Extrusion for Producing Low-fat Pork and its Use in Sausage as Affected by Soy Protein Isolate

H. Ahn, F. Hsieh, A.D. Clarke, and H.E. Huff

ABSTRACT
Low-fat pork was produced at extrusion temperatures (ET) of 25, 32.2, 43.3, 54.4, or 65.6°C with addition of soy protein isolate (SPI) at 0, 1.5, or 3% and evaluated by measuring chemical and physical properties of low-fat pork sausage links. ET and SPI addition influenced moisture retention and fat reduction. The highest ET (65.6°C) gave the highest fat reduction in extrudates. TBARS decreased as ET and SPI increased. Extrudates at higher ET made darker and redder sausages. The hardness value of the control was not different from that of sausages from 65.6°C ET extrudates. The fat-reduced sausages were more springy and cohesive than the control. Depending on fat reduction, twin-screw extrusion influenced sausage color, texture, and lipid oxidation. The sausage links from 65.6°C ET extrudates with 1.5% SPI had the lowest fat, lowest TBARS, least cooking loss and were not different in hardness from control high-fat sausages.

Key Words: extrusion, soy protein isolate, pork sausage

INTRODUCTION
Many methods have been suggested to produce low-fat beef or pork products (Mandigo, 1992). A twin-screw extruder could be used to develop nontraditional food products using under-utilized meat (Flores et al., 1992). The twin-screw extruder system has potential to separate fat from meat products. However, separating fat may alter functional properties, decrease meaty flavor and increase undesirable flavors. Soy proteins are widely used as meat binders to improve physical and chemical properties of processed meat products, such as frankfurters and ground meat patties. Studies (Megard et al., 1985; Alvarez et al., 1990) have shown that addition of soy protein isolate (SPI) resulted in better binding and texturization of extrudates.

Our objective was to develop an innovative method to reduce fat in pork through extrusion technology. Little information on use of extrusion to produce low-fat meat products is available. Information is also needed on the processing methods and physical characteristics of extruded and fat-reduced pork sausage products. Our objectives were to determine the effects of extrusion temperature on separation of fat, and addition of SPI to the defatted pork, on chemical and physical properties of fat-reduced pork sausage links.

MATERIALS & METHODS
Raw materials
Fresh pork trimmings, ratio 60% lean to 40% fat (mainly from pork bellies and shoulders) were obtained from the Meat Lab, Univ. of Missouri-Columbia. Fat content was visually estimated and confirmed later as the non-extruded treatment (control) (40.6±1.6% fat, w.b.). The trimmings were manually cut into large chunks with a knife and ground through a 0.32 cm plate using a meat grinder (Model A200, Hobart MFG, Co., Troy, OH). Curing salt (0.25%), based on meat weight, mixed with sodium nitrite (6.25%), based on curing salt weight, was added. All meat sources were ground again through the same plate. The meat was covered with white freezer paper and cured overnight at 2.5°C prior to extrusion. All treatments were replicated 3 times.

Extrusion processing
Fat removal was done by extrusion in an MPF 50/25 intermeshing, corotating twin-screw extruder (APV Baker, Inc., Grand Rapids, MI). An L:D (barrel length:barrel diameter) ratio of 15:1 was used. The barrel contained independently controlled heating (5) and cooling (6) zones with electrical cartridge heaters and water cooling channels. The feeding zone and the accompanying second zone were always cooled to ensure that feeding would not be interrupted by steam lock. Cooling was provided by water from a 227.1L closed loop recirculator with a Fenwal controller. The barrel was a “clamshell” design and was horizontally split and vertically segmented into 5 modules. Each module had 2 zones and a length of 5 screw diameters. The screw diameter was 50 mm. Only the last 3 modules were used since the L:D ratio was 15:1 (Fig. 1, Table 1A). The die plate was bolted to the end of the extruder. The die was composed of two plates bolted together front to back. The front plate (nearest the extruder) contained two partially overlapping circles, diameter 50.3 mm for each circle. The distance across the entire opening was 89.7 mm. The depth of the circles was 18.74 mm. The second plate (farthest from extruder) had a rectangular hole in the center in the plate which measured 30.5 mm long and 10.5 mm wide. This was the opening to the outside from which the extrudate flowed. A platform was bolted to the second die plate to convey the extrudate to a cooler. Extrudates were collected from the die and placed in a walk-in cooler (2°C for 3 days).

The authors are affiliated with the Departments of Biological & Agricultural Engineering and Food Science & Human Nutrition, Univ. of Missouri-Columbia, Columbia, MO 65211. Address inquiries to Dr. Fu-Hung Hsieh, Food Science & Human Nutrition Dept., Univ. of Missouri-Columbia, Columbia, MO 65211.
SPI Effects on Extruded Pork Sausage...

