Replacement of Pork Fat in Chicken-based Bologna Sausage with Oleogels of High-Oleic or Conventional Soybean Oil and Rice Bran Wax

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Rodrigo Tarté, Assistant Professor, Departments of Animal Science and of Food Science and Human Nutrition;
Jona S. Paulus, Graduate Research Assistant, Department of Animal Science;
Nuria C. Acevedo, Associate Professor, Department of Food Science and Human Nutrition;
Kenneth J. Prusa, Professor, Departments of Food Science and Human Nutrition and of Animal Science;
Show-Ling Lee, Associate Scientist;
Department of Animal Science, Iowa State University

Summary and Implications

In this study, pork fat in bologna sausage made with mechanically separated chicken (MSC) as the primary lean raw material was successfully replaced with either high-oleic (HOSO) and conventional (CSO) soybean oil oleogels structured with rice bran wax (RBW). Textural parameters, sensory attributes (except color), and lipid oxidation over 98 d of storage were unaffected by lipid source, while color was darker and redder in pork fat-containing samples. Raw batter stability was not different, except it was lower when liquid soybean oil was the lipid source. Samples containing oleogels made with HOSO had a more favorable lipid profile. These results complement previous studies by us and others, and highlight the potential of oleogelation technology to modify the lipid profile of finely-comminuted meat products without negatively affecting product quality attributes.

Introduction

Previous atempts to replace saturated fat in meat products have meet with varying degrees of success. Replacement with liquid vegetable oils in comminuted products have resulted in harder, chewier, lighter and less red product. Therefore, in order to maintain acceptable product attributes, animal fat must be replaced with a material of similar mechanical and functional properties.

In recent years, oleogelation has emerged as a potential technology for replacing saturated fats in various food products. Oleogelation involves the use of a gelator molecule to structure liquid oil into a three-dimensional gel network possessing viscoelastic properties similar to those of naturally-saturated fats or hydrogenated oils. This technology has been successfully tested to replace saturated fat in products such as cream cheese, ice cream, and cookies. In meat products they have been used as partial animal fat replacers in hot-serve products such as beef frankfurters, pork frankfurters, and spreadable cold-serve products such as liver pâté, and, in a previous study in our laboratory, soybean oil oleogels with rice bran wax as gelator were used to replace >97% of the pork fat in pork frankfurters.

Over the last three decades, the seed oil industry has introduced high-oleic acid varieties of various vegetable oils, which contain higher (3–4 X) oleic acid (C18:1n9) and lower linoleic acid (C18:2n6) contents than their conventional versions. These high-oleic oils have shown improved oxidative stability, which makes them more suitable as frying oils. From a nutrition standpoint, the higher level of oleic acid may be beneficial, given its ability to lower LDL cholesterol. Recent diet studies have also reported that replacing saturated fats or oils with high-oleic oils generally results in lower total cholesterol, LDL cholesterol, and apolipoprotein B (apoB), but no change in HDL cholesterol, triglycerides and apoA, which suggests reduced risk of cardiovascular disease.

The objective of this study was to evaluate the impact of replacing pork fat with oleogels made with either high-oleic or conventional soybean oil, structured with rice bran wax, on the quality attributes and processing characteristics of a chicken and pork bologna sausage, a sliceable cold-serve comminuted meat product. The bologna product was formulated to simulate mid-quality tier bologna products commercialized in the United States

Materials and Methods

Oleogels were prepared one week before use by mixing proper amounts of soybean oil (SBO) and RBW, heating to 90°C in a convection oven set to 121°C, and cooling at 2.7°C. Six treatments of bologna sausage (Table 1) were formulated to compositional targets of 25.4% lipid, 11.1% protein, and 56.5% moisture by a linear optimization mathematical model, and made in batches of 11.36 kg in the ISU Meat Laboratory. MSC was the lean source raw material in all treatments. Each treatment utilized one of six lipid sources: **PF**: pork back fat, **LSO**: liquid soybean oil;

