ACS Sustainable Chemistry & Engineering

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Research Article

Assessing Rodent Gnawing of Elastomers Containing Soybean Oil Derivatives

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Cite This: *ACS Sustainable Chem. Eng.* 2020, 8, 18015−18022

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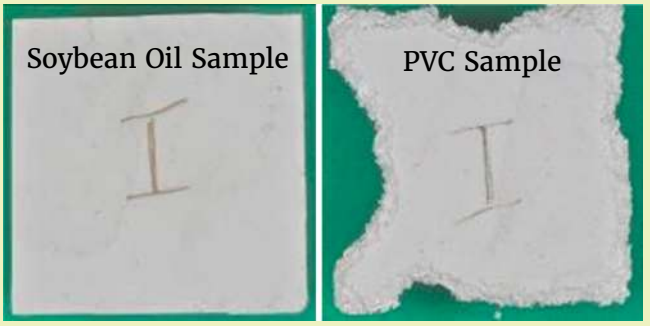
ABSTRACT: Replacing petroleum-based components with bio-based materials makes products more sustainable, but anecdotal evidence has suggested that this might also make them more attractive to rodents for gnawing. This study was conducted to determine if the inclusion of soybean oil or its derivatives in natural rubber, styrene−butadiene rubber, ethylene−propylene diene monomer, or flexible polyvinyl chloride (PVC) plaque samples affects the extent of gnawing damage by mice. The components tested were epoxidized soybean oil, degummed soybean oil, high oleic soybean oil, and styrenated soybean oil. Twelve treatments were tested, each exposed individually to 10 mice for 14 days. At days 8 and 15, the plaques were assessed for gnawing damage, both subjectively and by weight loss. Extensive gnawing was noted only on plaques made of PVC (both PVC standard and PVC with 10 PHR epoxidized soybean oil), and the gnawing damage difference between these two PVC treatments was not statistically significant. The other 10 treatments all showed negligible gnawing. The inclusion of soybean oil or its derivatives in common elastomers did not affect rodent gnawing.



KEYWORDS: *Rodent damage, Elastomers, SBR, EPDM, PVC, Natural rubber, Soybean oil*

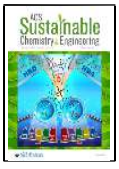
INTRODUCTION

Elastomers (long polymeric chains of carbon, hydrogen, and oxygen) are some of the most versatile materials in use today, with a wide range of elasticity and resilience. For this reason, they are used in a variety of industrial and consumer applications. Historically, elastomers have been manufactured from petroleum-based oils, but biobased sources are increasingly being used to make products more environmentally friendly. For example, plant-based oils from soybean (*Glycine max*), corn (*Zea mays*), canola (*Brassica napus*), sunflower (*Helianthus annuus*), palm (*Elaeis guineensis*), linseed (*Linum usitatissimum*), coconut (*Cocos nucifera*), and others are used in fuels, lubricants, elastomers, surfactants, and many additional products.[1]

In particular, soybean oil is a cost-competitive, renewable, plant-based replacement for many petrochemicals, decreasing volatile organic compounds and sequestering greenhouse gases in the growing soybean.[2] Post harvest, soybeans are transformed into primary coproducts (soybean oil and soybean meal) which are used for food, feed, fuel, and industrial applications. While nearly all soybean meal (protein, carbohydrates, and minerals) is used in human and animal nutrition, only about 65% of the soybean oil is used for food.[3] This results in a readily available, stable supply of soybean oil at low cost relative to most other oils. Consequently, soybean oil is often used as a replacement for fossil fuel-derived components. For example, when evaluated by the GREET and GTAP-BIO models, soy biodiesel was shown to be capable of an 80% reduction in fossil energy consumption and a 66−72% reduction in overall greenhouse gas emissions relative to its petroleum counterpart.[4] Soybean oil is currently used in a wide range of industrial applications, including rubber, coatings, solvents, plastics, lubricants, and adhesives, reducing the product's carbon footprint and environmental impact while delivering the same or improved quality and functionality in the final product.[1] Newer varieties of oil, such as high oleic soybean oil (HOSO), are chemically stable even under high heat conditions, extending the possible range of applications.

