Effects of Rigor State, Salt Level and Storage Time on Chemical and Sensory Traits of Frozen and Freeze-Dried Ground Beef

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ABSTRACT

Both pre- and post-rigor beef semimembranosus muscles were ground with salt (0, 2 and 4%) and then subdivided into two treatment groups (freezing and freeze drying) and evaluated during storage of 0, 5, 10 and 15 wk for chemical and sensory traits. Rehydration ratios of pre-rigor freeze-dried beef (salted or unsalted) were not significantly changed during a 15-wk storage period at 25°C. With the addition of 2 and 4% salt, pre-rigor freeze-dried beef was less susceptible (P<0.05) to lipid oxidation (lower TBA values) than post-rigor, freeze-dried beef. Pre-rigor, freeze-dried beef was superior to post-rigor, freeze-dried meat in all sensory traits studied. Differences in TBA values were not significant between pre-rigor and post-rigor, frozen beef treatments at any salt level (0, 2 and 4%). Pre-rigor, frozen beef samples were superior (P<0.05) to conventional post-rigor, frozen meat in panel tenderness and acceptability scores. The TBA values of pre- and post-rigor beef (frozen or freeze dried), in general, increased with increased salt level (0, 2 and 4%). Freeze-dried beef samples (pre- or post-rigor) were less (P<0.05) tender, cohesive, acceptable and more rancid and/or off-flavor than frozen meat (pre- or post-rigor). Rehydrated post-rigor, freeze-dried meat is drier than frozen control meat (10) and this dryness of product is one of the primary problems which remains to be solved in the field of freeze-drying of meat. Turner (22) evaluated freeze-dried meat and found that the tissue rehydrated more efficiently in a sodium chloride solution than in water. Freeze-dried chicken meat is readily distinguished from frozen chicken meat (3). Freeze-dried chicken meat has a poorer texture, is less juicy, has greater shear resistance, and has more expressible liquid than frozen tissue. However, Hamm (9) used freeze-dried, pre-rigor beef as a raw material for a variety of sausages. He found that the quality (water-holding capacity, fat emulsification, flavor, bite and color) of sausages manufactured from this kind of meat was identical with that of sausages manufactured from freshly slaughtered "hot" beef.

The purpose of the current research was to further examine the use of freeze-dried and frozen pre- and post-rigor meat as a raw material not only for sausage products but also for Chinese snack foods containing beef, such as beef won-ton, beef dumpling and beef shau mai, which are popular in Taiwan, Hong Kong and the Chinese communities in Asia. Most such foods are made by wrapping a filling of post-rigor ground beef which contains ca. 2% salt, spices and/or vegetables in a flour dough skin. The product is then cooked in boiling water or fried in oil. These foods are prepared in quantity by

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restaurants and kept frozen until used. Recently, frozen food companies have commercially prepared and packaged these frozen beef snack foods for sale to supermarkets. Therefore, the use of pre-rigor ground frozen or freeze-dried beef with added salt could possibly increase the palatability and production convenience of sausage and Chinese beef snack foods.

The objectives of these experiments were to investigate the effects of rigor state, salt level (0, 2, and 4%), storage conditions (frozen or freeze-dried) and storage time (0, 5, 10 and 15 wk) on composition, TBA value (lipid oxidation), sensory traits and rehydration ratio of ground beef.

**MATERIALS AND METHODS**

**Preparation of samples and experimental design**

The semimembranosus muscles (ca. 2.3 kg) from the right and left sides of Hereford steer carcasses were randomly assigned to pre- and post-rigor treatments on each replicate (Fig. 1). Pre-rigor muscle was removed (hot-boned) ca. 35 min post-exsanguination. Samples were quickly ground twice through a 9.5-mm plate in a cooler (3 ± 1°C), and the ground and mixed samples were evenly divided into three batches (0, 2 and 4% salt). Following the addition of salt, the ground beef was re-ground twice to obtain a uniform sample. The pH was determined (14) and the salted and unsalted pre-rigor ground beef were made into uniform-shaped 100-g patties using a Tastee Ring Burger Press plastic mold (Robinson Co.). The process for making the pre-rigor beef patties was completed within 1.5 h after obtaining the pre-rigor muscle. Each batch was further divided into two sub-batch treatments for freezing and freeze drying. The beef patties of the frozen treatment were vacuum packaged (0.6 kg/cm²) with refrigerated film (Smith Co.) by Super Vac (Model GK/165, Smith Co.), and immediately frozen and stored at -29°C. The beef patties of the freeze-dried treatment were also quick-frozen in the same type of freezer bags at -29°C for ca. 24 h and then freeze-dried (Model No. 10-145MR-BA, VirTis, Gardiner, N.Y.) for 48 h (10p,m vacuum, shelf temperature 22°C). After freeze drying, the beef patties were quickly vacuum packaged under the same conditions and stored at 25°C.

