Effect of freezing and thawing on meat quality

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Abstract
Effects of freezing and thawing on meat quality are reviewed in terms of freezing methods, rate of freezing and frozen storage. The effects of three successive freeze-thaw cycles on ground beef patty shrinkage and Warner Bratzler shear (WBS) were investigated. Freezing and total losses increased significantly after three refreezings. The WBS values were not significantly affected by any of the three freeze-thaw cycles.

Key words: Freezing, thawing, meat quality, meat patty, freezing method, freezing rate, frozen storage, freeze-thaw.

Introduction
The application of freezing for the preservation of foods has been practiced for several years to maintain their quality during storage, distribution and marketing. The overall freezing process applied to meats consists of three processes: (i) the actual freezing operation, where most of the water in the food is converted into ice, resulting in a hard solid material; (ii) frozen storage; and (iii) thawing, where the frozen food is more or less transformed back into its original state. Prefreezing treatments, if any, should be considered an integral part of the freezing process, since these too have the potential to influence product quality.

Most physical and chemical changes occurring in foods during freezing are caused either directly or indirectly from water to ice transformations. The following factors were considered to be involved in food damage during the freezing operation: (i) damage pertaining to the size and location of ice crystals within the food structure; (ii) mechanical damage caused by volume changes in the food structure and (iii) chemical damage resulting from the concentration of nonaqueous constituents. Commercial frozen storage is generally the most damaging phase of the entire freezing process, since these too have the potential to influence product quality.

The beef ageing is a technique that has been applied for years. Usually, if the meat is not tender prior to freezing, the tenderness will not be greatly enhanced by the freezing process. However, no interrelation was found between ageing and freezing variables in the study on beef, although the differences between aged and un-aged meat diminished as a function of frozen storage time. Great care should be taken to follow proper sanitary practice during the ageing of meat, since this process has been shown to cause the formation of certain bacterial enzymes which penetrate into the meat. Consequently, an aged beef product may demonstrate a lower degree of stability during frozen storage than an un-aged product. The longer meat is aged prior to freezing, the shorter will be its shelf-life. Beef aged for 7 days and then stored at -18°C, was found to be lightly undesirable in fat flavor after about 69 week. However, beef aged for 20 days prior to frozen storage at −18°C exhibited slight undesirability in flavor of fat at about 44 weeks of storage.

Freezing
It has been considered for many years, that foods which are ‘quick frozen’ yield optimum quality. At present, this subject is surrounded by some controversy. Terms which are generally used in expressing freezing rates include ‘sharp’ or ‘slow’, ‘rapid’ or ‘quick’ and ‘ultrarapid’. A wide degree of variation is evident in the methods of expression and the rate associated with each term. What one author may define as slow freezing, another may define as rapid. According to the International Institute of Refrigeration, the freezing rate of a food mass is the ratio between the minimum distance from the surface to the thermal center (slowest cooling point), and the time required for the thermal center to reach a temperature of 10°C lower than the temperature of initial ice formation at the thermal center, once the surface attains a temperature of 0°C. However, for frozen beef patties, the term ‘freezing rate’ was chosen to represent the time required to change internal patty temperature from +5°C to -5°C. Freezing rate determinations were classified into various methods. Other definitions which have been considered in expressing freezing rates include: the rate of heat liberation and the quantity of ice formed per unit mass of food material per unit time. There exist various standards for distinguishing between slow and quick frozen products. Unfortunately most of these are not unequivocally established.

Methods of freezing: The commonly used freezing methods are classified into three groups: (i) freezing in a blast of cold air, (ii) freezing by direct contact with a refrigerant (e.g. plate freezing) and (iii) freezing by direct immersion in a refrigerating medium. In air blast freezing systems, the products to be frozen are placed on metal trays, either in loose form or in packages. The trays are...
loaded onto racks, and cold air is blown over the foods by large fans. Fluidized bed freezing was developed to freeze food particles individually and quickly. A stream of cold air is forced upwards through a conveyor belt carrying food pieces, at a sufficient rate to practically maintain the food in suspension12. Each piece is continuously moved and turned so that all the surfaces are subjected to the freezing air stream.

