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Development of anti-insect food packaging film containing a polyvinyl alcohol and cinnamon oil emulsion at a pilot plant scale

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ABSTRACT

Anti-insect packaging films containing cinnamon oil (CO) encapsulated by polyvinyl alcohol (PVA) for repelling *Plodia interpunctella* (Hübner) larvae were manufactured using pilot plant scale instruments. The microcapsule emulsion of CO and PVA was printed onto polypropylene (PP) film as an ink mixture using the gravure printing method. The printed PP film was then laminated with a low-density polyethylene (LDPE) film to protect the printed side. Four types of multilayer films were produced: control film, 2% CO film, encapsulated 1% CO film, and encapsulated 2% CO film. When mechanical properties were assessed, tensile strength and elongation-at-break were not significantly different among films, whereas the Young's modulus values were different between the control film and the three types of CO-containing films. In a repellent test, 2% CO film repelled *P. interpunctella* larvae most effectively. For sensory evaluation, which was performed using milk chocolate, caramel soft candy, and cookies packaged with the produced films, the produced films did not affect the sensory characteristics. Therefore, the films printed with emulsions of CO and PVA could be applied in the food industry to help protect foods from infestation by *P. interpunctella*.

1. Introduction

In recent years, the use of plastic films instead of traditional packaging materials such as paper and cardboard has increased (Riudavets et al., 2007). Plastic film is advantageous, since it could protect food products against external damage caused by handling, contamination, and attacks by different insects (Paine and Paine, 1993). The most frequently used plastic films are polyethylene (PE) and polypropylene (PP).

In spite of modern food distribution and storage systems, most packaged food products, except for canned and frozen goods, are vulnerable to attacks by insects (Xingwei et al., 2004; Lee et al., 2011). The most devastating insect pests of stored products are (in order): Coleoptera (beetles) and Lepidoptera (moths), which are found in a range of climates (Robertson, 2006). *Plodia interpunctella* (Hübner) (Lepidoptera: Pyralidae), also known as Indian meal moth, is a major stored product pest that develops on grains, nuts, and processed foods (Johnson et al., 1992). *P. interpunctella* are called "penetrators" because of their well-developed, sharp mandibles that can make small holes and tear plastic films to penetrate into foods (Highland, 1984). The penetration into packaged foods can occur during the distribution phase, such as transportation and storage in warehouses, or in retail stores (Licciardello et al., 2013).

Many synthetic pesticides, such as methyl bromide and phosphine, have been used to control *P. interpunctella*. However, there are environmental concerns associated with the use of these synthetic materials. Essential oils (EO) derived from plants as secondary metabolites have been used for many purposes including antibacterial, antifungal, and anti-insect effects. Cinnamon

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(*Cinnamomum zeylanicum* Blume) leaf oil (CO) potently kills insect pests in stored products. The major compounds in CO include *trans*-cinnamaldehyde (58.1%), benzaldehyde (12.2%), and eugenol (5.1%) (Yang et al., 2005). Although EOs are environmental friendly materials with effective anti-insect activity, the high volatility of EOs make it difficult for them to be applied in the food packaging industry. To control the volatility and achieve an intended release of EOs, a range of microencapsulation technologies that surround tiny particles or droplets with outer coatings have been investigated. The core contains the active compound, while the wall protects the core permanently or temporarily from the external atmosphere (Alikhani and Garmakhany, 2012). In addition, controlled release of active compounds could be accomplished by microencapsulation, which has many potential applications for which the active agents are desired to be left in a certain container at a specific concentration (Dowding et al., 2005). Maji et al. (2007) produced microcapsules that repelled mosquitos using *Zanthoxylum limonella* oil as an insect repellent and gelatin as an encapsulant (wall material). Jo et al. (2013) developed an anti-insect PVA polymer strips embedding CO droplets that efficiently repelled *P. interpunctella* larvae. The application of microencapsulation technologies on EOs affords several advantages including protecting unstable core materials and preventing the core materials from poor environments. Gum arabic, whey protein, maltodextrin, gelatin, and polyvinyl alcohol (PVA) are commonly used as the wall materials (Kim et al., 2013). Among these, PVA is a hydrophilic semicrystalline synthetic polymer produced commercially by the hydrolysis of poly(vinyl acetate) (Jansson et al., 2006). Despite being a synthetic polymer, PVA is biodegradable and water soluble (Lenz, 1993; Ishigaki et al., 1999), and has excellent chemical resistance and physical properties. Because of these properties, PVA has been frequently used as an encapsulant (wall material) in microencapsulation technology.