Post-rigor muscle (cold-boned) was obtained from the sides stored at 3 ± 1°C for at least 48 h. The post-rigor salt treatments (0, 2 and 4% salt) were also subdivided into two treatment groups (frozen and freeze-dried). Procedures for making post-rigor, frozen and freeze-dried beef patties and storage conditions were the same as the pre-rigor treatment. Packages of freeze-dried and frozen beef patties were randomly assigned to be held for 0, 5, 10, and 15 wk.

**Analytical methods**

**Composition.** Moisture, crude fat and protein of these products were determined according to AOAC procedures (1) as described by Ockerman (16). The frozen beef patties (pre- and post-rigor) were thawed at room temperature before completing chemical analysis.

**Rehydration ratio of dried meat.** Freeze-dried samples were broken into small pieces in a mortar (to facilitate water adsorption) and then rehydrated by adding distilled water (6:1) at room temperature for 30 min with stirring at 5-min intervals. After rehydration, the samples were filtered through 2-layer cheesecloth for another 30 min to remove excess water. The rehydration ratio is defined as:

\[
\text{Rehydration ratio} = \frac{\text{Wt. of the rehydrated meat}}{\text{Dry wt. of the sample}}
\]

This is a modification of the method of Klose et al. (13).

**Thiobarbituric acid (TBA) value.** TBA values were determined using the distillation method of Tarladgis et al. (19) as described by Ockerman (16). A 10-g sample of frozen tissue and a 3-g sample of freeze-dried tissue of the same dry weight equivalent were used to determine the TBA values which were calculated with a K value of 7.3, which was experimentally obtained. The TBA values were expressed as mg of malonaldehyde per kg of sample.

**Sensory panel evaluation**

Six to eight trained panelists participated in each panel. A 10-point scale was used to evaluate the cohesiveness, tenderness, rancidity, and off-flavor and acceptability (10 representing extremely cohesive, tender, not rancid or off-flavor, and acceptable and 1 representing uncohesive, tough, rancid and off-flavor, and unacceptable).

All panel evaluations were done at each storage interval for all treatments and the beef patties of the three different salt levels (0, 2 and 4%) were evaluated at separate panel sessions to reduce the obvious influence of salt on panel evaluation. Salt levels were therefore absorbed in the analysis of panel scores. Patties from the frozen treatments were cooked from the thawed state for sensory panel evaluation. All samples were cooked in a fry pan for 6 to 8 min on each side to an internal temperature of ca. 71°C which was monitored in the geometric center by a thermometer. One-fourth of a pattie was used as a sample for each of the panelists.

The freeze-dried patties were broken into small pieces and rehydrated in distilled water (4:1, wt/wt) for ca. 1 h at 3 ± 1°C and reshaped into patties by a plastic mold (Robinson Co., Inc.). The main purpose of this process was to increase the rehydration of the freeze-dried meat. Patties made with pre-rigor meat with salt (2 and 4%) were very difficult to rehydrate without breaking into small pieces. More salt (2 and 4%) soluble proteins were extracted in the pre-rigor beef samples, hence the binding properties of meat were very strong. A protein layer probably was formed around sample particles that retarded the rehydration of the meat. The cooking procedure was the same as that used for the frozen treatment.

**Figure 1. Experimental design.**

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Statistical analysis

Data were analyzed by analysis of variance procedures of the Statistical Analysis System (18). Individual F-tests were used to determine the significance of rigor state, salt level (absorbed in sensory evaluation), storage method, storage time and all 2-, 3- and 4-way interaction effects. Least squares means were obtained and were separated by the Duncan (7) technique.