In plate freezing, the food product (packaged or unpackaged) is brought into direct contact with metal plates which are cooled down to the desired temperature by either cold brine or evaporating refrigerants. This method of freezing operates on the principle of heat transfer by conduction, although having the product packaged offsets this advantage somewhat15. Immersion freezing involves a direct contact between the food and a cold liquid medium, such as a cryogenic freezant. Spray freezing is considered to be a special type of immersion freezing. Cryogenic freezants include liquid nitrogen, liquid and solid carbon dioxide, liquid air and liquid nitrous oxide, with liquid nitrogen, and both solid and liquid carbon dioxide receiving the widest attention on a commercial level. The freezing rates are decreased by direct immersion where boiling is so intense that there is negligible liquid to product contact12. Heat transfer rates are reduced by liquid nitrogen immersion freezant due to the low thermal conductivity of the vapor film surrounding the product15. Foods cracking, peeling and shattering during liquid nitrogen immersion freezing were also reported12, 13. This is to be due to thermal shock13 and rapid contraction of the outer surface of the food. Such fracturing has the tendency to expose more surface area for evaporative losses to occur during cooking13, 14. Spray freezing with cryogenic freezants provides higher degree of contact between liquid and solid, since the freezant boils less intensely. As a result, higher heat transfer coefficients are possible.

**Effect of freezing rate on ice crystal size and location within food structures:** Slow freezing of foods generally results in the production of large ice crystals, located exclusively in extracellular spaces. Slow freezing is characterized by extensive dislocation of water, and consequently the cells have a shrunken appearance in spaces. Mechanical damage caused by changes in product volume: Food systems undergo non-uniform changes in volume during freezing, as a result of the expansion of water into ice during the contraction of most of the other constituents. Consequently, there will be localized areas of expansion, with a likelihood of local stresses and mechanical damage1. Generally, the magnitude of the volume change occurring during freezing, is not considered to be significantly dependent on the rate of freezing.

**Chemical damage caused by concentration of nonaqueous constituents:** During food freezing, nearly all of the nonaqueous constituents are stranded in the unfrozen water, leading to a ‘concentration effect’. There is much uncertainty as to the significance of solute concentration in relation to its role in tissue damage during freezing. Nevertheless, this effect has been found to be involved in the insolubilization of protein and in the loss of muscle elasticity15. The extent of concentration was associated1 with such variables as the rate of freezing, the final product temperature and the nature of the product in question. This concentration effect has been observed to cause obvious changes in the following physical properties associated with the unfrozen portion of food materials: ionic strength, osmotic pressure, vapor pressure, freezing point, pH, surface and interfacial tension and oxidation reduction potential. Fast freezing, performed by the use of cryogenic materials for example, has the tendency to encourage the formation of a filamentous type of ice crystal, which subsequently has the ability to entrap the solutes, minimizing the concentration effect5.

**Effect of freezing rate on meat quality:** Quick frozen foods generally exhibit minimal textural damage, release less thaw exudate and undergo less chemical deterioration than those frozen at low rates1, 5, 16. Although fast freezing of meats is generally agreed to result in quality advantages, the actual freezing operation was not considered5 to be the most significant step in the overall freezing process in terms of final food quality. Instead, it is considered to be of less significance than the frozen storage conditions and thawing treatments. In cases where high rates of freezing result in the optimum quality retention of foods, this effect can easily be offset by improper frozen storage or thawing. Some of the small ice crystals present in the food tissue as a result of fast freezing may recrystallize and enlarge due to a metamorphic process, becoming more typical of those produced by slower rates of freezing.

