaneously, the free-moving adult *T.*

Table 2. Mean (SD) of population growth of *T. putrescentiae* fed on 0-wk-old, 4-wk-old, and 8-wk-old small dry-cured ham cubes treated with xanthan gum and propylene glycol infused nets after 2 wk ($n = 10$)

	0-wk-old		4-wk-old		8-wk-old	
Treatment[1]	Mites	Molds	Mites	Molds	Mites	Molds
Control without net	483 (183)^{a}	Yes	240 (172)^{a}	Yes	212 (61)^{a}	Yes
Control with untreated net	281 (70)^{b}	Yes	158 (137)^{a}	Yes	188 (94)^{a}	Yes
XG	383 (237)^{ab}	Yes	167 (142)^{a}	Yes	95 (32)^{b}	Yes
XG + low PG	19.6 (10.9)^{c}	Yes	7.2 (9.7)^{b}	Yes	6.6 (4.8)^{c}	Yes
XG + medium PG	2.9 (2.2)^{c}	No	1.6 (2.0)^{b}	No	1.8 (1.4)^{c}	Yes
XG + high PG	3.3 (3.2)^{c}	No	1.1 (1.7)^{b}	No	1.2 (1.9)^{c}	No
SEM	15.6		10.4		6.0	

$^{a–c}$Means with same letter within each column are not different ($P > 0.05$) using Tukey's Honestly Significant Difference test.

[1]XG: xanthan gum, PG: propylene glycol.

Table 3. Mean (SD) of population growth of *T. putrescentiae* fed on 0-wk-old, 4-wk-old, and 8-wk-old small dry-cured ham cubes treated with carrageenan, propylene glycol alginate, and propylene glycol infused nets after 2 wk ($n = 10$)

	0-wk-old		4-wk-old		8-wk-old	
Treatment[1]	Mites	Molds	Mites	Molds	Mites	Molds
Control without net	670 (250)^{a}	Yes	196 (134)^{a}	Yes	220 (73)^{a}	Yes
Control with untreated net	287 (243)^{b}	Yes	77 (50)^{b}	Yes	143 (64)^{b}	Yes
CG + PGA	513 (174)^{a}	Yes	129 (101)^{a}	Yes	188 (107)^{ab}	Yes
CG + PGA + low PG	10.3 (15.8)^{c}	Yes	2.1 (2.5)^{c}	No	3.2 (2.5)^{c}	No
CG + PGA + medium PG	2.7 (4.1)^{c}	No	1.1 (1.1)^{c}	No	2.0 (1.5)^{c}	No
CG + PGA + high PG	0.7 (1.1)^{c}	No	0.5 (0.7)^{c}	No	0.8 (1.0)^{c}	No
SEM	19.1		7.6		7.3	

$^{a–c}$Means with same letter within each column are not different ($P > 0.05$) using Tukey's Honestly Significant Difference test.

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

putrescentiae mites exhibited clear preferences. Mites discriminated between untreated and treated ham cubes. Most mites chose to feed (~10 moving mites/cube) and lay approximately 100 eggs on each ham cube that was wrapped with an untreated net within the 4 d period. The result of mite orientation to and oviposition on untreated ham cubes was in agreement with the previous study by Abbar et al. (2016a). That study tested several food additives that were applied to ham cubes without nets, and *T. putrescentiae* oriented to untreated controls when compared to dry-cured ham pieces that were treated with 25 to 100% PG. In addition, those researchers reported that fewer eggs ($P < 0.01$) were laid on PG treated ham cubes in comparison to the untreated ham cubes.

In the reproduction assay, mites were contained in the jar where either untreated or treated ham cubes were kept. The total number of mites was the sum of mites from the initial 20 mites placed on the ham cube and all the progeny produced by these mites over the 2-wk period. When the uncovered ham was provided, *T. putrescentiae* fed on the ham and reproduced. Twenty mites eventually multiplied to 200 or more moving mites and many unhatched eggs. Most mites were found on the meat rather than in the jar or black paper. After the ham cube was covered with untreated nets, fewer moving mites were found after 2 wk of incubation, indicating that nets limited their movement to a small extent because of the smaller mesh size and tight attachment to the ham cubes. The nets infused with XG or the combination of CG and PGA did not necessarily reduce mite settling when compared to the uncovered control. However, all net products infused with gum and PG inhibited the population growth and/or reproduction of *T. putrescentiae* when compared to the control samples without nets or with untreated nets. Also, the inhibitory effects did not decline with the application time of gum and PG treated nets on hams, which revealed that the treated nets were effective at controlling mites for a minimum of 10 wk.