The automotive industry, in 1941, was an early adopter of petroleum alternatives when Henry Ford made fenders and deck lids for automobiles from soy-based green biopolymers.[5] While not commercially viable at the time, use of renewable source materials to increase sustainability remains an industry goal and marketing differentiator. For example, the 2008 Ford Mustang was the first car with soy in the seating foam, and now cars

Received: August 10, 2020
Revised: October 26, 2020
Published: December 4, 2020



produced by both Ford Motor Co. and General Motors Co. use soy-based foam. Goodyear Tire and Rubber Co. recently launched several tire product lines containing soybean oil after discovering that the addition increased tread traction in winter conditions on wet roads,[6] and John Deere uses soy-based materials in their tractor and combine panels.[7]

Original equipment manufacturers have begun to use soybean oil and its derivatives for partial replacement of petroleum-derived components in elastomers and flexible materials. In rubber formulations, soybean oil is often used as a replacement for petroleum-derived mineral oils (e.g., paraffinic or naphthenic oil) by serving as a plasticizer to improve material processing and properties of the finished product.[8] These materials are classified based on their hydrocarbon structures, with paraffinic fractions consisting of saturated linear or branched alkanes and naphthenic fractions containing five- and six-carbon cyclic structures.[9] Commodity soybean oil is primarily composed of five fatty acids: linoleic acid (18 carbons:2 double bonds), oleic acid (18:1), palmitic acid (16:0), linolenic acid (18:3), and stearic acid (18:0),[10] making it highly versatile. High oleic soybean oil has a higher level of oleic acid and reduced linoleic acid compared to commodity soybean oil.[11] In addition, soybean oil can be epoxidized, styrenated, and/or degummed (lecithin removed) to impart unique material properties for the intended application.

Despite this potential, concerns that soybean oil may lead to increased levels of rodent gnawing have been barriers to widespread adoption. Mice, rats, squirrels, and other rodents gnaw to keep their continuously growing front teeth from getting too long. Gnawing is also a survival mechanism in the wild, often enabling access to food.[12] Rodents have long been known to gnaw cables and wires in both indoor and outdoor applications. As early as 1979, Bell Laboratories scientists determined that a plastic covering with a triangular shape could deter rats from chewing communication wires.[13]

Both weasels[14] and squirrels[15] have been identified as causing damage to automobiles. Recently, unsuccessful class action lawsuits in California[16−19] and Alabama,[20] among other places, have specifically alleged that the use of soy-containing compounds increased rodent damage in vehicles. Increases in modern automobile complexity require additional wiring to connect interdependent electronic systems which, if damaged, can be costly to diagnose and repair.[21,22] Consequently, there is significant industry interest in determining whether or not the use of soybean oil and its derivatives in industrial materials affects the extent of rodent gnawing damage.

Limited scientific research has been published on the gnawing preferences of rodents. Mice have exhibited varying levels of aversion to repellents,[23] and different testing methods demonstrate consistency in the relative strengths of various repellents.[24] In 1995, three rodent species were presented with different material types, cures, lubricants, and bevel, and while "a protruding edge" seemed "to be essential for initiation of gnawing behavior", no other preferences were identified.[25]

In a 6-month study in 1992, five types of insulation (cellotex, fiberglass, rockwool, styrofoam, and vermiculite) were determined equally susceptible to damage by house mice.[26]

Corporations remain interested in improving their environmental footprint by replacing petroleum sources; however, adoption has been slowed by the concerns detailed above. Consequently, the objective of this study was to determine if the presence of soybean oil and its derivatives in flexible, elastomeric materials affects the extent of gnawing by rodents.

EXPERIMENTAL SECTION

Test Subjects. A total of 120 standard male CD-1 mice, age 8−9 weeks, were housed individually and randomly assigned to samples with 10 mice assigned to each of 12 treatments. All procedures were in compliance with the Animal Welfare Act Regulations, 9 CFR 1−4 §2131−§4.11 under Integrated Laboratory Systems (ILS) study 56022.00201 and IACUC approval. Animals were handled and treated according to the eighth edition of the *Guide for the Care and Use of Laboratory Animals*.[27,28] They were housed individually with absorbent