RESULTS AND DISCUSSION

Composition

Proximate compositions of pre- and post-rigor, frozen beef (SM) with three different salt levels (0, 2 and 4%) are shown in Table 1. The percentage of water was affected by rigor state (P<0.05) and salt level (P<0.05). At each salt level (0, 2 and 4%), pre-rigor frozen samples contained less percentage moisture (P<0.05) than post-rigor frozen samples. This was probably due to the higher temperature (ca. 35°C) of pre-rigor samples during the grinding process in the cooler. Therefore, moisture evaporated more quickly in pre-rigor samples than in chilled post-rigor samples.

Proximate compositions of pre- and post-rigor, freeze-dried beef (SM) with three different salt levels are also shown in Table 1. Both pre-rigor and post-rigor samples with 4% salt contained slightly higher percentages (although not significant for post-rigor samples) of moisture than the 0% salt treatment. This suggests that salt or salt soluble proteins probably retarded the removal of moisture from beef patties during the freeze drying process. The formation of an “impermeable” layer of the sample during freezing may occur due to the concentration of salt or salt soluble proteins at the surface of the sample.

The percentage of moisture of freeze-dried meat ranged from 3.3 to 4.2%. It is well-established that moisture content is very important in the deteriorative changes in dehydrated foods (17). Thomson et al. (20) reported that freeze-dried meat containing less than 2% moisture had maximum quality during storage.

Due to different raw material, rigor state, sample preparation and the freeze-drying process, the beef patties in our research contained 3.3% or more moisture even after 48 h of freeze drying. The decrease in fat and protein percentages with the increase of salt level (0, 2 and 4%) in pre- and post-rigor, freeze-dried beef was probably due in part to the “dilution effect” of salt and higher moisture in the samples containing salt.

Rehydration ratio

Rehydration ratio is often used as a measure of protein denaturation and protein functional properties. Rehydration ratios of pre-rigor, freeze-dried beef (Table 2) were higher (P<0.05) than those of post-rigor, freeze-dried

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Salt (%)</th>
<th>Water (%)</th>
<th>Fat (%)</th>
<th>Protein (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frozen</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-rigor</td>
<td>0</td>
<td>71.7c</td>
<td>5.3d</td>
<td>21.7e</td>
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<td>Pre-rigor</td>
<td>2</td>
<td>70.1d</td>
<td>5.7e</td>
<td>20.9f</td>
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<td>Pre-rigor</td>
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<td>68.3e</td>
<td>5.7e</td>
<td>20.6f</td>
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<tr>
<td>Post-rigor</td>
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<td>72.5e</td>
<td>4.5f</td>
<td>21.6e</td>
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<tr>
<td>Post-rigor</td>
<td>2</td>
<td>71.1e</td>
<td>5.0f</td>
<td>20.9f</td>
</tr>
<tr>
<td>Post-rigor</td>
<td>4</td>
<td>70.0f</td>
<td>5.0f</td>
<td>20.5f</td>
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<tr>
<td>Freeze-dried</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Pre-rigor</td>
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<td>3.3v</td>
<td>21.7e</td>
<td>73.1f</td>
</tr>
<tr>
<td>Pre-rigor</td>
<td>2</td>
<td>3.9v,w</td>
<td>19.7w</td>
<td>67.9w</td>
</tr>
<tr>
<td>Pre-rigor</td>
<td>4</td>
<td>4.1w</td>
<td>18.1w</td>
<td>65.7w</td>
</tr>
<tr>
<td>Post-rigor</td>
<td>0</td>
<td>4.0v,w</td>
<td>19.5w</td>
<td>75.0w</td>
</tr>
<tr>
<td>Post-rigor</td>
<td>2</td>
<td>4.1w</td>
<td>18.4v,w</td>
<td>69.6w</td>
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<tr>
<td>Post-rigor</td>
<td>4</td>
<td>4.2w</td>
<td>17.5v</td>
<td>65.1v</td>
</tr>
</tbody>
</table>

*Data within columns for frozen treatment with different letters (c, d, e, f) are different (P<0.05).