In this study, multilayer anti-insect films were developed based on PP and low-density polyethylene (LDPE) films laminated with a mixture of ink and CO or PVA–CO emulsions using pilot plant scale machines. The mechanical properties, repellent effects against *P. interpunctella*, and sensory effects of the produced films were evaluated to demonstrate the potential of the films as practical food packaging for industrial applications.

2. Materials and methods

2.1. Manufacturing of pilot plant scale film

2.1.1. Preparation of PVA-CO microcapsule emulsion

The microcapsule emulsion of PVA–CO was prepared according to the method described by Kim et al. (2013). PVA was purchased from Sigma–Aldrich Co., Ltd. (St. Louis, MO, USA), and CO was obtained from Scentpia Co., Ltd. (Bucheon, Korea). Two grams of PVA and 98 g of distilled water were mixed for 2 h. Next, 5.5 g of CO was added to the PVA solution, which was then homogenized for 5 min using a homogenizer (IKA T25-Digital Ultra Turrax; Staufen, Germany). Finally, 0.07 g Tween 80 (Ilshinwells Co., Ltd.; Seoul, Korea) was added to the mixture as an emulsifier to form the stable microcapsule emulsion of PVA–CO.

2.1.2. Manufacturing of pilot plant scale anti-insect film

The pilot plant scale anti-insect film was produced by printing a mixture of PVA–CO microcapsule emulsion and white ink on PP film (0.06 mm thickness, Au Co., Ltd.; Bucheon, Korea), and then laminating the printed PP film with LDPE film (0.01 mm thickness, Au Co., Ltd.; Bucheon, Korea). The ink (Daihan Ink Co., Ltd.; Anyang, Korea) consisted of methyl ethyl ketone (30–50%), toluene (11–21%), ethyl acetate (10–15%), urethane resin (aliphatic) (8–12%), white organic pigment (8–12%), propylene glycol methyl ether acetate (6–11%), isopropyl alcohol (3–5%), vinyl resin (3–5%), and polyethylene wax (<1%). The formulation of the emulsion-ink mixture and the types of films used is shown in Table 1. During the printing process, the mixture of ink and PVA–CO emulsion was printed onto PP film using a gravure printing press (Roto Gravure Printing Press; Ilsung Machinery Co., Ltd.; Gumi, Korea) at a speed of 20–200 m/min at room temperature. The printed PP film was laminated with LDPE film using a laminator (Dry laminating & Extrusion laminating machine, INT CO., Ltd; Ansan, Korea) at a speed of 120–160 m/min. The finished films were aged at 62–63 °C for 72 h before use. The film thickness was measured using a digital micrometer (ID-C112X. Mitutoyo Co., Kawasaki, Japan) accurate to within 0.1 μm, with the film thickness used in calculating the mechanical properties of the films.

2.2. Mechanical properties of the pilot plant scale anti-insect films

Tensile strength, percentage elongation-at-break, and Young's modulus of the films were measured according to the American Society of Testing and Materials (ASTM) standard method D 882-01. A texture analyzer (TAXTplus 50; Stable Micro Systems Ltd.; Vienna, UK) was used for the tests. Before measuring, the films were cut into 50 × 8-mm strips and incubated at 25 °C with 50% RH for 48 h. A prepared strip of film was placed between two grips at an initial distance of 50 mm apart, and cross-head speed was 30 mm/min. After the strip broke, a force–distance curve was obtained, and the TS and %E were calculated as follows:

$$\text{Tensile strength (MPa)} = \frac{F}{A}$$

where *F* is the peak force at failure (*N*), and *A* is the cross-sectional area of the film (mm^2).

$$\text{elongation} - \text{at} - \text{break (\%)} = \frac{l_b - l_0}{l_0} \times 100$$

where l_b is the measured elongation-at-break (mm), and l_0 is the original length of the film placed between the grip heads that were 50 mm apart.

$$\text{Young's modulus (MPa)} = \frac{\text{Stress}}{\text{Strain}} = \frac{F/A}{(l_b - l_0)/l_0} = \frac{F \cdot l_0}{A \cdot (l_b - l_0)}$$

At least 12 replicates were analyzed for each film type.