The freezing of meats generally results in an increased quantity of exudate which is released during thawing. Slow freezing (at -15°C) of beef (both ground and cuts) resulted in a small but significant decrease in water holding capacity (WHC)17. This phenomenon is speculated to be due to the destruction of protein structures by the formation of large ice crystals between the cells. A higher WHC of ground beef patties was reported18 when frozen by liquid nitrogen immersion than frozen at slower rates. Beef patties frozen at slow rates demonstrated significantly lower WHC than patties frozen with cryogenic methods19. Drip loss from meat cuts upon thawing was related to freezing rate only when the surface area to volume ratios of the cuts were large20. The free water has to move to the surface before it can drip from the meat, and hence, the greater the surface area per unit volume, the less distance the water needs to travel. The drip loss from beef cuts was also a function of the cutting method5 (i.e. cutting could either be parallel or perpendicular to the fibers) and the thawing treatment. No significant change was found in the amount of drip from pork slices and beef steaks, whether they were frozen rapidly or slowly20, 21.

Quick freezing of meats using cryogenic methods has the potential to minimize tissue damage and consequently enhance quality, as opposed to the slower conventional freezing methods22. A higher degree of palatability and less structural changes associated with ground beef patties were found23 when frozen at higher rates. The ‘freezing rates’ chosen were 6, 30, 80 and 100 min., defined as the time required to change the patty temperature at the thermal center, from +5°C to -5°C. However, palatability was found to drop significantly between the 80 and 100 min. rates. The
color of frozen meats was found to vary with the rate of freezing. This was attributed to the change in light reflectance, as caused by small ice crystals. Frozen meats had lighter colors at faster freezing rates. Frozen liver exhibited a lighter appearance with increased freezing rates. No apparent difference was found in color between frozen lamb chops subjected to three freezing rates:

- (i) slow (-18°C, still air),
- (ii) rapid (-29°C, moving air) and
- (iii) extremely rapid (-107°C, liquid nitrogen vapor).

However, the chops frozen with liquid nitrogen, exhibited some cracks, as well as separation between the longissimus dorsi muscle and fat areas in the frozen state.

Reported findings concerning the effect of freezing rate on the palatability and appearance of beef were inconclusive, attributing this partly to the vague definitions of freezing rate normally used and the inexactness of quality assessment by sensory panels. The application of cryogenic freezing of red meats has been found to be most productive for small unpackaged items, such as patties, steaks and chubs, where the rate of heat transfer is governed by the ability of the cryogen to remove heat, not by the heat transfer characteristics of the products. The rapid rate of heat transfer characteristic of cryogenic freezing methods is also limited if the product is packaged. Cryogenic freezants such as liquid nitrogen and solid and liquid carbon dioxide have been used with success in the area of meat preservation, in maintaining quality and wholesomeness.

Other freezants such as nitrous oxide, liquid freon and liquid air have also been considered experimentally. Rapidly moving air which is exceptionally cold (i.e. -80 to -100°C) should also be considered as ‘cryogenic’, since the freezing rates resulting from such a method are significantly greater than those obtained by conventional commercial methods.

Cryogenic methods of meat preservation also have the potential to minimize tissue damage, which leads to improved quality.

The benefits of liquid nitrogen freezing were discussed in terms of optimizing such variables as yield, quality and shelf-life of food materials. Freezing foods with cryogenic freezants such as liquid nitrogen, generally results in the foods acquiring physical appearances closer to their fresh states than any other freezing process practiced on a commercial level. The highest cooking losses were observed for the patties frozen at the slowest of the three rates. No difference was found in quality retention of ground beef patties as frozen by either liquid nitrogen or liquid carbon dioxide; but a higher degree of quality retention was observed in the patties frozen by either cryogenic method. The quality variations observed in meats frozen at different rates seem to be more related to structural rather than chemical alterations in the tissue.

An improvement in the overall keeping quality of beef steaks frozen in liquid nitrogen was observed, and a greater reduction in bacterial counts in ground beef was reported after freezing it cryogenically as compared to freezing it slowly. No significant change in palatability was found between pork chops frozen by either direct immersion in liquid nitrogen or a mechanical freezer at -18°C. The effect of three types of freezing techniques was studied, namely air blast, liquid nitrogen boosted air blast and dichlorodifluoromethane (DDM) immersion on salmon quality and observed no differences attributable to the rate of freezing. Cases relating to quality deterioration of meat products frozen by direct immersion in cryogenic fluids have been reported. For example, poor quality of meat cuts frozen in liquid nitrogen was reported due to surface rupturing resulting from the extremely high freezing rates. Liquid nitrogen immersion freezing of cooked beef gave an off-flavor due to the liquid nitrogen bath acting as a cold trap for odorous compounds from the surrounding work area. An unusually pale color was associated with frozen ground beef patties as a result of immersion freezing in liquid nitrogen, but noted that this color disappeared upon thawing.