Table 1. Summary of Elastomer Plaque Treatment Formulations[a]

treatment name	plaque type	treatment ID	treatment formulation
NR standard	NR	K	10 PHR naphthenic oil
NR with HOSO substitution	NR	J	10 PHR HOSO
NR with SSO substitution	NR	G	10 PHR SSO
NR with DSO substitution	NR	B	10 PHR DSO
SBR standard	SBR	C	10 PHR naphthenic oil
SBR with HOSO substitution	SBR	L	10 PHR HOSO
SBR with SSO substitution	SBR	F	10 PHR SSO
SBR with DSO substitution	SBR	H	10 PHR DSO
EPDM standard	EPDM	D	70 PHR paraffinic oil
EPDM with HOSO and paraffinic oil substitution	EPDM	A	14 PHR HOSO + 56 PHR paraffinic oil (20% replacement)
PVC standard	PVC	I	50 PHR phthalate
PVC with ESO and phthalate substitution	PVC	E	10 PHR ESO + 40 PHR phthalate (20% replacement)

[a]Abbreviations: DSO = degummed soybean oil; EPDM = ethylene propylene diene monomer; ESO = epoxidized soybean oil; HOSO = high oleic soybean oil; NR = natural rubber; PHR = parts per hundred rubber; PVC = polyvinyl chloride SBR = styrene butadiene rubber; SSO = styrenated soybean oil.

Table 2. Specific Composition of Ethylene Propylene Diene Monomer Plaques[a]

	standard	HOSO
treatment ID	D	A
	PHR	PHR
Royalene 539 EPDM	100.00	100.00
paraffinic oil-sunpar 2280	70.00	56.00
high oleic soybean oil		14.00
N550 carbon black	105.00	105.00
zinc oxide	5.00	5.00
stearic acid	1.50	1.50
Tuex/TMTD	1.00	1.10
BZ/BZX/ZDBC	1.80	1.98
MBTS	3.00	3.30
sulfur	0.80	0.88
total	288.10	288.76
mixing time (min)	2.80	3.53
mixing temp (°F)	262.57	237.26

[a]Abbreviations: BZ/BZX/ZDBC = zinc dibutyl dithiocarbamate; EPDM = ethylene propylene diene monomer; MBTS = benzothiazyl disulfide; PHR = parts per hundred rubber; TMTD = tetramethylthiuram disulfide.

https://dx.doi.org/10.1021/acssuschemeng.0c05868
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Table 3. Specific Composition of Natural Rubber Master Batches

	NR-1	NR-2	NR-3	NR-4 (standard)
treatment ID	B	J	G	K
	PHR	PHR	PHR	PHR
NR CV60	100.00	100.00	100.00	100.00
carbon black N550	50.00	50.00	50.00	50.00
degummed soybean oil	10.00			
high oleic soybean oil		10.00		
styrenated soybean oil			10.00	
naphthenic oil				10.00
zinc oxide	10.00	10.00	10.00	10.00
stearic acid	2.00	2.00	2.00	2.00
antiozonant PD-2	2.00	2.00	2.00	2.00
antioxidant DQ	2.00	2.00	2.00	2.00
total	176.00	176.00	176.00	176.00
mixing time (min)	8.15	7.35	6.68	4.45
mixing temp (°F)	290.35	292.55	299.59	299.84

[a]Abbreviations: DQ = polymerized 2,2,4-trimethyl-1,2-dihydroquinoline; NR = natural rubber; PD-2 = *N*-(1,3-dimethyl butyl) *N*′-phenyl-*P*-phenylenediamine; PHR = parts per hundred rubber.

Table 4. Specific Composition of Natural Rubber Plaques[a]

	NR-1	NR-2	NR-3	NR-4 (standard)
treatment ID	B	J	G	K
	PHR	PHR	PHR	PHR
master batch: first pass	176.00	176.00	176.00	176.00
sulfur	0.25	0.25	0.25	0.25
TBBS	2.10	2.10	2.10	2.10
TMTD		1.00	1.00	1.00
total	179.35	179.35	179.35	179.35
mixing time final pass (min)	2.68	2.58	2.00	1.88
mixing temp final pass (°F)	202.69	209.54	210.75	210.03

[a]Abbreviations: NR = natural rubber; PHR = parts per hundred rubber; TBBS = *N*-*tert*-butyl-benzothiazole sulfonamide; TMTD = tetramethylthiuram disulfide.