2.3. Repellency test

P. interpunctella was obtained from the Laboratory of Population Ecology at Korea University (Seoul, Korea), which maintained the *P. interpunctella* for 5 years on dried vegetable commodities at 28 °C with 70–80% RH. The ability of the developed anti-insect films to repel *P. interpunctella* was assessed according to the method

Table 1
Formulations of emulsion and ink mixtures used for coating layer of anti-insect food packaging films containing cinnamon oil.

Type of film	Formulation
Control (0% CO)	10 kg ink
CO 2%	9.8 kg ink + 0.2 kg CO
Encapsulated CO 1%	7.9 kg ink + 2.1 kg emulsion of encapsulated CO with PVA
Encapsulated CO 2%	5.8 kg ink + 4.2 kg emulsion of encapsulated CO with PVA

Control, film consisting of PP, ink, and LDPE; 2% CO, film consisting of PP/ink with 2% CO/LDPE; Encapsulated 1% CO, film consisting of PP/ink with encapsulated CO with 1% PVA/LDPE; Encapsulated 2% CO film consisting of PP/ink with encapsulated CO with 2% PVA/LDPE.

described by Na et al. (2008), which was conducted using a quadruple choice test in a delivery box suitable for the retail market. Film bags (100 × 200 mm) were made to perform repellency test with the developed films, and 80 g of wheat flour was introduced into the film bag. One hundred 4th-instar larvae were introduced into a plastic box (280 × 340 × 190 mm) containing 12 film bags comprising four sets of three film bags that were prepared containing the developed films (control, 2% CO, and encapsulated 1% CO, encapsulated 2% CO). The experimental box was covered with cotton cloth for ventilation, and maintained at 25–30 °C with 50–70% RH for 30 days. The number of pupae from the larvae on the surface of the film bags was counted to estimate the insect repellent effects of the developed films. The tests were repeated six times.

2.4. Sensory evaluation

Milk chocolates (Lotte confectionary, Inc.; Seoul, Korea), caramel soft candies (Orion Inc.; Seoul, Korea), and cookies (Orion, Inc.; Seoul, Korea) were packaged with the four types of produced anti-insect films. Milk chocolates were wrapped with films sized 5 × 7 cm using a heat sealer (SK-310, Chueng-Il Co., Seoul, Korea). Caramel soft candies were prepared in the same forms as market products using 4 × 7-cm films. Cookies were covered with pouches made of 5 × 10 cm-sized films using a heat sealer. Sensory evaluation was performed using a 9-point intensity scale. Seventy-five untrained panelists participated in the sensory evaluation. Panelists were divided into three groups of 25 individuals, and one group evaluated the sensory traits of each milk chocolate, caramel soft candy, and cookie sample. The attributes evaluated were the odor of the films, and the odor, color, texture, taste, and overall preference of the food samples. For evaluating the odor, color, texture, and taste of samples, panelists chose different samples compared with other samples and evaluated their preference of selected samples using a 9-point intensity scale. If panelists felt no difference between samples, then they did not choose different samples nor evaluate the preference. The odor of the films and the overall sample preference were evaluated using a 9-point intensity scale without choosing any sample. For assessing film odor, a higher score represented a stronger odor compared with other films. In other attributes, a higher score meant a higher preference compared with other samples.

2.5. Statistical analysis

Data analyses were performed using Statistical Analysis System (SAS) software, version 9.2 (SAS Institute; Cary, NC, USA). Differences between the means of the groups were determined using analysis of variance (ANOVA) with Duncan's multiple-range test. Statistical significance was identified at the 95% confidence level ($p \le 0.05$).

Table 2
Mechanical properties (mean ± SD, $N = 12$) of the anti-insect food packaging films containing cinnamon oil.