*Data within columns for freeze-dried treatment with different letters (v, w, x, y, z) are different (P<0.05).

Rehydration ratio = \frac{\text{Wt. of the rehydrated meat}}{\text{Dry wt. of the meat}}

*Data within columns with different letters (c, d) are different (P<0.05); data within rows with different letters (w, x, y, z) are different (P<0.05).
beef. This is probably due to the higher pH values (14) of pre-rigor, freeze-dried beef. Auerbach et al. (2) found that the highest level of rehydration of freeze-dried beef occurred in solutions in which the pH was near 7.0.

Rehydration ratios of pre- and post-rigor, freeze-dried beef increased with the 4% salt level at the various storage times. Both in pre- and post-rigor samples, rehydration ratios of beef (salted and unsalted) were not significantly changed during 15 wk of storage at 25°C. Townsend et al. (21) also found no significant change in percent rehydration ratio of freeze-dried chicken and pork due to storage time or temperature. This suggests that both pre- and post-rigor, freeze-dried beef (salted and unsalted) could be stored at 25°C for 15 wk without changing its rehydration ratios significantly.

**TBA values**

TBA values of frozen and freeze-dried beef as affected by rigor state and salt level are shown in Figure 2. Differences, as determined by Duncan’s technique, in mean TBA values were not significant between pre- and post-rigor, frozen beef treatments at any salt level (0, 2 and 4%). Due to different fat composition between beef and pork, storage temperature, time, and packaging method, our results did not agree with the studies of Lin (15); Judge and Aberle (11) and Drerup et al. (6) who reported that pre-rigor fresh pork sausage (salted and unsalted) was less susceptible to lipid oxidation during storage.

With the addition of 2 and 4% salt, pre-rigor, freeze-dried beef had lower (P<0.05) TBA values than post-rigor, freeze-dried beef; however, the difference between these groups with no added salt was not significant. This suggests that pre-rigor, freeze-dried beef (salted) was less susceptible to lipid oxidation than post-rigor, freeze-dried beef (salted). In general, TBA values in all four groups studied significantly increased with increased salt level (0, 2 and 4%). Forrest et al. (8) and Ockerman (16) reported that salt enhanced the development of rancidity of post-rigor meat.

**Sensory panel scores**

The panel tenderness scores of pre- and post-rigor beef as affected by freezing and freeze drying are shown in Table 3. Pre-rigor, frozen raw beef at each salt level contained less moisture (P<0.05) than post-rigor, frozen samples (Table 1), but pre-rigor, frozen beef patties were more tender (P<0.05) than post-rigor frozen samples (Table 3). This is probably due to the higher pH values of pre-rigor samples resulting in a higher water-holding capacity (14) and a lower cooking loss. Cross et al. (5) also reported that patties from pre-rigor, frozen beef were more tender than patties from chilled beef. Pre-rigor, freeze-dried beef had higher panel tenderness scores than post-rigor, freeze-dried beef. In both pre- and post-rigor beef samples, frozen meat was more tender (P<0.05) than freeze-dried meat.

Least squares means of the analysis of variance calculations of panel cohesiveness scores of beef patties also are shown in Table 3. In frozen beef patties, pre-rigor meat samples were more cohesive (P<0.05) than post-rigor meat samples. This is probably due to a higher pH which results in more extractable salt-soluble proteins of pre-rigor beef samples (14). Kuo and Ockerman (14) reported that more salt-soluble proteins were extracted from pre-rigor frozen beef samples than post-rigor samples.

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**Figure 2. TBA values of frozen and freeze-dried beef as affected by rigor state and salt level.**

**TABLE 3. Least squares means (LSM) and standard errors (SE) of panel tenderness, cohesiveness, rancid and off-flavor and over-all acceptability scores of beef patties as affected by rigor state and storage method.**