Table 5. Specific Composition of Styrene Butadiene Rubber Master Batches[a]

master batch	SBR-1	SBR-2	SBR-3	SBR-4 (standard)
treatment ID	H	L	F	C
	PHR	PHR	PHR	PHR
SBR 1502	100.00	100.00	100.00	100.00
carbon black N550	50.00	50.00	50.00	50.00
degummed soybean oil	10.00			
high oleic soybean oil		10.00		
styrenated soybean oil			10.00	
naphthenic oil				10.00
zinc oxide	10.00	10.00	10.00	10.00
stearic acid	2.00	2.00	2.00	2.00
antiozonant PD-2	2.00	2.00	2.00	2.00
antioxidant DQ	2.00	2.00	2.00	2.00
total	176.00	176.00	176.00	176.00
mixing time (min)	7.67	6.47	4.85	4.30
mixing temp (°F)	299.59	299.55	299.99	299.70

[a]Abbreviations: DQ = polymerized 2,2,4-trimethyl-1,2-dihydroquinoline; PD-2 = *N*-(1,3-dimethyl butyl) *N*′-phenyl-iP-phenylenediamine; PHR = parts per hundred rubber; SBR = styrene butadiene rubber.

Table 6. Specific Composition of Styrene Butadiene Rubber Plaques[a]

	SBR-1	SBR-2	SBR-3	SBR-4 (standard)
treatment ID	H	L	F	C
	PHR	PHR	PHR	PHR
master batch: first pass	176.00	176.00	176.00	176.00
sulfur	0.25	0.25	0.25	0.25
TBBS	2.10	2.10	2.10	2.10
TMTD	1.00	1.00	1.00	1.00
total	179.35	179.35	179.35	179.35
mixing time (min)	1.98	1.67	1.50	1.45
mixing temp (°F)	210.51	212.50	211.76	209.80

[a]Abbreviations: PHR = parts per hundred rubber; SBR = styrene butadiene rubber; TBBS = *N*-*tert*-butyl-benzothiazole sulfonamide; TMTD = tetramethylthiuram disulfide.

Table 7. Specific Composition of Polyvinyl Chloride Plaques

	standard	ESO
treatment ID	I	E
	PHR	PHR
PVC	100.00	100.00
DINP	50.00	40.00
epoxidized soybean oil		10.00
Ca/Zn stabilizer-MARK QTS	5.00	5.00
calcium carbonate	40.00	40.00
titanium dioxide	3.00	3.00
antimony trioxide	3.00	3.00
hindered phenol-Wingstay L	1.00	1.00
total	202.00	202.00
mixing time (min)	19.20	17.85
mixing temp (°F)	360.53	353.29

[a]Abbreviations: DINP = diisononyl phthalate; PHR= parts per hundred rubber; PVC = polyvinyl chloride.

heat-treated hardwood bedding (Northeastern Products Corp., Warrensburg, NY). Certified Purina Pico Chow No. 5002 (Purina Mills LLC, Gray Summit, MO) and reverse osmosis-treated tap water (City of Durham, NC) were provided ad libitum.

A single plaque was placed in the cage of each mouse for 14 days as the only source of enrichment. Each plaque was weighed prior to placement on day 1, day 8, and day 15. A subjective four-point scale determined the degree of observed gnawing: 1 = 0−25%, 2 = 25−50%, 3 = 50−75%, and 4 = 75−100%, where the percentage represented the total estimated material affected.

Mice were weighed within 2 days of arrival for use in allocation to treatment groups. They were weighed again prior to exposure, on day 8, and at termination of the study.

Individual plaque data, treatment group means, and standard deviations were calculated. Plaque weight change was analyzed using the nonparametric, posthoc Kruskal−Wallis Test.[29,30] Following a significant result ($p \leq 0.05$), Dunn's Test was applied to compare mean differences among sets where significant differences were observed ($p \leq 0.05$). Plaque gnawing subjective ratings were compared with the nonparametric Mann−Whitney *U* test. Statistical analysis was done using R version 4.0.3[31] with the PMCMR package.[32]