Type of film	Thickness (mm)	Tensile strength (MPa)	Elongation-at-break (%)	Young's modulus (MPa)
Control	0.073 ± 0.001[b]	54.29 ± 8.49[a]	7.68 ± 2.36[a]	2001.49 ± 260.31[a]
2% CO	0.074 ± 0.001[a]	48.56 ± 7.90[a]	8.21 ± 3.13[a]	1800.20 ± 152.04[b]
Encapsulated 1% CO	0.074 ± 0.001[a]	54.93 ± 9.70[a]	9.22 ± 3.41[a]	1812.78 ± 79.22[b]
Encapsulated 2% CO	0.073 ± 0.001[a]	52.00 ± 8.79[a]	8.81 ± 2.76[a]	1668.23 ± 141.24[b]

Control, film consisting of PP, ink, and LDPE; 2% CO, film consisting of PP/ink with 2% CO/LDPE; Encapsulated 1% CO, film consisting of PP/ink with encapsulated CO with 1% PVA/LDPE; Encapsulated 2% CO film consisting of PP/ink with encapsulated CO with 2% PVA/LDPE. Values in the same columns that do not share a common letter are significantly different ($p \le 0.05$).

3. Results

3.1. Mechanical properties

The mechanical properties of the produced films are shown in Table 2. The thickness of control film was 0.073 mm, which was significantly ($p \le 0.05$) thinner than the thicknesses of the three types of CO-containing films. The tensile strengths of the control film, 2% CO film, encapsulated 1% CO film, and encapsulated 2% CO film were not significantly ($p > 0.05$) different each other. The addition of CO did not influence the elongation-at-break of the films. However, there was a slight modification in Young's modulus between the control film and the three types of CO-containing films.

3.2. Repellency test

Table 3 shows the results of the repellency experiment. Because the test was performed for 30 days, 4th instar larvae of *P. interpunctella* emerged to adulthood via the pupae state and died during this period. Therefore, pupae vestiges in the tested boxes would represent the positions of *P. interpunctella* that would be related to the repellent effect of the films; fewer pupae on the film bags indicated a better insect repellency. The different developed films (control, 2% CO, encapsulated, 1% CO, encapsulated, 2% CO) exerted different repellencies. A clear insect-repelling effect of the films coated with either encapsulated or directly applied CO was observed. Coated films including CO showed fewer pupae vestiges on surface than control after 30 days.

3.3. Sensory evaluation

During sensory evaluation of milk chocolates packaged in the four types of anti-insect films, the odor of film itself was not significantly ($p > 0.05$) different between samples (Table 4). The odor, color, texture, and taste of the samples were also not significantly ($p > 0.05$) different. This indicated that the produced anti-insect films containing CO did not affect the original sensory characteristics of the milk chocolate. Furthermore, when assessing the attributes of overall preference, the scores of all four films were >5, suggesting that CO acted as a flavor-improving agent. During the sensory evaluation of caramel soft candies, the odor of the films was significantly ($p \le 0.05$) different between control film and the three types of films containing CO (Table 5). By contrast, there was no significant ($p > 0.05$) difference between samples for the attributes of odor, color, texture, taste, and overall sample preference.

Table 3
The numbers (mean ± SD, $N = 6$) of *Plodia interpunctella* pupae from larvae that were found on the surface of the anti-insect food packaging bags containing cinnamon oil after 30 storage days.

	Control	2% CO	Encapsulated 1% CO	Encapsulated 2% CO
Number of pupae	8.24 ± 0.34[a]	5.00 ± 0.41[c]	6.33 ± 0.40[b]	5.78 ± 0.34[bc]

Control, film consisting of PP, ink, and LDPE; 2% CO, film consisting of PP/ink with 2% CO/LDPE; Encapsulated 1% CO, film consisting of PP/ink with encapsulated CO with 1% PVA/LDPE; Encapsulated 2% CO film consisting of PP/ink with encapsulated CO with 2% PVA/LDPE. Values in the same rows that do not share a common letter are significantly different ($p \le 0.05$).

Table 4
Sensory evaluation scores (mean ± SD) of the anti-insect food packaging films containing cinnamon oil produced by a pilot plant scale for milk chocolate packaging.