Table 1—(A) Mean barrel temperatures (°C) and (B) mean product temperatures (°C) as related to (treatment) extrusion temperatures.

<table>
<thead>
<tr>
<th>Zone 2</th>
<th>Zone 3</th>
<th>Zone 4</th>
<th>Zone 5</th>
<th>Zone 6</th>
<th>Die</th>
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<tbody>
<tr>
<td>32.2</td>
<td>26.8</td>
<td>33.6</td>
<td>32.6</td>
<td>35.7</td>
<td>35.3</td>
</tr>
<tr>
<td>43.3</td>
<td>26.8</td>
<td>41.1</td>
<td>43.6</td>
<td>45.8</td>
<td>45.9</td>
</tr>
<tr>
<td>54.4</td>
<td>26.7</td>
<td>50.1</td>
<td>54.7</td>
<td>57.5</td>
<td>56.5</td>
</tr>
<tr>
<td>65.6</td>
<td>26.6</td>
<td>59.3</td>
<td>65.7</td>
<td>69.0</td>
<td>69.6</td>
</tr>
<tr>
<td>(°C)</td>
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</table>

(A) Mean barrel temperatures (°C) and (B) mean product temperatures (°C) as related to (treatment) extrusion temperatures.

Values with same lower case letters within a column of same variable are not significantly different (P>0.05).

The vacuum annexed to the vacuum pump unit increased the effectiveness of the vacuum. The vacuum was run first, and then 43.3°C treatment served as the control and was cooled in a refrigerator (1.7°C) to retain product properties and functionality before pork sausage manufacturing. After cooling, the extruded pork was packaged in plastic bags for individual tests.

The fat-reduced pork extrudates and control were immediately taken to a kitchen in the Meat Laboratory for sausage processing. Samples were kept at 4–5°C after the sausages were made. The samples were repeatedly. For each treatment and control, the entire procedure was repeated twice, allowing for 4 different sets of readings per sample; these readings were averaged to provide 1 color value/sample estimate. After each treatment, the cover glass was cleaned to prevent dirt from building-up.

FIG. 2—Platform that was bolted to the second plate of the extruder die. Numbers are mm.
Montejano et al. (1985) were followed with slight modifications. All sausage samples were analyzed within a day after cooling at 5°C (to achieve uniform temperatures). Measurements were conducted for hardness, springiness, and cohesiveness. These parameters were defined as follows (Bourne (1978)): Hardness: Height of the force peak on first compression cycle; Cohesiveness: Ratio of positive force areas of the force peak on first compression cycle; as follows [Bourne (1978)]: Springiness: Distance sample recovered its height during the time that elapsed between the end of the first bite and the start of the second bite.

Six slices (6.35 cm dia and 1.2 cm ht) were obtained from each treatment. The deformation of sausage product on the Texture Analyzer was set to compress axially to 20% of the 1.2 cm thick sample with a contact area of 5.07 cm². The crosshead speed was set at 0.5 mm/s. The force detected by the cylindrical shape probe (2.54 cm dia) of the machine was monitored by a computer.

**Measurement of TBARS value.** The 2-Thiobarbituric acid-reactive substances (TBARS) test according to the distillation procedures of Tarladgis et al. (1960) was used to determine the extent of oxidative rancidity of the sausage products and the control. The sausages were ground in a chopper for 1 min and two 10g portions were removed for TBARS analysis. Reagents were 0.02M 2-thiobarbituric acid (C14H10N2O5, Kodak, Rochester, NY) and 4N HCl (A114-212, Fisher, Fairlawn, NJ). The chopped sausage sample was placed in a Kjeldahl flask containing 97.5 mL distilled water. The flask was connected to a Kjeldahl distillation apparatus and heated until 50 mL of distillate was collected. To prevent further oxidation, 2.5 mL 4N HCl was added and stirred until no clumps were visible. About 5 to 6 drops of antifoam A (A-5758, Sigma, St. Louis, MO) and 3 to 4 glass beads were added. From each sample of distillate, two 5mL samples were transferred into test tubes containing 5 mL of TBARS reagent and placed in a boiling water bath for 35 min. Then, samples were removed from the water bath and cooled for 10 min in a cool water bath (158°C). The absorbance for each sample was read at 538 nm against the reagent blank. The TBARS value (mg malonaldehyde/kg of sample) was determined by multiplying the sample absorbance by the constant k value of 7.8.

**RESULTS & DISCUSSION**

**Analysis of product temperatures**

The product temperatures were measured to evaluate stability of temperatures and to determine final product temperatures. Tables 1A and 1B show the extruder barrel temperatures and product temperatures in the barrel and the extruder die temperature. The barrel temperatures were controlled and were close to the set temperatures.