Elastomer Treatment Formulations. Treatment formulations were based on natural rubber (NR), styrene butadiene rubber (SBR), ethylene−propylene diene monomer (EPDM), and polyvinyl chloride (PVC). In order to maintain a similar texture between soy-containing plaques and nonsoy-containing (standard) plaques, petroleum-based process oil or phthalate plasticizer was replaced by an equivalent amount of soybean oil, as is generally consistent with industry practice. A variety of soybean oil materials were investigated, including

https://dx.doi.org/10.1021/acssuschemeng.0c05868
ACS Sustainable Chem. Eng. 2020, 8, 18015−18022

Table 8. Initial and Final Mean Weights of Plaques by Treatment

treatment description (ID)	initial mean plaque weight (g) ± SD	final mean plaque weight (g) ± SD	plaque weight change (g) ± SD[a]
NR with DSO (B)	42.52 ± 1.73	42.88 ± 1.83	0.36 ± 0.48
NR with HOSO (J)	42.10 ± 1.85	41.31 ± 2.55	−0.79 ± 1.24
NR with SSO (G)	41.61 ± 0.85	41.67 ± 0.95	0.06 ± 0.30
NR standard (K)	42.71 ± 1.64	42.70 ± 1.72	−0.01 ± 0.18
SBR with DSO (H)	41.88 ± 1.70	41.88 ± 1.70	0.00 ± 0.18
SBR with HOSO (L)	42.70 ± 1.81	42.57 ± 1.95	−0.13 ± 0.19
SBR with SSO (F)	42.38 ± 1.36	42.52 ± 1.42	0.14 ± 0.32
SBR standard (C)	44.01 ± 1.64	44.00 ± 1.64	−0.01 ± 0.28
EPDM with HOSO (A)	41.70 ± 0.62	41.94 ± 0.56	0.24 ± 0.33
EPDM standard (D)	39.63 ± 1.17	39.49 ± 1.42	−0.14 ± 0.37
PVC with ESO (E)	46.91 ± 0.80	32.54 ± 11.24	−14.37 ± 11.44
PVC standard (I)	46.58 ± 1.41	34.75 ± 8.39	−11.83 ± 8.17

[a]Calculated from individual plaque data. Abbreviations: DSO = degummed soybean oil; EPDM = ethylene propylene diene monomer; ESO = epoxidized soybean oil; HOSO = high oleic soybean oil; NR = natural rubber; PHR = parts per hundred rubber; PVC = polyvinyl chloride; SBR = styrene butadiene rubber; SSO = styrenated soybean oil.

Table 9. Subjective Gnawing Ratings for Treatment Groups[a]

treatment description (ID)	plaque grades (day 8)	plaque grades (day 15)	day 15 average grade
NR with DSO (B)	1 (10 total)	1 (10 total)	1
NR with HOSO (J)	1 (10 total)	1 (10 total)	1
NR with SSO (G)	1 (10 total)	1 (10 total)	1
NR standard (K)	1 (10 total)	1 (10 total)	1
SBR with DSO (H)	1 (10 total)	1 (10 total)	1
SBR with HOSO (L)	1 (10 total)	1 (10 total)	1
SBR with SSO (F)	1 (10 total)	1 (10 total)	1
SBR standard (C)	1 (10 total)	1 (10 total)	1
EPDM with HOSO (A)	1 (10 total)	1 (10 total)	1
EPDM standard (D)	1 (10 total)	1 (10 total)	1
PVC with ESO (E)	1 (8 total)	1 (6 total)	
		2 (1 total)	
	3 (2 total)	3 (2 total)	1.8
		4 (1 total)	
PVC standard (I)	1 (9 total)	1 (4 total)	
		2 (3 total)	
	3 (1 total)	3 (2 total)	2.0
		4 (1 total)	

[a]Key: 1 = 0−25%, 2 = 25−50%, 3 = 50−75%, 4 = 75−100%, where the number represents the percentage of the total material that was affected by gnawing. Abbreviations: DSO = degummed soybean oil; EPDM = ethylene propylene diene monomer; ESO = epoxidized soybean oil; HOSO = high oleic soybean oil; NR = natural rubber; PHR = parts per hundred rubber; PVC = polyvinyl chloride; SBR = styrene butadiene rubber; SSO = styrenated soybean oil.

degummed soybean oil (DSO), high oleic soybean oil (HOSO), styrenated soybean oil (SSO), and epoxidized soybean oil (ESO).