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C90: 90% CSO/10% RBW oleogel, **C97.5**: 97.5% CSO/2.5% RBW oleogel, **H90**: 90% HOSO/10% RBW oleogel; **H97.5**: 97.5% HOSO/2.5% RBW oleogel. All SBO-containing samples were formulated to replace 100% of the fat provided by the pork back fat, for a total lipid replacement of 41.9% (the remaining 58.1% of the lipid fraction was contained in the MSC material). In a bowl chopper, flaked frozen MSC and non-lipid ingredients were comminuted under vacuum to 4.4°C, followed by addition of the lipid source and vacuum comminution to 13°C. At this point, raw samples were collected for batter stability analysis. Batters were then stuffed into 32.8 cm (circumference) fibrous casings and cooked to 73°C. Samples were chilled for 18 h at -1.1°C, sliced into 1-mm-thick slices (each weighing approx. 14 g), vacuum-packaged (6 slices per package) and stored at 1.1°C in the dark for 98 d. Color (CIE L*a*b* color space; illuminant D65; 2.54-cm aperture; 10° observer angle), lipid oxidation (thiobarbituric acid-reactive substances), and instrumental texture (texture profile analysis [TPA] on 25.4 mm [height] x 25.4 mm [diameter] cores; incisor puncture probe) were analyzed on days 0, 14, 28, 42, 56, 70, 84, and 98. Sensory evaluation by a trained panel was conducted on days 21, 49, 70 and 98. Microstructure was analyzed by light microscopy, with Sudan IV stain used to stain the lipid phase. Fatty acid profile of raw materials and final products was analyzed by gas chromatography (GC-FID). The study was designed as a randomized complete block and, where storage time was a factor (color, texture, lipid oxidation, sensory analysis), was arranged as a split-plot in time, with lipid source as the whole-plot factor and storage time as the subplot factor. The experiment was replicated three times. Data were analyzed as a mixed model using JMP Pro statistical software (version 15.0.0, SAS Institute, Cary, NC, USA) with treatment and storage time as fixed factors and replication and sensory panelist (where applicable) as random factors. The Tukey-Kramer pairwise comparison method was used to determine differences between means.

Results and Discussion

No treatment effects were observed for fat loss in emulsion stability, but CO resulted in significantly greater ($P < 0.05$, Table 2) water loss, suggesting a less stable batter. L* instrumental color values revealed that PF was significantly darker ($P < .05$) and CO and C97.5 were significantly lighter ($P < .05$) than all other treatments (Table 3). a* values were also highest ($P < 0.05$) for PF and lowest ($P < .05$) for CO and C97.5. b* values were highest ($P < .05$) for PF and lowest ($P < .05$) for C97.5. This agrees with sensory color analysis, which found color intensity to be highest ($P < .05$) in PF and lowest ($P < .05$) in CO. TPA parameters (firmness, cohesiveness, springiness, resilience, chewiness) were not significantly different ($P > .05$) among treatments (Table 4). No treatment effects were observed for incisor peak force values ($P < .05$). There were no treatment effects for the following sensory parameters: sensory bologna aroma, other aroma, texture, moistness and other flavor (Table 5). However, bologna flavor was significantly greater ($P < .05$) for PF than CO, H90 and C97.5, but not greater than H97.5 and C90. No storage time effects were observed in sensory analysis ($P > .05$). There were significant ($P < .05$) treatment effects on lipid oxidation, with TBARS values being lowest for PF and CO; however, none exceeded 0.29 mg malondialdehyde/kg over the length of the study, indicating acceptable oxidative stability for all treatments throughout the entire storage period. Microstructure analysis showed fat globule size was larger in PF and smaller in CO than in all other treatments, which could be partly responsible for the lower emulsion stability observed

Oleogels made with either high oleic or conventional soybean oil resulted in bologna products of similar quality and organoleptic properties, indicating they are easily interchangeable for this application. Use of high oleic soybean oil, however, would result in a product with a more favorable fatty acid profile (Table 6). Pork fat replacement with liquid oil, while possible, could result in more unstable raw batters, less desirable color and lower flavor intensity

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Table 1. Bologna treatment formulations (values expressed in percentages).

	PF	LSO	C90	C97.5	H90	H97.5
MSC	74.12	78.22	78.22	78.22	78.22	78.22
PBF	12.92	–	–	–	–	–
CSO	–	9.95	–	–	–	–
90% CSO:10% RBW OG	–	–	9.95	–	–	–
97.5% CSO:2.5% RBW OG	–	–	–	9.95	–	–
90% HOSO:10% RBW OG	–	–	–	–	9.95	–
97.5% HOSO:2.5% RBW OG	–	–	–	–	–	9.95
Water/ice (50/50)	5.74	4.57	4.57	4.57	4.57	4.57
Optiform PD4	2.50	2.50	2.50	2.50	2.50	2.50
Salt	1.60	1.60	1.60	1.60	1.60	1.60
Dextrose	0.91	0.91	0.91	0.91	0.91	0.91
Sodium tripolyphosphate	0.44	0.44	0.44	0.44	0.44	0.44
Curing salt (6.25% $NaNO_2$)	0.22	0.22	0.22	0.22	0.22	0.22
Sodium erythorbate	0.05	0.05	0.05	0.05	0.05	0.05
Seasoning	1.50	1.50	1.50	1.50	1.50	1.50

MSC: mechanically separated chicken; PBF: pork backfat; CSO: conventional soybean oil; HOSO: high-oleic soybean oil; RBW: rice bran wax; OG: oleogel

Table 2. Least squares means[1] for main effect of lipid source on proximate composition, pH, batter stability, and cook/chill yield of bologna sausage (means of three replications).

