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THE EFFECT OF FRESH AND FROZEN BELLIES ON BACON PROCESSING CHARACTERISTICS AND BACON QUALITY

Carmina Citlali Robles

University of Nebraska - Lincoln

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THE EFFECT OF FRESH AND FROZEN BELLIES ON BACON PROCESSING CHARACTERISTICS AND BACON QUALITY

by

Carmina Citlali Robles

A THESIS

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The objective of the study was to evaluate the impact of fresh vs. frozen bellies on bacon parameters. Differences among bellies from pigs of different genetic lines and sexes were evaluated. A population of 578 pork bellies from barrows and gilts of Berkshire, Chester White, Duroc, Landrace, Poland China and Yorkshire lines were processed to sliced bacon and cooked bacon to be evaluated. Bellies were divided into two storage treatments: fresh (stored at 3°C) or frozen (held at -15°C). Fat samples were collected from each belly to establish a fatty acid profile. Differences in percent pump, smokehouse yield, slicing yield and total yield were evaluated. The bacon slabs were sliced and cooked to evaluate differences in fatty acid content, slicing yield, shattering, cooking yield, distortion and proximate composition. Fresh bellies had bacon slicing yields 1.74 percent higher (P<0.05) than frozen bellies. Total yield was not different (P>0.05) for fresh and frozen bellies. No differences (P>0.05) were found in the saturated and unsaturated fatty acid profile of the bellies due to storage treatment. Gilts had a profile with a 1.08 percent higher (P<0.05) unsaturated fatty acid (palmitoleic, oleic, linoleic, linolenic and 11-eicosenoic) when compared to barrows. In the center of the slab (locations B, C and D,) frozen bellies had a higher total shatter mark length (P<0.05). Genetic lines with higher fat content had lower (P<0.05) cooking yields. Frozen bellies had higher (P<0.05) distortion scores of the cooked bacon slice than fresh bellies. Distortion was affected by an interaction (P<0.05) among line and sex. Higher
yields were associated with sex and lines containing higher percentage of fat in the bellies. Overall, fresh and frozen bellies had similar characteristics when processed. Although statistical difference among treatments existed, the practical advantages of these values may be slight. Considering that bellies were stored frozen for 15 d, it is not known if longer periods of storage could result in lower yields and significant processing and cooking differences.
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I dedicate my work to:

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“Every day you may make progress. Every step may be fruitful. Yet there will stretch out before you an ever-lengthening, ever-ascending, ever-improving path. You know you will never get to the end of the journey. But this, so far from discouraging, only adds to the joy and glory of the climb.”  *Sir Winston Churchill*
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I. Curing Technology

Historical Perspective

The curing of meat is not a new concept, but rather a collection of techniques that have evolved from years of product processing. According to Lechowich et al. (1978), prior to 1900, curing was strictly an art and not a science, being largely a matter of secret recipes handed down from generation to generation. Curing of meat today is based on sound scientific principles developed since the turn of the century. Curing is a complex procedure involving chemical, biochemical and enzymatic processes (Lautenschläger, 1997).

Several authors define curing as the treatment of meat with substances for the purpose of durability or to increase the keeping qualities, fix the color, and alter and improve the flavor (Lautenschläger, 1997; Lechowich et al., 1978). Cassens (1995) stated that the resulting cured meat characteristics of color, flavor, and texture, are properties well recognized by consumers.

Curing Methods

Meats are cured by bringing them into intimate contact with a curing agent (“dry cure” or “sweet pickle cure”). The time required for curing will depend on the ability of the curing agent to penetrate to all parts of the meat (Lechowich et al., 1978).

Pickle refers to a mixture of curing ingredients dissolved in a given volume of water. Cure is a dry mixture of ingredients including salt and nitrites. A pickle will also include sugar, phosphates and ascorbates (Lechowich et al., 1978). Cure may also include
spices and seasonings according to the preference of the manufacturer and the product (Cassens et al., 1979). Xargayó et al. (2001) stated that a wide range of products such as spices, fruit extracts, aromatic liquor, oils, oriental sauces, have been used to increase palatability of meat.

The curing ingredients can be introduced into the meat by several different methods. A dry mixture of the ingredients may be rubbed on the surface of pieces of meat. It will dissolve in the moisture of the meat, and with allowed time, diffusion will carry them to the interior of the product. Alternatively, a piece of meat can be soaked in a liquid solution or pickle. This liquid solution may also be injected into the meat under pressure (Cassens et al., 1979).