**Frozen storage**: Frozen storage as conducted on a commercial basis is considered to be the most significant contributing factor in the entire freezing process in terms of food damage. Foods during frozen storage undergo a gradual and significant declination in quality with time. Certain sensory attributes of precooked minced beef patties generally declined with frozen storage time. The effects of frozen storage on ground beef, pork and pork fat and frankfurters were studied and observed a gradual decline in quality characteristics as a function of storage time. The rate of deterioration in frozen foods was attributed to the storage temperature and the nature of the product, with lower temperatures leading to decreased rates of deterioration, and thus increased storage periods. The deterioration of meat during frozen storage could be delayed by holding the storage temperature at a constant low level. Several of the initial quality advantages of faster freezing rates such as texture and color, are lost in foods as the frozen storage period increases. This adverse effect was attributed to the growth of larger ice crystals.

Non-enzymatic changes occurring during frozen storage may result in the development of rancidity in frozen meats. Gradual declinations were shown in various organoleptic properties of a flaked and cured pork product, with frozen storage time. A deterioration in pork muscle flavor before the fourth month of frozen storage was reported. A rise in both the peroxide value and free fatty acids in beef was noted as a result of frozen storage, while no change was detected in the total amount of lipids. However, negligible lipid oxidation in sliced and ground raw beef with frozen storage time at various temperatures was reported. No change in the palatability of pork loin chops was found with increased frozen storage periods, while even an improvement in beef palatability during frozen storage was reported.

Possibility of freezer burn was discussed taking place in foods during frozen storage. This phenomenon was attributed to the sublimation of ice from the product surface, but this can be avoided by packaging the product in a material of low permeability to water vapor. Freezer burn in beef patties was associated with dehydrated exterior surfaces and granulated centers. With regards to the interrelationship between drip loss and frozen storage, an increase in thaw and total exudate was reported from beef muscle as a result of increased storage time at -3°C.

Meat tenderness in relation to frozen storage conditions has also been studied. Increased levels of tenderness (WBS value) was reported in beef with extended frozen storage time at -23°C. Similar finding also indicates that beef muscle tenderness increased during frozen storage at -3°C. However, no change in beef tenderness was found as a function of frozen storage time. No change in tenderness of boneless beef loin steaks was found when stored at -18°C and -23°C for up to 9 months. Unfrozen beef steaks were significantly more tender than those stored at -21°C for either 90 or 180 days. Little observable difference in tenderness between frozen and unfrozen beef steaks was...
reported\(^1\). These discrepancies in the effect of frozen storage time on meat tenderness arise from differences among the variables (e.g. freezing rates, thawing rates, cooking procedures, methods used in measuring tenderness, etc.) pertaining to each study \(^{45}\).

**Thawing**

In many experiments concerning the quality of frozen foods, thawing has gained relatively little attention \(^6\). However, there are compelling reasons for ranking thawing as a more significant cause of quality damage than freezing \(^5\). Proper precautions must be exercised during meat thawing to prevent microbial spoilage. Such precautions would imply the application of reduced thawing times as well as a relatively cool thawing medium. A sufficient number of microorganisms invariable survive the freezing process and the frozen storage conditions, after which they can multiply and promote spoilage both during and after thawing. Thawing in a refrigerator was recommended\(^1\) to suppress the growth of microorganisms which may occur if the food material is allowed to remain at temperatures near or above \(0^\circ\)C for extended periods. Another similar study \(^32\) indicated that ground beef should be thawed at refrigerator temperatures for 24 h to avoid undesirable bacterial growth. In general, thawing at temperatures ranging from room temperature to \(49^\circ\)C is considered to be detrimental in inducing surface spoilage prior to the completion of thawing \(^4\).