A trend of increasing product temperatures was observed from zones 3 through 6 due to heat conduction from the barrel. Product temperature in zone 4 was slightly higher than that in zone 5, indicating zone 4 product temperature shown was probably higher than its true temperature. This was because the barrel was not full and also due to localized overheating. Heating a product too quickly could alter the characteristics being tested and possibly result in overheating.

**Effects of ET and SPI on moisture content**

The moisture content (wet basis) was analyzed for the pork sausage links (Table 2). Low-fat (7.4%) bologna has Inog ben known to be considerably higher in moisture and protein than high-fat (24%) bologna (Rongey and Bratzler, 1966). Other researchers have reported the same trend in low- and high-fat frankfurters (Decker et al., 1986; St. John et al., 1986). Extrusion temperature had a significant effect on moisture content. A trend of increasing moisture content was noted in pork sausages as extrusion temperature increased. Control sausages from non-extruded pork (25°C treatment) had lower moisture due to a greater amount of fat (Table 3). Moisture content of pork sausage with 3% SPI was slightly lower than 0% or 1.5% SPI samples and no difference was found between 0% SPI and 1.5% SPI treatments.

**Effects of ET and SPI level on fat reduction**

The percentage fat reduction for each of the fat-reduced pork sausages was also evaluated based on the non-extruded high-fat pork sausage (0% SPI and 25°C treatment). Effects of ET and SPI were compared (Table 3) on the fat content of pork extrudates and sausage links on both wet and dry bases. The fat content of pork extrude and sausage links decreased with increase in extrusion temperature. For pork sausage links, SPI addition reduced the fat content of sausages from non-extruded pork only (P<0.05). The effects of ET and SPI for the pork sausages were evaluated by RSM (Fig. 3) on percent of fat reduction (on dry basis). Fat reduction ranged...
from 6.9% to 35.4% among the treatments and was affected by extrusion temperature. The highest percentage of fat reduction within a level of SPI occurred at the highest extrusion temperature (65.6°C). Fat reduction was affected (P<0.01) by SPI. As SPI increased, fat reduction also increased at non-extrusion 25°C treatment, but no difference was observed at 32.2, 43.3, 54.4, or 65.5°C. Fat reduction was increased more by increasing the extrusion temperature than by addition of SPI.

**Effects of ET and SPI**

The TBARS or malonaldehyde content is a direct measure of the amount of lipid oxidation. Increasing extrusion temperature had an effect (P<0.01) on pork sausage TBARS. The non-extruded 25°C treatment had a higher TBARS than the fat-reduced treatments. A trend toward decreasing TBARS was observed with increase of extrusion temperatures (Table 4). This might have been caused by reduced fat in the extrudate after increasing the extrusion temperature. Thus, the TBARS value may have been lower because less substrate was available for lipid oxidation. Addition of SPI also influenced (P<0.01) the TBARS. Lowest values were observed when 1.5% SPI had been added. However, there were no interactions of SPI levels with extrusion temperatures (P>0.05).

### Table 4—Mean TBARS of pork extrudates and sausage links as related to extrusion temperatures and soy protein isolate (SPI) levels

<table>
<thead>
<tr>
<th>Trt (<em>°C</em>)</th>
<th>TBARS Value (mg malonaldehyde/1000g)</th>
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<tbody>
<tr>
<td>25.0 (NE)</td>
<td>0.826&lt;sup&gt;a&lt;/sup&gt; 0.757&lt;sup&gt;a&lt;/sup&gt; 0.758&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>32.2</td>
<td>0.782&lt;sup&gt;b&lt;/sup&gt; 0.627&lt;sup&gt;a&lt;/sup&gt; 0.670&lt;sup&gt;b&lt;/sup&gt;</td>
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<tr>
<td>43.3</td>
<td>0.685&lt;sup&gt;b&lt;/sup&gt; 0.571&lt;sup&gt;a&lt;/sup&gt; 0.624&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>54.4</td>
<td>0.699&lt;sup&gt;b&lt;/sup&gt; 0.549&lt;sup&gt;a&lt;/sup&gt; 0.575&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>65.6</td>
<td>0.562&lt;sup&gt;a&lt;/sup&gt; 0.541&lt;sup&gt;a&lt;/sup&gt; 0.543&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
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<sup>a</sup>Values with same lower case letters within a column of same treatment variable are not significantly different (P>0.05).