Similar studies that were conducted with gum and PG coatings also indicated the effectiveness of PG at controlling *T. putrescentiae* population growth. According to Zhao et al. (2016b), ham cubes coated with XG or CG + PGA plus 20% PG or higher had no live mites after 2 wk of incubation. The gum and PG coating was slightly more effective than the gum and PG infused nets, which may be due to the consistent film coating formed directly on the ham cubes providing mites with less access to meat in comparison to the gum and PG infused nets. However, the netting technique could have 2 advantages over the coating on a commercial scale. First, treated nets can be produced on a large scale and would be ready to use by ham producers in their current production process. However, applying the PG-infused gel coating to hams would require an additional spraying or dipping operation that would need to be added to the production process. Second, preliminary results with whole hams indicated that the use of netting required approximately half of the amount of PG and gum solution when compared to the coating (Campbell et al., 2016a). Since propylene glycol procured during the last 2 yr was approximately $12 per gallon (http://www.essentialdepot.com/product/CUBE-4PG.html), use of nets would provide an economical advantage over coating the ham surface.

It is evident that PG inhibited the mites from staying on the ham at the benchtop level. Propylene glycol is affirmed to be Generally Recognized As Safe by the US Food and Drug Administration's (ID Code 57556) and the Code of Federal Regulations (21CFR184.1666). Propylene glycol has been used as an ingredient in pharmaceuticals, foods (Fiume et al., 2012), and cosmetics (Anonymous, 1994) due to its antifungal and pesticidal qualities. In this study, medium and high concentrations of PG plus gum treated nets controlled mite infestations. In addition, none or only a very small amount of eggs was detectable on these samples, which indicated that the reproductive ability of the mites was also greatly inhibited.

A study conducted in Kansas State University on the whole ham indicated that only the coating of CG + PGA + 40% PG significantly lowered the number of resident mites when compared to the control 3 mo after the gums were applied, whereas lower concentration of PG, as well as the combination of XG + 20%/40% PG did not differ from the control (Abbar et al., 2016a). These results indicate that the coatings are also effective at controlling mites on whole hams, but that a greater concentration of PG is needed, when used on whole hams in comparison to ham cubes. Therefore, the application of netting on whole hams to control mite infestation needs further study to determine the effective PG concentration that is needed to control mites on whole hams.

The inclusion of high concentrations of PG may raise a concern regarding ham sensory quality. Previous studies conducted in our laboratory (Campbell et al., 2016c; Zhao et al., 2016b) indicated that the sensory quality attributes of hams were not affected by coating under laboratory conditions. In addition, minimal sensory differences were detected on whole hams, but ham quality was still excellent. This is logical since the PG was incorporated directly into the netting solution before forming the gel, so it be-

came locked into the gum matrix (Nieto, 2009), which inhibited the ham muscles from absorbing PG.

In addition, the treatments with the highest PG concentration controlled mite infestations and fungal growth or propagation. Carrageenan, PGA, and PG combination controlled mold better than XG and PG. The ham samples wrapped in CG + PGA + medium and high concentrations of PG treated nets had no visible fungal growth after 4 wk of storage. However, the XG + low-PG treatment had fungal growth during all experimental periods. This was plausibly due to the killing of most of the potential fungal spores or other contaminating microorganisms in the formula by heating CG + PGA + PG combination during netting. The development of molds is part of ham aging. It has been reported that *T. putrescentiae* consume a substantial quantity of molds (Hubert et al., 2004). In this study, mites were present on certain types of mold but not others. This was conceivably due to the presence of different types of molds on hams. In general, molds were divided into the following 4 groups based on mite preferences or fungal attractiveness and fungal suitability that was for mite development: 1. preferred and suitable for mite growth; 2. preferred but unsuitable; 3. avoided but suitable; and 4. avoided and unsuitable (Hubert et al., 2004). Although *T. putrescentiae* prefers more fungal species compared to a wide range of other mites, certain fungi developed in this study might be unpalatable or indigestible by *T. putrescentiae*, and thus avoided.

Conclusions

Incorporating propylene glycol into ham nets, as a natural food-grade processing aid, inhibited the growth and reproduction of *T. putrescentiae* and mold growth on dry-cured ham cubes in benchtop experiments. Ham nets that were infused with propylene glycol and gums are potential candidates for use during aging to control mites in dry cured ham plants. The infused ingredients are safe for humans and have no adverse effects on the sensory quality attributes of hams (proved by previous studies). The gum and propylene glycol treated nets should be considered for testing and potential use during whole ham aging. Further studies are required to evaluate the efficacy of treated nets in inhibiting mite infestation when they are applied on whole hams in commercial settings.

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