Sample plaques were prepared by the Akron Rubber Development Laboratory (ARDL) from 12 treatment formulations selected to be representative of industrial rubber compounds[33] (as shown in Table 1). The PVC treatment formulation was obtained from ChemCeed.[34] Plaques were blinded by group before being delivered to ILS.

The DSO and HOSO were provided by Corteva Agriscience (Johnstown, IA, USA). The ESO was provided by ARDL (Akron, OH, USA). The SSO was obtained from North Dakota State University.

Plaque Formulation and Manufacture. Each treatment formulation was mixed in a 1.6-L laboratory internal mixer with tangential rotors. Mix cycles for each treatment are listed below. A sweep indicates that the ram was raised and the batch was allowed to turn over in the mixer. A dump indicates the batch was dropped and put on a 16" rubber mill to sheet out.

The slabs were molded in a 300-ton Adamson press (Adamson United, Akron, OH) with 24" × 24" platens. All samples were molded in 0.25" thick slabs and cut to 3" × 3" pieces.

Ethylene Propylene Diene Monomer (EPDM). Each EPDM treatment was created with the formulations shown in Table 2. For the soybean oil-containing treatment, 20% of the paraffinic oil content was replaced by HOSO. At t = 0 min, the ingredients were mixed upside down. At 180 and 220 °F, the batch was swept. At 240 °F, the batch was dropped. The treatments were cured for 13 min at 350 °F.

Natural Rubber (NR). Each natural rubber treatment was created with the formulations given in Table 3. For the soybean oil-containing treatments, all of the naphthenic oil content was replaced by soybean oil (degummed, high oleic, or styrenated). At t = 0 min, the natural rubber was added. At 30 s, 75% of the carbon black and all other chemicals were added. After heating to 200 °F, the oil and remaining carbon black were added. At 220 and 280 °F, the batch was swept. At 300 °F, the batch was dropped.

A final pass was completed from the master batches (Table 4). For the final pass, at t = 0 min the cures were sandwiched. There was a sweep at 180 °F, and the batch was dropped at 210 °F. The NR was cured for 16 min at 320 °F.

Styrene Butadiene Rubber (SBR). A master batch (first pass) for each SBR treatment was created with the formulations shown in Table 5. For the soybean oil-containing treatments, all of the naphthenic oil content was replaced by soybean oil (degummed, high oleic, or styrenated). At t = 0 min, the SBR was added. At 30 s, 75% of the carbon

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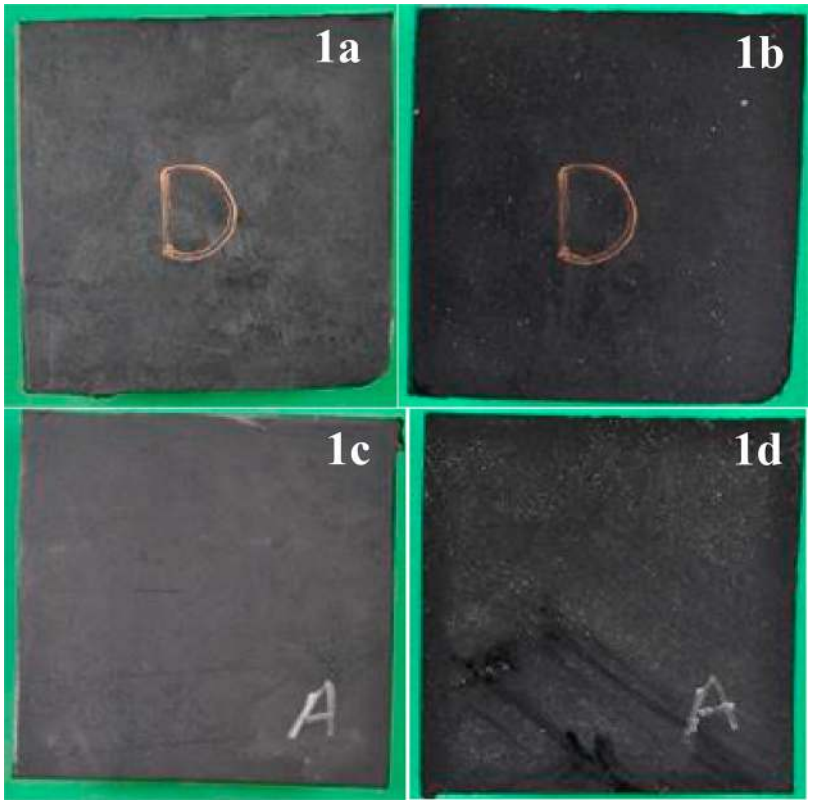