Most cures are made as a “pickle” or brine solution. A specified amount of the pickle is injected (pumped) into the product with the objective of delivering a predetermined amount of each of the curing ingredients in the final product (Lechowich et al., 1978). According to Xargayó et al. (2001) injection is the most widely used method because it allows dosing an exact quantity of pickle. It also increases the uniformity of the products and decreases the diffusion time required by the dry cure or soaking methods. These are in agreement with Rust and Olson (1973). They reported that with an automatic multiple needle stitch pumping machine cure distribution was so even, tempering periods were not needed before cooking. The injection of the pickle accelerates the curing process because it reduces the time and range required for the brine to diffuse (Lautenschläger, 1997).
Curing Ingredients

Water

Water is the largest ingredient (on a weight basis) used in the manufacture of cured meat. It is used to dissolve, transport and distribute non-meat ingredients into the product. It is also used to replace natural meat juices that will be cooked out when the product is heated. Therefore, water helps maintain profit margins by reducing shrinkage in the heat processing (Mandigo, 1999; Romans et al., 1985).

According to Mandigo (1999) there are additional attributes associated with water. Water must be suitable for drinking (potable). Additionally, it should be free of contaminants. The hardness of water has a major impact on the solubility of certain non-meat ingredients. Therefore, in some geographical areas it is recommended to consider additional water treatment.

Nitrite

The salts of nitrite are soluble in water, which allows them to react in numerous ways with functional groups and therefore have many industrial applications (Cassens et al., 1979). The well recognized sensory effect nitrite has on the final product (pink color and characteristic flavor) is proof that it reacts when it is added to meat (Cassens et al., 1979). Furthermore, some of the added nitrite disappears (Widdus and Busta, 1982). Greenwood (1940) found that when nitrite was added to a meat slurry, immediate analysis showed that up to 50 percent of the nitrite could not be recovered.

Nitrate has been used for centuries in the process of cured meat. Sebranek (1979) concluded that nitrite was formed by bacterial reduction on nitrate. Hoagland (1914)
reviewing previous work, mentioned that Kisskalt studied the production of red color during cooking and found that the color appeared when meat was cooked in water containing nitrites. Meat boiled in water with saltpeter did not take on the red color, but if the meat was first allowed to stand several days in contact with saltpeter and then boiled, the red color appeared. Lehman as cited by Sebranek (1979) and Hoagland (1914) showed that the cured color was derived from nitrite. When fresh meat was boiled in water containing nitrites and free acid or in old meat broth the surface of the meat turned bright red in color, in contrast to the brown color which fresh meat took on when boiled in water free from nitrites (Hoagland, 1914). Haldane (1901) found that the color of uncooked salted meats was soluble in water and gave a spectrum characteristic of NO-hemoglobin. Hoagland (1908) provided the first schematic description of curing: reduction of nitrite to nitric oxide and the modification of pigments by cooking. Lewis et al. (1925) demonstrated that the direct addition of nitrite to cures reduced the cure penetration process in whole muscle meats from 2 to 1 months. Kerr et al. (1926) demonstrated that replacing nitrates with nitrites in ham and bacon production diminished nitrite quantities in the final product. Brooks et al. (1940) demonstrated that sodium nitrite could replace sodium nitrate for curing hams and bacon. The reduction of nitrites in the final product was beneficial. They demonstrated that reactions between nitrite and secondary amines, which are natural components of meat, may lead to formation of carcinogenic nitroso compounds.

Wasserman and Talley (1972) subjectively studied the influence of nitrite on the flavor of frankfurters. Judges could detect flavor differences of franks prepared with or without nitrite in a triangle test. The test consisted of comparing two samples to a
reference sample. The panelists were to determine which one of the two samples is similar to the reference. They found that there was a highly significant difference in flavor produced by the addition of nitrite. When the frankfurters were smoked, however, there was essentially no difference in the scores of the untreated and nitrite-treated franks. The opposite results were found by Cho and Bratzler (1970), who reported that the panelists were able to detect the different sample in a triangle test. Panelist indicated that the nitrite cured smoked sample had more cured flavor than the smoked samples without nitrite.

The United States Department of Agriculture (USDA) has regulated nitrate and nitrite use in meat products since the early 1900s. In 1925 the USDA authorized the use of nitrite for curing (Kerr et al., 1926). In general, only nitrite is now used to cure meat (Cassens, 1995; Sebranek, 1979). Its use is restricted to a maximum of 120 ppm of sodium nitrite in the production of bacon (USDA, 1991).