Milk chocolate	Odor of film		Odor		Color		Texture		Taste		Overall preference	
	Scorers (N)	Score	Scorers (N)	Score	Scorers (N)	Score	Scorers (N)	Score	Scorers (N)	Score	Scorers (N)	Score
Control	25	3.9 ± 2.5^{a}	5	6.2 ± 1.1^{a}	2	5.0^{a}	6	6.0 ± 1.1^{a}	3	5.7 ± 1.2^{a}	25	6.0 ± 1.7^{a}
2% CO	25	5.7 ± 2.3^{a}	6	4.3 ± 1.3^{a}	2	5.0^{a}	3	6.3 ± 3.1^{a}	4	6.0 ± 3.5^{a}	25	5.9 ± 1.8^{a}
Encapsulated 1% CO	25	4.6 ± 2.4^{a}	4	4.5 ± 1.0^{a}	0	–	3	6.3 ± 1.2^{a}	0	–	25	6.2 ± 1.6^{a}
Encapsulated 2% CO	25	5.0 ± 2.9^{a}	5	4.6 ± 0.9^{a}	4	5.5 ± 1.0^{a}	5	6.6 ± 0.9^{a}	5	5.0 ± 1.4^{a}	25	6.1 ± 1.5^{a}

Control, film consisting of PP, ink, and LDPE; 2% CO, film consisting of PP/ink with 2% CO/LDPE; Encapsulated 1% CO, film consisting of PP/ink with encapsulated CO with 1% PVA/LDPE; Encapsulated 2% CO film consisting of PP/ink with encapsulated CO with 2% PVA/LDPE. Scorers (N), number of individuals who identified the sample as different from the other samples.
Values in the same columns that do not share a common letter are significantly different ($p \le 0.05$).

Table 5
Sensory evaluation scores (mean ± SD) of the anti-insect food packaging films containing cinnamon oil produced by a pilot plant scale for caramel soft candy packaging.

Caramel soft candy	Odor of film		Odor		Color		Texture		Taste		Overall preference	
	Scorers (N)	Score	Scorers (N)	Score	Scorers (N)	Score	Scorers (N)	Score	Scorers (N)	Score	Scorers (N)	Score
Control	25	4.5 ± 2.8^{a}	4	3.5 ± 3.0^{a}	3	5.0^{a}	3	3.0 ± 2.0^{a}	1	5.0^{a}	25	4.8 ± 1.8^{a}
2% CO	25	2.8 ± 2.3^{b}	12	4.7 ± 1.7^{a}	7	4.7 ± 1.8^{a}	8	5.2 ± 2.0^{a}	3	5.7 ± 1.2^{a}	25	6.0 ± 1.8^{a}
Encapsulated 1% CO	25	2.0 ± 1.4^{b}	2	3.0^{a}	0	–	1	5.0^{a}	6	5.0 ± 1.8^{a}	25	5.2 ± 1.9^{a}
Encapsulated 2% CO	25	3.0 ± 2.5^{b}	6	4.0 ± 1.7^{a}	2	5.0^{a}	5	6.2 ± 2.3^{a}	3	6.3 ± 1.2^{a}	25	5.2 ± 1.9^{a}

Control, film consisting of PP/ink/LDPE; CO 2%, film consisting of PP/ink with CO 2%/LDPE; Encapsulated CO 1%, film consists of PP/ink and CO encapsulated with PVA 1%/LDPE; Encapsulated CO 2%, film consists of PP/ink and CO encapsulated with PVA 2%/LDPE; Scorers (N), number of individuals who identified the sample as different from the other samples. Values in the same columns that do not share a common letter are significantly different ($p \le 0.05$).

Table 6
Sensory evaluation scores (mean ± SD) of anti-insect food packaging films containing cinnamon oil produced by a pilot plant scale for cookie packaging.

Cookie	Odor of film		Odor		Color		Texture		Taste		Overall preference	
	Scorers (N)	Score	Scorers (N)	Score	Scorers (N)	Score	Scorers (N)	Score	Scorers (N)	Score	Scorers (N)	Score
Control	25	2.1 ± 1.3^{b}	7	7.6 ± 1.0^{a}	6	5.3 ± 0.8^{a}	3	5.7 ± 1.1^{a}	1	7.0^{a}	25	6.3 ± 1.6^{a}
2% CO	25	7.5 ± 2.2^{a}	6	3.9 ± 2.5^{b}	2	6.0 ± 1.4^{a}	2	5.0^{a}	2	4.0 ± 1.4^{a}	25	5.9 ± 1.7^{a}
Encapsulated 1% CO	25	3.2 ± 2.3^{b}	4	2.4 ± 1.0^{b}	5	5.0 ± 1.4^{a}	4	6.5 ± 1.0^{a}	5	4.2 ± 2.3^{a}	25	5.3 ± 1.7^{ab}
Encapsulated 2% CO	25	3.3 ± 2.2^{b}	8	2.8 ± 1.2^{b}	7	5.9 ± 1.9^{a}	9	3.9 ± 1.8^{a}	8	3.0 ± 2.6^{a}	25	4.6 ± 2.2^{b}