A relatively low thawing rate at not too low a temperature is beneficial to meat products such as beef, chicken or fish, where texture is an important criteria \(^6\). The reason for this advantage is thought to be due to the greater amount of time allowed for diffusion to occur in the thawed tissue. This enables a higher proportion of water to migrate to its original location in the tissue\(^10\), consequently resulting in higher tenderness and juiciness ratings \(^6\). Lower amounts of drip associated with beef was found\(^34\) as thawing rate was decreased. In the study on the thawing of beef and pork cuts \(^54\), a slight preference was found for those cuts that were thawed prior to cooking over those cooked directly from the frozen state. No differences in aroma, texture, flavor and juiciness of sirloin, loin and rib (lamb) chops were reported \(^55\) whether thawed before or during cooking. However, both the sirloin and rib chops were less tender when thawed during cooking.

A higher yield in beef slices was observed \(^56\) when thawed during cooking, as opposed to cooking after thawing. As well, lamb patties thawed during cooking were liked by a taste panel over pre-thawed patties \(^57\). No difference was found \(^58,59\) in either the cooking yield or tenderness when beef cuts were cooked from the frozen or thawed states. The application of dielectric and microwave heating has been considered in food thawing. Such thawing methods provide more rapid and uniform thawing than thermal conduction to homogeneous foods \(^60\). Most foods exhibit a rather high degree of heterogeneity during thawing due to a simultaneous existence of frozen and unfrozen phases. Consequently, these distinct phases heat at quite different rates when subjected to a dielectric field, usually resulting in localized overheating prior to complete thawing \(^4\).

The above reviews, concerning work done on meat freezing, meat storage and meat thawing are summarized in Tables 1, 2 and 3, respectively.

**Table 1. Summary of work done on meat freezing.**

<table>
<thead>
<tr>
<th>Reference</th>
<th>Freezing rate and/or method</th>
<th>Product</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>17</td>
<td>(i) Slow freezing: meat placed in stoppered tubes and frozen at -15°C; (ii) fast freezing: meat placed in stoppered tubes and frozen in acetone-CO(_2) mixture at -55°C</td>
<td>Ground and cut beef</td>
<td>Slow freezing resulted in a small but significant decrease in the WHC of meat samples, while fast freezing resulted in a small but significant increase in the WHC</td>
</tr>
<tr>
<td>18</td>
<td>(i) Liquid N(_2) immersion and (ii) simulated in package pallet freezing</td>
<td>Raw beef patties</td>
<td>Higher WHC in patties frozen with liquid N(_2) as compared to other methods; highest cooking losses at the slowest freezing rate; pale color in raw patties frozen by N(_2); no significant changes in sensory attributes</td>
</tr>
<tr>
<td>22</td>
<td>Cryogenic freezing</td>
<td>Meat in general</td>
<td>Minimized tissue damage and enhanced quality</td>
</tr>
<tr>
<td>14</td>
<td>(i) Liquid N(_2) immersion and (ii) mechanical freezing at -18°C</td>
<td>Pork chops</td>
<td>No significant change in palatability</td>
</tr>
<tr>
<td>26</td>
<td>Slow freezing: in still air at -18°C; rapid freezing: in moving air at -28°C; and ultrarapid freezing: in liquid N(_2) vapor at -107°C</td>
<td>Lamb chops</td>
<td>No change in color of chops</td>
</tr>
<tr>
<td>32</td>
<td>DDM immersion at -30°C; liquid N(_2) boosted air blast at -57°C; and mechanical air blast at -34°C</td>
<td>Salmon steaks</td>
<td>No quality variations as a result of different freezing methods</td>
</tr>
<tr>
<td>19</td>
<td>Cryogenic method (liquid N(_2) and liquid CO(_2)) and air blast freezing at -29°C</td>
<td>Ground beef patties</td>
<td>No difference in quality retention as frozen by either cryogenic method; however, the use of the cryogenic methods resulted in higher quality retention and higher WHC as compared to air blast freezing</td>
</tr>
<tr>
<td>31</td>
<td>Cryogenic methods (i.e. liquid N(_2) or liquid CO(_2) spray freeze); air blast freezing at -29°C</td>
<td>Ground beef patties</td>
<td>Greater reduction in bacterial counts after subjection to cryogenic freezing as opposed to air blast freezing</td>
</tr>
<tr>
<td>23</td>
<td>Liquid CO(_2) freezing at -80°C ('rate' = 6 min); air blast freezing at -30°C ('rate' = 30 min); air blast freezing at -15°C ('rate' = 80 min); and still air blast freezing at -10°C ('rate' = 100 min)</td>
<td>Beef patties</td>
<td>Higher freezing rates resulted in more palatable products</td>
</tr>
<tr>
<td>66</td>
<td>Slow freezing: in stationary freezer at -18°C; fast freezing: by liquid N(_2) immersion</td>
<td>Bovine muscle</td>
<td>Greater degree of damage in muscle ultrastructure due to fast freezing</td>
</tr>
</tbody>
</table>
The experiments were carried out in two runs (RUN). The patties were made of 100% beef. The carcasses for the two runs were divided into eight groups of eight. Six groups were randomly selected samples from each run. The mean fat and moisture contents of the patties were 11.25% and 68.12%, respectively in the first run, and 5.24% and 74.66%, respectively in the second run.