Nitrite contributes to the formation of color, specific flavor and texture of the final product; it also has antioxidant properties. Nitrites have an antimicrobiological preservative effect. Nitrites provide specific protection against Clostridium botulinum (Cassens, 1995). Pivnick et al., (1969) found that meat with a low inoculate (1 spore per g) became toxic if salt and nitrite were omitted. In contrast, meat inoculated with log 10^6 spores per g remained non-toxic after the same thermal process provided sufficient salt and nitrite in the formulation. From the point of view of immediate health protection, the antibotulinal action is considered the most important contribution (Widdus and Busta, 1982).

In recent years the use of nitrites has stimulated some health concerns. Food can
be contaminated with nitroso compounds. Rywotycki (2001) established that nitroso compounds are formed in slightly acid environments as a result of the reaction of sodium nitrite and nitric oxide with proteins, amino acids and amines present in the foodstuff, which are precursors for the reaction. Yagmur and Özer (2001) reported that it is important to control nitrite levels because of their dosage-dependent toxic characteristics. High levels of nitrites in the meat can lead to the formation of carcinogenic nitrosamines.

Phosphates

Phosphates are the salt form of phosphoric acid. Phosphates are formed when the acid is neutralized with alkali metal ions (sodium, potassium or calcium). Phosphates are classified based on the amount of anions the molecule contains. Ortho or simple phosphates contain a single phosphate ion (Dziezak, 1990; Wagner, 1986). Orthophosphates are made by partially or fully neutralizing phosphoric acid with an alkali source. There are three types of orthophosphates based on the hydrogen atoms available on the phosphoric acid. Monobasic orthophosphates have one hydrogen atom replaced with an alkali metal. Dibasic orthophosphates have two hydrogen atoms replaced. Tribasic orthophosphates have all three hydrogen atoms replaced (Shimp, 1983). Poly or condensed phosphates contain two or more phosphate anions (Dziezak, 1990; Wagner, 1986). Polyphosphates are made by heating mixtures of orthophosphates to high temperatures where they condense into phosphate chains. Pyrophosphate is a simple polyphosphate and contains two phosphorus atoms. Tripolyphosphate contains three phosphorus atoms. Both pyro and tripolyphosphates are crystalline solids, while sodium polyphosphates with chain lengths greater than three phosphorous atoms are not
crystalline, but amorphous products, commonly called “glassy” phosphates (Shimp, 1983; Ellinger, 1972). The crystalline phosphates are fully neutralized and act as bases. One of the fully neutralized polyphosphates, sodium acid pyrophosphate (SAPP), is unique in that it contains two hydrogen atoms and thus, is not basic but, displays a very acidic pH (Ellinger, 1972; Wagner, 1986).

In foods, phosphates have specific roles. They control pH by buffering, they sequester metal ions and they act as polyanions increasing the ionic strengths of solutions. The ability of phosphates to interact in food systems allows them to provide the final product with specific characteristics. In meat and meat products, their functions are water binding, retardation of oxidative rancidity, emulsification, color development and stabilization and improvement of firmness (Lechowich et al., 1978; Wagner, 1986).

The greatest benefit of the use of phosphates in meat products is to manage water. This is accomplished by a mechanism in which phosphates shift the pH of the meat system. Increased ionic strength will dissociate the muscle proteins and create more binding sites for water. Therefore, less of the meat juices (water) will be released during cooking. When phosphates are used in combination with salt, the effect on the water binding ability is increased (Dziezak, 1990). This synergetic effect is widely used in processed meats to improve juiciness, increase water retention and improve texture.

Phosphates are used in most pumped meats, such as ham, bacon, roast beef, cooked corned beef, pastrami, and some similar poultry products. Their advantages include a reduction in cookout, improvement in sliceability, retention of flavor, and greater juiciness (Pearson and Gillett, 1999).

Generally, the orthophosphates have the least value in improving yields, emulsion
stability and shelf life. Sodium acid pyrophosphate accelerates the development of cured color, but is generally detrimental to emulsion stability and the water-binding ability of meat proteins: hence, the alkaline polyphosphates are the phosphates that give the greatest benefit to processed meat products (Rust and Olson, 1983). Pyrophosphates or diphosphates work best when used for emulsion products. In curing brines, mixtures of tripolyphosphate and sodium hexametaphosphate are used. They are dissolved in water and injected into hams and bacons. Hexametaphosphates are slowly hydrolyzed to diphosphate and become active more slowly. A pumping temperature of 0°C/32°F is recommended. High temperatures may result in faster hydrolysis and cause rapid formation of monophosphate, which is inactive in the tissues (Pearson and Gillett, 1999).