Figure 1. Representative ethylene propylene diene monomer plaques. Ethylene propylene diene monomer standard with 70 parts per hundred rubber paraffinic oil: (1a) pre-exposure; (1b) postexposure. Ethylene propylene diene monomer with 14 parts per hundred rubber high oleic soybean oil + 56 parts per hundred rubber paraffinic oil (20% replacement): (1c) pre-exposure; (1d) postexposure.

black and all chemicals were added. After heating to 200 °F, the oil and remaining carbon black were added. At 220 and 280 °F, the batch was swept. At 300 °F, the batch was dropped.

A final pass was completed from the master batches (Table 6). For the final pass, at $t = 0$ min the cures were sandwiched. There was a sweep at 180 °F, and the batch was dropped at 210 °F. The SBR was cured for 20 min at 320 °F.

Polyvinyl Chloride (PVC). Each PVC treatment was created with the formulations given in Table 7. For the soybean oil-containing treatment, 20% of the DINP content was replaced by epoxidized soybean oil. The hot oil heat was set to 400 °F. All materials were loaded, and at 300 °F the ram was raised for a sweep. At 350 °F, the batch was dropped from the mixer and milled to the desired form.

For each of the 12 treatments (A–L), 10 plaque samples were generated by Akron Rubber Development Laboratory (Akron, OH). The samples were blinded by type, randomized, and provided to Integrated Laboratory Services (Morrisville, NC) for rodent exposure testing.

RESULTS AND DISCUSSION

Plaque weight data are provided in Table 8. In some cases, the plaques gained small amounts of weight over the course of the study, attributed to urine and cage dust absorption and build up on the plaque. There was no change in the mean body weight of the mice over the course of the experiment, suggesting no significant difference in general health status among treatment groups (see Supporting Information).

Significant weight loss occurred only with PVC plaque samples. The other 10 treatment groups had negligible observable gnawing damage. Weight loss in the PVC plaque treatment groups (standard (I) and soy-containing PVC (E)) differed from every other treatment tested. In addition, weight loss in the PVC standard (I) and soy-containing PVC (E) plaques did not differ from each other. In fact, there was no difference in weight loss between the standard and the corresponding soy-containing samples for any of the materials evaluated (EPDM, NR, SBR, or PVC). Dunn's Test, posthoc p-values for all treatment pairs are provided in the Supporting Information.

All material types were graded with a subjective gnawing score of 1 except for the PVC standard and PVC with ESO, which both showed extensive gnawing (Table 9). The plaque grades for the standard and the ESO-containing PVC samples did not differ.

Pre-exposure and post-exposure plaques demonstrated negligible versus extensive gnawing damage for two different formulations (Figures 1 and 2). Images of the plaques used in the study are provided in the Supporting Information.

One possible explanation for increased gnawing on the PVC is that it was more abrasive. When rated on the Mohs hardness scale, rodent tooth enamel is 5.0–5.5.[35] Since mice gnaw mainly to wear down their teeth, they need to gnaw on something that is harder than their teeth. The PVC contained 1.5% rutile titanium dioxide (6.5 on the Mohs hardness scale)[36] and was the only elastomer to have an ingredient with a Mohs value higher than 5. The higher abrasiveness of the PVC may have proven more effective at wearing down teeth and thus more attractive to the mice.

For the treatments tested in this study, gnawing was only observed on the materials that were white in color, giving rise to the question of the influence of color on gnawing behavior. However, the literature does not provide evidence to support gnawing behavior choice based on color. Mice are dichromats and therefore can only distinguish a fraction of the wavelengths that can be distinguished by humans.[37] A 1998 study

https://dx.doi.org/10.1021/acssuschemeng.0c05868
ACS Sustainable Chem. Eng. 2020, 8, 18015–18022