Patties weighing 100-105 g each, were formed by hand using a manual patty maker for well formed patties. This operation was performed at room temperature for 24 h. In the latter case, a large scale alteration was evident in the ultrastructure after the third freeze-thaw cycle. In general, refreezing of foods is considered a safe procedure. If the thaw cycle time is minimized, the thawing medium temperature should be low enough to suppress microbial growth.

### Materials and Methods

The experiments were carried out in two runs (RUN). The patties were made of 100% beef. The carcasses for the two runs were aged for two days at ±2°C. The meat was obtained from the chucks of the carcass and stored in an air cooler (±2°C) after deboning. The beef was ground two times through a Hobart grinder (Model 4532, Hobart Manufacturing Co., Don Mills, Canada) first through a 6 mm diameter holes, then through a 3.2 mm diameter holes. The resulting batch of ground beef was mixed in a Butcher Boy mixer (Model L50, Lasar Company Inc., Los Angeles, CA, U.S.A.) for 3 min. Freeze-dry moisture measurements and ether extraction for fat content were conducted on three randomly selected samples from each run. The mean fat and moisture contents of the patties were 11.25% and 68.12%, respectively in the first run, and 5.24% and 74.66%, respectively in the second run.

Patties weighing 100-105 g each, were formed by hand using a manual patty maker for well formed patties. This operation was performed at room temperature for 24 h. In the latter case, a large scale alteration was evident in the ultrastructure after the third freeze-thaw cycle. In general, refreezing of foods is considered a safe procedure. If the thaw cycle time is minimized, the thawing medium temperature should be low enough to suppress microbial growth.

### Effect of repeated freeze-thaw cycles on meat quality:

The possibility of quality changes in foods due to freezing and subsequent thawing has long been of interest to the food industry and consumers, although there is limited data available on the application of this practice. It has been a general tendency to assume that any change resulting in meat products due to freezing and thawing would be a reduction in quality. However, this is not necessarily the case. Several changes, occurring in food quality during freezing and thawing, may not be perceived by the consumer. Consequently, it is necessary to analyze each type of change independently and to determine how it affects food quality. Meat may often be regarded as somewhat more tender after freezing and thawing. Small but progressive increases were observed in the tenderness of beef sternomandibularis muscle after each of three consecutive freeze-thaw cycles. The overall increase in tenderness during the three cycles was significant. Cooking losses, as a function of repeated freezing and thawing increased significantly after the first cycle, but only slightly after subsequent ones. The refreezing of fish has the potential to reduce both the quality and storage life.