Salt

"Common salt" (sodium chloride) is composed of the ions of sodium and chloride. In the manufacture of meat products, salt has the following functions: it strengthens water binding which decreases water activity; acts as a preservative reducing microbial growth and increasing shelf life; and improves flavor acting as a flavoring agent and flavor enhancer (Kühne, 1989; Lechowich et al., 1978). According to Pearson and Gillett (1999) the use of salt might result in harsh, dry, salty product that is not very palatable. It could also result in a dark, undesirable colored lean that is unattractive to the consumers. The cover pickle, used for immersing the meat, may contain about 15 percent of salt, in contrast to the pumping pickle, injected into the meat, which has a higher concentration, approximate 24 percent. Its primary purpose is to lower water activity (a_w) (Frazier and Westhoff, 1988).
Impurities in salt can affect the solubility of the proteins and interfere with the water holding capacity and emulsifying properties of the meats. Only food grade salt should be used in curing, since impure salt can cause flavor and color problems (Pearson and Gillett, 1999).

Sugar

The role of sugar in the curing process has been to reduce the harshness of salt, and improve flavor and color (Lechowich et al., 1978). Pearson and Gillett (1999) reported that sugar softens the products (counteracting harshness) by preventing some of the moisture removal and by a direct moderating action on flavor. According to Frazier and Westhoff (1988) besides adding flavor it also serves as an energy source for nitrite reducing bacteria in the curing solution or pickle.

Brown or white sugars can be used (Rust and Olson, 1973). Mainly sucrose is used, but glucose can be substituted if a curing time is employed, or no sugar may be added (Frazier and Westhoff, 1988). Dextrose is often added to cured products. It is about 75% as sweet as sucrose and more can be added without affecting the flavor. It also increases the water holding capacity of the products (Pearson and Gillett, 1999). Corn syrup, molasses, honey and other natural sugar substitutes are sometimes used in place of sugar. Sugar substitutes have been used in bacon cures to prevent excessive browning during cooking (Pearson and Gillett, 1999).

Sodium Erythorbate

The use of ascorbate or isoascorbate (erythorbate) speeds the color reaction and increases stability of the final product. As a result of the accelerated reaction, they
reduce nitrite levels in the meat product and consequently reduce potential nitrosamine formation (Lechowich et al., 1978). Fox et al. (1967), studied color formation in frankfurter emulsions and found that the lag phase, when oxygen is scavenged from the system, was about 300 minutes in an emulsion held at 38°C/100°F. Under the same conditions if ascorbate was added to the emulsion, the phase took 38 minutes. The corresponding times for the color-production phase (the pink hemochrome is formed) were 8 hours and 25 minutes, respectively (Fox et al., 1967). The presence of ascorbate significantly reduced the time necessary to obtain the desired color. Fujimaki et al. (1975) used mixtures of myoglobin, sodium nitrite and sodium ascorbate in a buffer solution as a meat curing model system. These researchers found that there was an increase in gas production as the amount of ascorbate in the mix was increased. Furthermore, they found that the gas production proceeded not only in the curing period but at the cooking stage. When the molar ratio of ascorbate went from 10 to 100, the decomposition of the added nitrite was remarkably enhanced. They concluded that when the curing period is 0 day and the concentration of nitrite and ascorbate is relatively high at the cooking stage, the color development is higher and gas is generated (Fujimaki et al., 1975).

Rywotycki (2001) agreed with similar results in previous reported studies. The nitrosamine contents in cured meat might be decreased considerably by an addition of sodium ascorbate to the brine. It causes a fast change of nitrites and at the same time decreases the number of nitroso groups which may react with amines. Rywotycki (2001) observed that ascorbate dissolved in water and introduced into the meat, caused a decline in nitrosamine amount as compared to the control sample. The dimethylnitrosamine
(DMNA) content was reduced to 24.8% and the diethylnitrosamine (DENA) to 24.4%. When ascorbate was added to brine containing polyphosphates and sodium nitrite the DMNA content increase in a 15.1% and DENA increased by 15.9%. In contrast to a 31.5% and 36.3% increased (DMNA and DENA respectively) showed by the injection of brine containing polyphosphates and sodium nitrite but no sodium ascorbate (Rywotycki, 2001). The addition of ascorbate as a reducing agent was able to lower the nitrosamine content in the meat even when phosphates were used in the brine.