	Raw			Cooked				Batter stability (% separation)		
	Lipid (%)	Moisture (%)	Protein (%)	Lipid (%)	Moisture (%)	Protein (%)	pH	Water	Lipid	Yield (%)
PF	25.3[a]	59.3[a]	10.6[a]	25.8[ab]	58.4[a]	11.0[a]	6.54[a]	4.1[b]	2.2[a]	94.9[a]
LSO	25.7[a]	58.5[a]	10.5[a]	26.0[ab]	58.1[a]	10.7[a]	6.59[a]	7.7[a]	3.1[a]	95.3[a]
C90	24.3[a]	59.2[a]	10.5[a]	25.0[b]	58.4[a]	10.7[a]	6.57[a]	3.8[b]	2.0[a]	96.1[a]
C97.5	25.4[a]	59.0[a]	10.5[a]	26.5[a]	57.6[a]	10.8[a]	6.56[a]	4.3[b]	1.8[a]	96.4[a]
H90	24.4[a]	59.3[a]	10.4[a]	25.1[ab]	58.7[a]	10.8[a]	6.52[a]	4.4[b]	2.7[a]	95.8[a]
H97.5	25.2[a]	59.4[a]	10.4[a]	26.1[ab]	58.3[a]	10.7[a]	6.56[a]	3.9[b]	2.6[a]	96.4[a]
S.E.M.	0.34	0.40	0.09	0.32	0.47	0.16	n/a	0.55	0.44	0.54

S.E.M.: standard error of mean.
[1] Means of three replications.
[a-b] Means in the same column with different letters are significantly different ($P < .05$).

Table 3. Least squares means[1] for main effect of lipid source on color attributes of bologna sausage stored in the dark at 0°C, averaged across all storage time sampling points

	Instrumental[2]					Sensory[3]
	L*	a*	b*	C*	HA	Color intensity[4]
PF	65.00[d]	13.88[a]	16.54[a]	21.59[a]	49.99[c]	10.69[a]
LSO	70.85[a]	11.48[c]	15.87[bc]	19.58[c]	54.11[a]	5.36[c]
C90	70.30[ab]	11.66[bc]	16.11[bc]	19.89[bc]	54.11[a]	6.35[bc]
C97.5	70.70[a]	11.50[c]	15.84[c]	19.57[c]	54.02[ab]	6.09[bc]
H90	69.62[c]	11.93[b]	16.16[b]	20.09[b]	53.55[b]	6.83[b]
H97.5	70.08[bc]	11.69[bc]	16.08[bc]	19.88[bc]	54.00[ab]	6.71[b]
S.E.M.	0.117	0.063	0.090	0.096	0.100	0.542

S.E.M.: standard error of mean.
[1] Means of three replications.
[2] Averages of means from days 0, 14, 28, 42, 56, 70, 84 and 98.
[3] Averages of means from days 21, 49, 70 and 98.
[4] *Light* (0) to *dark* (15) on 15-cm unstructured line scale.
[a-d] Means in the same column with different superscripts are significantly different

Table 4. Least squares means[1] for main effect of lipid source on instrumental texture parameters of bologna sausage, averaged across all storage time sampling points[2].

	Texture profile analysis					Incisor
	Hardness (N)	Resilience (%)	Cohesive-ness	Springiness (%)	Chewiness (N mm)	peak force (N)
PF	28.82[a]	45.53[a]	75.83[a]	93.93[a]	22.21[a]	2.33[a]
LSO	31.73[a]	46.78[a]	78.38[a]	93.92[a]	23.07[a]	2.66[a]
C90	30.05[a]	44.83[a]	76.50[a]	93.87[a]	22.13[a]	2.57[a]
C97.5	30.58[a]	44.73[a]	75.46[a]	94.45[a]	22.73[a]	2.50[a]
H90	31.67[a]	45.42[a]	77.25[a]	94.06[a]	23.69[a]	2.65[a]
H97.5	31.27[a]	45.10[a]	76.96[a]	93.66[a]	23.66[a]	2.52[a]
S.E.M.	1.392	0.868	0.979	0.772	1.089	0.125

S.E.M.: standard error of mean.
[1] Means of three replications.
[2] Days 0, 14, 28, 42, 56, 70, 84 and 98.
[a] Means in the same column with different superscripts are significantly different ($P < .05$).