### Summary of work done on meat thawing.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Thawing method</th>
<th>Product</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>57</td>
<td>Prior to cooking and during cooking</td>
<td>Lamb patties</td>
<td>Patties thawed during cooking were favoured</td>
</tr>
<tr>
<td>55</td>
<td>Prior to cooking and during cooking</td>
<td>Lamb chops</td>
<td>No notable differences in aroma, texture, flavor and juiciness</td>
</tr>
<tr>
<td>56</td>
<td>Prior to cooking and during cooking</td>
<td>Beef slices</td>
<td>Higher yield when thawed during cooking</td>
</tr>
<tr>
<td>58,59</td>
<td>Prior to cooking and during cooking</td>
<td>Beef cuts</td>
<td>No differences in cooking yield and tenderness</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reference</th>
<th>Frozen storage condition</th>
<th>Product</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>59</td>
<td>At -21°C, for periods of 0, 90 and 180 days</td>
<td>Beef steak</td>
<td>Unfrozen steaks were more tender than those stored for either 90 or 180 days</td>
</tr>
<tr>
<td>47</td>
<td>At -3°C</td>
<td>Cooked beef</td>
<td>Increased levels of tenderness with time</td>
</tr>
<tr>
<td>49</td>
<td>At -18°C and at -23°C for nine months</td>
<td>Boneless beef loin steak</td>
<td>No change in tenderness with time</td>
</tr>
<tr>
<td>33</td>
<td>At -20°C for 2 and 7 months</td>
<td>Precooked ground beef patties</td>
<td>Certain sensory attributes declined with frozen storage time</td>
</tr>
<tr>
<td>41,42</td>
<td>Various frozen storage temperatures</td>
<td>Sliced and ground raw beef</td>
<td>Negligible lipid oxidation with frozen storage time</td>
</tr>
<tr>
<td>45</td>
<td>At -3°C, for 4 h to 28 days</td>
<td>Beef cuts</td>
<td>Increased thaw and total exudate with time</td>
</tr>
</tbody>
</table>

### Table 2. Summary of work done on frozen storage applications concerning meats.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Frozen storage condition</th>
<th>Product</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>At -3°C, for periods of 0, 90 and 180 days</td>
<td>Beef cuts</td>
<td>Increased thaw and total exudate with time</td>
</tr>
</tbody>
</table>

### Table 3. Summary of work done on meat thawing.
and total losses increased significantly after three refreezings. The WBS values were not significantly affected by any of the three freeze-thaw cycles.

**Results and Discussion**

**Effect of freezing and thawing on shrinkage**: Significant differences were found between the number of freeze-thaw cycles, for freezing losses (FL) (P<0.05) (Table 4). Freezing losses were significantly higher following the first and second freeze-thaw cycles (Table 5). This was most likely caused by longer exposure to the frozen storage conditions. The total losses increased significantly after the second cycle (Table 5). No significant difference was observed in FL and TL after third cycle. Cooking losses were not affected by treatments. Previous study 60 also found minimal differences in the total moisture losses (including freezing, thawing and cooking losses) in both the dark and light meat of broiler carcases, as a result of five repeated refreezings.

Cooking and total losses were both significantly higher in the second run (Table 4). The patties in the second run seemed to break apart during grill cooking more than in the first run probably due to more lean beef. Consequently, a greater mass of meat solids may have been lost during cooking in the second run, giving higher cooking and total losses.

**WBS response to freezing and thawing**: The WBS values were not significantly different between the four treatments (Table 4). A significant overall reduction in the mean shear force was found 61 pertaining to beef neck muscles after three freeze-thaw cycles relative to the unfrozen samples. However, in our study, the samples were ground products, hence, it is likely that a large fraction of the cells and connective tissues were damaged prior to freezing. Thus, the damage caused by freezing had no significant effect in increasing product tenderness. No change in the shear values of the dark meat of broiler carcases was detected 62 as a result of five successive freeze-thaw cycles. A slight reduction was observed in the shear values of the light meat after the first refreezing, indicating a slight tenderizing effect. The shear measurements 63 were conducted using the standard shear cell of the Allo-Kramer shear press. An insignificant change in the tenderness of broiler meat was also reported 64, evaluated by sensory analysis, as a result of subjecting the broilers to four freeze-thaw cycles.

**Conclusions**

Hamburger patties were refrozen three successive times to determine subsequent changes in shrinkage (as determined by freezing, cooking and total losses) and WBS values. Both freezing and total losses increased significantly after three refreezings.

**References**

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