**Effects of ET and SPI on smokehouse cooking loss**

Effects of ET and SPI were compared (Fig. 4) on percent cooking losses of pork sausages during smokehouse heat processing. Extrusion temperature had an effect on smokehouse cooking loss. The pork sausage from 65.6°C extrudates had the lowest cooking loss (P<0.05), indicating that extrusion temperature gave the highest processing yield. Smokehouse cooking loss of control sausage was not different from those of sausages prepared from 43.3°C or 54.4°C extrudates, but was less than that from 32.2°C extrudates. This slight decreasing trend in cooking loss with increasing extrusion temperature could be attributed to fat reduction during extrusion processing and smokehouse cooking. Cooking losses were not affected by SPI level (P>0.05).

**Effects of ET and SPI on color**

The control sausage (25°C treatment) had a higher lightness value than other treatments (Fig. 5A). This was probably caused by the higher proportion of the (white) fat in the product. Increased fat reduction with a simultaneous increase in moisture resulted in lower lightness. Hand et al. (1987) had reported that lower fat frankfurters were redder than high-fat frankfurters. There was no effect (P>0.05) of SPI level on Hunter “L” values. The treatment at 25°C with 1.5% SPI had the highest “L” value (51.6), indicating the lightest color in the samples (P<0.05).

Extrusion temperature also had a significant effect on Hunter “a” color, the redness of samples (Fig. 5B). The “a” values increased as percentage of fat decreased. The higher fat sausages from non-extruded pork were less red compared to those from extruded, fat-reduced extrudates, except for the 32.2°C treatment which also showed a low “a” value. Hand et al. (1987) reported that the lower fat frankfurters were redder than high-fat frankfurters. Heat caused the red pigment of the meat to darken due to increased concentrations of heme pigments and surface dehydration (Price and Schweigert, 1987). Addition of SPI affected the sausage redness value. A decrease in “a” values occurred with addition of SPI. The fat-reduced sausage links were more red compared to controls.

Yellowness (Hunter “b”) of sausage links (Fig. 5C) was significantly affected by both SPI level and extrusion temperature. Sausage links from 43.3 and 54.4°C extrudates had higher “b” values as compared to 25°C extrudates (P<0.05). As SPI level increased, “b” values significantly increased (P<0.05), indicating addition of SPI resulted in yellower products. These values increased as percent SPI level increased from 0 to 3% within each of the temperature treatments.

**Effects of ET and SPI on textural properties**

Both control pork sausage (25°C) and sausages made from 65.6°C extrudates were hard.
with an increase of extrusion temperature from 25°C to 43.3°C might have been caused by the decreasing binding ability as pork was partially cooked. The reversing hardness trend coincided with a simultaneous decrease in fat content at higher extrusion temperatures (43.3, 54.4, 65.6°C) (Table 3). It appears, the effect of fat reduction on sausage hardness became more prominent than the effect of decreasing binding ability of pork in this range of extrusion temperature.

SPI addition did not influence (P>0.05) the hardness of the sausage products. Claus and Hunt (1991) reported increased hardness when 2% SPI was added to low-fat bologna products. Springiness of sausages tended to increase with an increase in extrusion temperature (Fig. 6B) but springiness was not affected (P>0.05) by SPI. Similar results had been reported by Claus and Hunt (1991) in low-fat bologna. The control sausages from non-extruded pork (25°C) within an SPI level had lower springiness than those from 54.4 and 65.6°C extrudates (P<0.05), but no differences were found between sausages from 32.2 and 43.3°C extrudates (P>0.05). Cohesiveness of sausages increased (P<0.05) as extrusion temperature increased from 43.3 to 65.6°C (Fig. 6C). Control sausages had lower cohesiveness than those from 54.4 and 65.6°C extrudates (P<0.05), they were not different from the 32.2°C extrudates (P>0.05). The sausage links containing SPI were higher than those without SPI in cohesiveness (P<0.05) except control sausages, which showed the lowest cohesiveness with 1.5% SPI. Several studies have reported that soy protein may influence textural characteristics of meat products (Keeton and Melton: 1978; Foegeding and Lanier, 1987; Claus and Hunt, 1991). There was an interactive effect between ET and SPI level on cohesiveness of sausage links (P<0.05). The main effect on texture profile analysis values was caused by extrusion temperature. The values for springiness and cohesiveness were greater for higher extrusion temperatures especially at 54.4°C and 65.6°C. The most notable difference among treatments was the level of fat content. Higher fat reductions occurred at high extrusion temperature treatments which may have caused more springy and cohesive products.

**REFERENCES**


Ms received 6/26/98; revised 10/6/98; accepted 10/14/98.

**Fig. 6—Effect of extrusion temperature and soy protein isolate content on hardness (A), springiness (B), and cohesiveness (C) of pork sausage.**