<table>
<thead>
<tr>
<th>Taste panel tests</th>
<th>Freezing</th>
<th>Freeze drying</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-rigor</td>
<td>Post-rigor</td>
</tr>
<tr>
<td></td>
<td>LSM&lt;sup&gt;b&lt;/sup&gt;→ SE</td>
<td>LSM</td>
</tr>
<tr>
<td>Tenderness scores</td>
<td>8.2&lt;sup&gt;c&lt;/sup&gt;→ 0.02</td>
<td>7.5&lt;sup&gt;d&lt;/sup&gt;→ 0.02</td>
</tr>
<tr>
<td>Cohesiveness scores</td>
<td>8.7&lt;sup&gt;c&lt;/sup&gt;→ 0.12</td>
<td>8.0&lt;sup&gt;d&lt;/sup&gt;→ 0.12</td>
</tr>
<tr>
<td>Rancid and off-flavor scores</td>
<td>8.2&lt;sup&gt;c&lt;/sup&gt;→ 0.10</td>
<td>8.1&lt;sup&gt;c&lt;/sup&gt;→ 0.10</td>
</tr>
<tr>
<td>Over-all acceptability scores</td>
<td>8.6&lt;sup&gt;c&lt;/sup&gt;→ 0.05</td>
<td>8.0&lt;sup&gt;d&lt;/sup&gt;→ 0.05</td>
</tr>
</tbody>
</table>

<sup>a</sup>Salt levels were absorbed for sensory data.
<sup>b</sup>LSM, least squares means; 1= extremely tough, uncohesive, rancid and off-flavor and unacceptable, and 10= extremely tender, cohesive, not rancid and off-flavor and acceptable.
<sup>c,d,e,f</sup>Means with different superscript letters within the same row are different (P<0.05).
Rehydrated freeze-dried samples were significantly less cohesive than frozen beef samples.

Panel rancid and off-flavor scores of beef patties as affected by rigor state and storage method are shown in Table 3. The difference of panel rancid and off-flavor scores between pre-rigor, frozen beef and post-rigor, frozen meat was not significant. Since TBA value is used as an indication of lipid oxidation, this reinforces the early statement that differences in TBA values were not significant between pre- and post-rigor, frozen beef treatments at any salt level (Fig. 2).

Both in pre- and post-rigor meat samples, frozen beef was less rancid and off-flavor than freeze-dried meat (Table 3). Pre-rigor, frozen beef patties were more acceptable (P<0.05) than post-rigor, frozen beef (Table 3). Freeze-dried beef samples (pre- or post-rigor) were less acceptable (P<0.05) than frozen beef (pre- or post-rigor) (Fig. 3).

This research indicates that pre-rigor, frozen beef samples, at each salt level (0, 2 and 4%), were superior to conventional post-rigor, frozen meat in panel tenderness, cohesiveness and acceptability scores, but not in the absence of panel and off-flavor scores. Results indicate that hamburgers (ground beef with 0% salt) made by pre-rigor ground beef were more acceptable than those made with post-rigor ground beef.

Kuo and Ockerman (14) reported that pH values, water-holding capacity and extractable salt-soluble proteins of pre-rigor, frozen beef increased with increased salt level (0, 2 and 4%). This indicates that pre-rigor ground beef samples with 2 or 4% added salt were excellent raw materials for the manufacture of sausages.

However, TBA values of pre-rigor, frozen beef, in general, increased with increased salt level during a 15-wk storage period. Therefore, salt could be added to pre-rigor beef to maintain its good functional properties, only if pre-rigor beef samples were not intended to be held for a long period of time.

Post-rigor ground beef should not contain any salt during storage, because salt not only increased the TBA values of meat, but also decreased the quantity of extractable salt-soluble proteins (14).

Pre-rigor, freeze-dried beef samples were more acceptable than post-rigor, freeze-dried beef. This is probably due to the higher rehydration ratios (Table 2) and lower TBA values (Fig. 2) of pre-rigor, freeze-dried beef. Freeze-dried beef samples (pre- or post-rigor) were inferior to frozen beef (pre- or post-rigor) in all sensory traits studied. Bird (4) also found that post-rigor, frozen controls were superior to post-rigor, freeze-dried meat in flavor, tenderness, appearance and over-all acceptability. Judge et al. (12) concluded that the freeze-drying process was less efficient than freezing because only a portion of the increased freeze-drying cost was compensated for by the reduction of transportation and storage cost. Based on energy usage and meat quality, it seems that freeze-dried ground beef (pre- or post-rigor) should not be used as a raw material for the manufacture of hamburger, sausages or Chinese beef snack foods.

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