Table 5. Least squares means[1] for main effect of lipid source on sensory attributes of bologna sausage, averaged across all storage time sampling points[2].

	Bologna aroma	Other aroma	Bologna flavor	Other flavor	Texture	Moist-ness
PF	8.07[a]	0.04[a]	8.43[a]	0.06[a]	7.99[a]	7.44[a]
LSO	7.76[a]	0.02[ab]	7.50[a]	0.13[a]	8.35[a]	7.14[a]
C90	7.71[a]	0.02[b]	7.58[a]	0.04[a]	7.59[a]	7.15[a]
C97.5	7.98[a]	0.02[ab]	7.69[a]	0.06[a]	7.09[a]	7.37[a]
H90	8.27[a]	0.02[b]	7.83[a]	0.04[a]	7.85[a]	7.47[a]
H97.5	7.62[a]	0.03[ab]	7.55[a]	0.05[a]	7.68[a]	7.49[a]
S.E.M.	0.362	0.015	0.400	0.031	0.416	0.309

S.E.M.: standard error of mean.
[1] Means of three replications.
[2] Days 0, 14, 28, 42, 56, 70, 84 and 98.
[ab] Means in the same column with different superscripts are significantly different ($P < .05$).

Table 6. Least squares means for fatty acid profiles of bologna sausage treatments and their formulation raw materials.