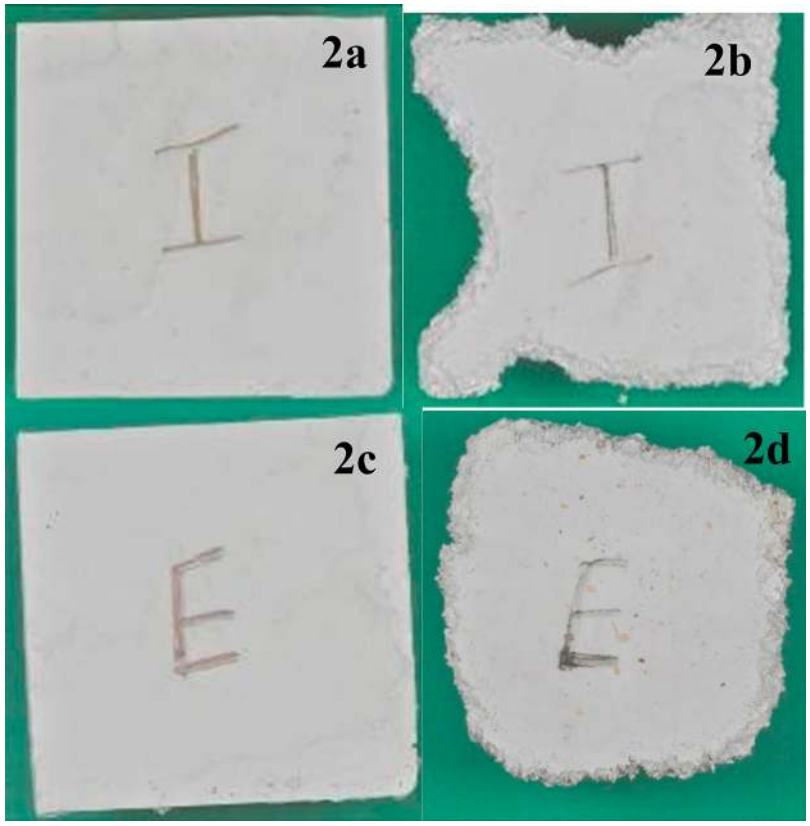

Figure 2. Representative polyvinyl chloride plaques. Polyvinyl chloride standard with 50 parts per hundred rubber phthalate: (2a) pre-exposure; (2b) postexposure. Polyvinyl chloride with 10 parts per hundred rubber epoxidized soybean oil + 40 parts per hundred rubber phthalate (20% replacement): (2c) pre-exposure; (2d) postexposure.

demonstrated that the addition of green coloring to mouse feed had no effect on consumption preferences,[38] and no impact from color has been reported for gnawing preferences.[39]

SUMMARY AND CONCLUSIONS

While mice gnawed on PVC more than other materials, the inclusion of soy oil derivatives into four different flexible, elastomeric materials (natural rubber, styrene−butadiene rubber, ethylene−propylene diene monomer, and flexible polyvinyl chloride) did not affect the extent of gnawing. Therefore, we conclude that other factors such as hardness may have caused the observed differences between types of elastomers. Therefore, the premise that rodents gnaw more on soy-containing materials is not substantiated and should not inhibit the commercial use of soy biobased materials to replace petroleum products in elastomer formulations.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge at https://pubs.acs.org/doi/10.1021/acssuschemeng.0c05868.

Initial and final weights of each group of mice, images of plaques before and after exposure to mice, details of the statistical analysis including the Dunn's Test, and posthoc *p* values based on plaque weight change of treatments pairs (PDF)

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Notes

The authors declare the following competing financial interest(s): Financial and material support for this research and writing of this manuscript was provided by the United Soybean Board. Technical experts employed by the funding source participated in the conception and writing of the manuscript and provided critical review. K.C.M. is an employee of the United Soybean Board. K.B.C., B.C.P., and L.M.B. are employees of SmithBucklin, a United Soybean Board contractor.

R.P.H. and M.A.S. received funding from the United Soybean Board to conduct the study.

■ ACKNOWLEDGMENTS

This work was funded by the United Soybean Board, project no. 1940-362-0727. Materials were produced by Akron Rubber Development Lab (ARDL), and the mouse study was conducted at Integrated Laboratory Systems (ILS).

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https://dx.doi.org/10.1021/acssuschemeng.0c05868
ACS Sustainable Chem. Eng. 2020, 8, 18015−18022