Control, film consisting of PP, ink, and LDPE; 2% CO, film consisting of PP/ink with 2% CO/LDPE; Encapsulated 1% CO, film consisting of PP/ink with encapsulated CO with 1% PVA/LDPE; Encapsulated 2% CO film consisting of PP/ink with encapsulated CO with 2% PVA/LDPE. Scorers (N), number of individuals who identified the sample as different from the other samples. Values in the same columns that do not share a common letter are significantly different ($p \le 0.05$).

However, the odor of cookies packed in the 2% CO film was stronger than that of the other films (Table 6).

4. Discussion

4.1. Mechanical properties

The addition of CO or PVA–CO emulsion to the PP laminated with LDPE decreased Young's modulus of plastic films. Ramos et al. (2012), who coated PP films with carvacrol and thymol, explained their result by suggesting that the addition of phenolic additives to the polymer matrix had a plasticizing effect, which would decrease Young's modulus; this implied an increase in the ductile properties of the film. A similar tendency of reducing Young's modulus after the addition of additives was reported in a study performed using LDPE coated with carvacrol (Persico et al., 2009). However, the slight changes in Young's modulus in our study were not unacceptable, and the tensile properties and elongation-at-break values were not significantly different ($p > 0.05$) among the four types of films. Therefore, the addition of CO or PVA–CO emulsion to the polymer at these concentration ranges (up to 2% [w/w] EO in ink formulation) could be used in the packaging industry without affecting the original mechanical property of the polymer.

4.2. Repellency test

Anti-insect packaging films containing CO efficiently repelled *P. interpunctella* larvae. Cinnamaldehyde, a major constituent of CO, is an antifeedant that repels various insect pests and acari, and can be used as a cream, patch, fumigant, or a direct contact treatment (Huang and Ho, 1998; Kim et al., 2006). Na et al. (2008) applied cinnamon extract to a chocolate packaging system, and observed that cinnamon extract successfully repelled *P. interpunctella* larvae for up to 60 days. Microencapsulated active ingredients are released at controlled rates over prolonged periods of time (Madene et al., 2006). However, the present study shows that the use of coated film of the microencapsulated CO did not result in different repellencies than the direct application of the same concentration of CO during storage for 30 days. Hence, the application of microencapsulation technology to CO using PVA as a wall material not only stabilized CO, but also exerted effective repellency against *P. interpunctella*. The present study suggests that CO could be coated onto the films used to store food packages to confer protection against infestation by *P. interpunctella*.

4.3. Sensory evaluation

Anti-insect packaging films containing CO showed the well-harmonized flavor-improving effects on milk chocolates. Albak and Tekin (2013) tested the effect of adding cinnamon powder to dark chocolate during the conching process, and reported that the flavor of cinnamon was fairly acceptable to the panelists, and acted as an aroma-enhancing agent. Whereas, the odors of the cookies that were wrapped in the three types of CO-containing films were significantly lower than that of the control. This result is different from the results obtained for milk chocolate and caramel soft candy. This is likely to be due to the differences in the surface of cookies and milk chocolate/caramel soft candy. The surfaces of chocolate and caramel soft candies are smooth and dense, cookies have a rough surface that easily absorbs moisture and odors. Other attributes (including color, texture, and taste) of the cookies were not significantly different between all samples. Overall, the produced anti-insect films containing CO did not affect the intrinsic characteristics of chocolate, caramel soft candy, and cookies except for the odor of the cookies, and were acceptable to the panelists.

5. Conclusions

Pilot plant scale anti-insect films were developed using CO or a PVA–CO emulsion. The thickness, tensile properties, and elongation-at-break of the CO-containing films were not significantly different than those of the control film; however, Young's modulus decreased significantly by CO addition. In a repellency test, films containing CO showed a better anti-insect property against *P. interpunctella* with 40% fewer pupae on the film surface. Furthermore, the three types of produced films containing CO did not affect the sensory properties of milk chocolate, caramel soft candy, and cookies. Therefore, the produced films containing CO could be applied to the food packaging industry as insect-repelling active packaging materials.

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