		% of FAME[1] total										
		Bologna sausage treatments[2]							Formulation raw materials[3]			
Fatty acid		PF	LSO	C90	C97.5	H90	H97.5	S.E.M.	MSC	PBF	CSO	HOSO
Capric	10:0	0.04^{a}	0.01^{b}	0.02^{b}	0.01^{b}	0.02^{b}	0.01^{b}	0.002	0.01	0.07	0.00	0.01
Lauric	12:0	0.05^{a}	0.03^{b}	0.03^{b}	0.03^{b}	0.03^{b}	0.03^{b}	0.001	0.03	0.07	0.01	0.00
Myristic	14:0	0.96^{a}	0.47^{bc}	0.48^{b}	0.46^{c}	0.47^{bc}	0.46^{c}	0.004	0.57	1.19	0.07	0.05
Myristoleic	14:1*n*-5	0.11^{a}	0.11^{a}	0.11^{a}	0.11^{a}	0.11^{a}	0.11^{a}	0.001	0.17	0.01	0.00	0.00
Pentadecanoic	15:0	0.07^{a}	0.05^{bc}	0.05^{bc}	0.05^{c}	0.06^{b}	0.06^{b}	0.001	0.07	0.06	0.00	0.04
Pentadecenoic	15:1*n*-5	0.08^{a}	0.08^{a}	0.08^{a}	0.08^{a}	0.08^{a}	0.08^{a}	0.002	0.00	0.00	0.00	0.00
Palmitic	16:0	23.47^{a}	18.70^{c}	18.96^{b}	18.72^{c}	17.64^{d}	17.33^{e}	0.032	24.19	21.02	10.67	6.11
Palmitoleic	16:1*n*-7	4.67^{a}	3.86^{e}	3.99^{bc}	3.91^{de}	4.03^{b}	3.93^{cd}	0.014	6.18	1.87	0.10	0.12
Margaric	17:0	0.23^{b}	0.11^{c}	0.11^{c}	0.11^{c}	0.34^{a}	0.35^{a}	0.003	0.12	0.43	0.11	0.75
Margaroleic	17:1*n*-8	0.20^{c}	0.09^{d}	0.09^{d}	0.09^{d}	0.56^{b}	0.60^{a}	0.002	0.10	0.34	0.06	1.35
Stearic	18:0	7.63^{a}	5.40^{b}	5.41^{b}	5.40^{b}	5.18^{c}	5.09^{c}	0.039	6.65	12.23	5.33	4.09
Oleic	18:1*n*-9c	39.52^{c}	32.30^{d}	32.51^{d}	32.41^{d}	52.59^{b}	53.38^{a}	0.082	40.02	39.04	21.41	71.98
Linoleic	18:2*n*-6	17.40^{c}	31.49^{a}	30.48^{b}	30.99^{ab}	13.94^{d}	13.94^{d}	0.103	16.88	17.19	51.94	9.10
γ-Linolenic	18:3*n*-6	0.15^{a}	0.14^{b}	0.14^{b}	0.14^{b}	0.14^{b}	0.14^{b}	0.001	0.00	0.07	0.00	0.32
α-Linolenic	18:3*n*-3	0.88^{e}	3.75^{a}	3.56^{c}	3.67^{b}	1.50^{d}	1.56^{d}	0.014	0.79	0.83	7.72	2.68
Arachidic	20:0	0.11^{d}	0.16^{abc}	0.15^{c}	0.15^{bc}	0.16^{ab}	0.17^{a}	0.002	0.10	0.28	0.44	0.44
Eicosenoic	20:1*n*-9	0.63^{a}	0.40^{c}	0.40^{c}	0.40^{c}	0.47^{b}	0.47^{b}	0.005	0.46	0.86	0.25	0.38
Eicosadienoic	20:2*n*-6	0.44^{a}	0.14^{b}	0.14^{b}	0.13^{b}	0.13^{b}	0.13^{b}	0.002	0.22	0.90	0.06	0.00
Dihomo-γ-linolenic	20:3*n*-6	0.17^{a}	0.12^{bc}	0.13^{bc}	0.12^{c}	0.13^{b}	0.13^{bc}	0.001	0.22	0.18	0.00	0.00
Eicosatrienoic	20:3*n*-3	0.47^{a}	0.37^{d}	0.38^{cd}	0.37^{d}	0.39^{b}	0.38^{c}	0.002	0.60	0.35	0.05	0.08
Arachidonic	20:4*n*-6	0.05^{a}	0.01^{b}	0.01^{b}	0.01^{c}	0.02^{c}	0.01^{c}	0.001	0.00	0.17	0.00	0.00
Eicosapentaenoic	20:5*n*-3	0.03^{a}	0.02^{a}	0.03^{a}	0.03^{a}	0.03^{a}	0.02^{a}	0.002	0.00	0.00	0.00	0.00
Behenic	22:0	0.02^{e}	0.11^{d}	0.14^{b}	0.12^{cd}	0.16^{a}	0.14^{bc}	0.003	0.03	0.00	0.43	0.46
Erucic	22:1*n*-9	0.24^{a}	0.23^{a}	0.24^{a}	0.24^{a}	0.25^{a}	0.24^{a}	0.005	0.03	0.01	0.00	0.01
Docosadienoic	22:2*n*-6	0.03^{ab}	0.03^{c}	0.03^{a}	0.03^{ab}	0.03^{ab}	0.03^{bc}	0.001	0.04	0.00	0.00	0.02
Lignoceric	24:0	0.05^{d}	0.06^{d}	0.12^{a}	0.10^{b}	0.11^{b}	0.09^{c}	0.002	0.32	0.42	0.31	0.00
Nervonic	24:1*n*-9	0.02^{b}	0.02^{b}	0.04^{a}	0.04^{a}	0.02^{b}	0.02^{b}	0.001	0.20	0.32	0.00	0.00
Unidentified		2.26	1.73	2.15	2.08	1.41	1.11	—	1.99	2.09	1.05	2.01
Iodine value[4], g/100g		71.95^{e}	96.64^{a}	94.73^{c}	95.69^{b}	78.03^{d}	78.78^{d}	0.16	71.99	68.16	128.85	85.93
∑*n*-6 fatty acids		18.25^{c}	31.93^{a}	30.93^{b}	31.43^{ab}	14.39^{d}	14.38^{d}	0.10	17.35	18.51	52.00	9.44
∑*n*-3 fatty acids		1.37^{e}	4.14^{a}	3.97^{c}	4.06^{b}	1.92^{d}	1.97^{d}	0.01	1.40	1.18	7.76	2.75
n-6:*n*-3 fatty acid ratio		13.33^{a}	7.71^{b}	7.79^{b}	7.74^{b}	7.50^{c}	7.31^{d}	0.03	12.40	15.68	6.70	3.43

S.E.M.: standard error of mean (bologna sausage treatment means only).
[1] FAME: fatty acid methyl ester.
[2] Means of three replications.
[3] Averages of triplicate measurements from same production lot.
[4] Calculated as IV = (% 16:1 × 0.950) + (% 18:1 × 0.860) + (% 18:2 × 1.732) + (% 18:3 × 2.616) + (% 20:1 × 0.785) + (% 22:1 × 0.723). (AOCS, 2017).
[a-f] Bologna sausage treatment means in the same row with different letters are significantly different ($P < .05$).