Smoke

Smoking (natural or liquid) adds numerous chemical components to the product (Cassens et al., 1979). Carbonyls, organic acids, phenols, organic bases, alcohols, hydrocarbons, CO₂, CO, O₂, N₂ and N₂O are among the chemical compounds that have been identified in the curing smoke (Gilbert and Knowles, 1975). According to Frazier and Westhoff (1988) the addition of smoke has two main purposes: to add desired flavors and to aid in preservation. In a study by Janky et al. (1975) the effect of smoke processing on product flavor, tenderness and juiciness was evaluated. They observed a significant improvement in the sensory panel evaluation scores in all the characteristics of poultry products manufactured using a solid smoke aerosol treatment. Panelist compared them to non smoked oven-roasted poultry. The products were rated with a scale of 1 to 5 (1= very unacceptable and 5= very acceptable). The smoked products had higher scores for flavor (4.36 vs 3.45, respectively) and tenderness (4.38 vs 3.88, respectively) than the oven roasted poultry.

There are some concerns that smoking can influence the formation of
nitrosamines in meat products. Knowles et al. (1974) mentioned that nitrites when combined with certain phenols in smokehouse smoke produced nitrosophenols. The nitrosophenols are said to have a catalytic property in relation to nitrosamine production. Citing early work of Jordan in 1985, Potthast (1993) found no increase in nitrosamines even when meat products were made with smoke condensates added to the meat mixture. In these experiments the result was more reduction in the nitrosamine concentration when phenol fractions were added to the meat mixtures. In recent research, Rywotycki (2001) established the possibility that smoke (generated by a glow smoke generator) increased nitrosamine levels in beef. When raw meat was smoked there was an increase in nitrosamine amount, in relation to the control sample by 21.2% of dimethylnitrosamines (DMNA) and 21.5% for diethylnitrosamines (DENA). When smoking was in conjunction with nitrites to beef ham, the raise was DMNA 80.8% and 80.9% DENA, respectively.

II. Type of Belly

Fresh vs. Frozen

The use of frozen bellies, followed by a thawing step prior to curing is a common practice in the production of bacon. The freezing step has been a convenient procedure for those processing plants were storage periods are necessary prior to curing (Rust and Olson, 1973). Cassens (1994) mentioned that the use of frozen meat facilitates inventory control. Therefore, it is an extensive practice among the meat industry.

Freezing provides an excellent means for storing meat for long periods of time. But the quality of meat is not improved by frozen storage (Cassens, 1994).
(1971) established that quality of meat could be affected greatly by reactions such as oxidation, insolubilization of proteins, and glycolysis. Other studies have shown a gradual deterioration in meat quality during frozen storage (Jeremiah, 1980; Miller et al., 1980; Huber and Stadelman, 1970). The conditions under which the meat is frozen have been reported to play a significant role on the final product. Berne (1994) reported that the freezing process affects the quality and shelf life of frozen foods. Special attention should be paid to the speed of freezing. Bjerklie (1996) opinion is that the faster the meat goes from the fresh into the frozen state, the higher the quality of the meat product.

**Freezing Meat**

Meat freezes at −2°C (28°F) (Cassens, 1994). The quality and shelf life of frozen foods are greatly affected by the freezing process by which they are prepared (Berne, 1994). Bjerklie (1996) explained that the speed of freezing is important. As water cools and turns to ice, it expands. Ice crystals form within the food product. The slower the transition from liquid to solid, the larger the ice crystals become (Berne, 1994). Ramsbottom et al. (1949) reported that the size and location of ice crystals in frozen meat depended, in large measure, on the rate at which the temperature of the meat was dropped from just above the freezing point (−1.4°C/29.5°F to −1.1°C/30°F for beef) to a temperature of −3.9°C (25°F). The size and location of the crystals determine the damage made to the tissue. Calvelo (1981) reported that the shape of the ice in the frozen tissue, the size of the crystals formed and their distribution among the intra or extracellular spaces are particularly important in a whole series of macroscopic effects which occur in frozen meat. These effects are, (a) change in the water holding capacity of muscle, once
thawed; (b) changes in texture; and (c) changes in surface color (Calvelo, 1981). Ramsbottom et al. (1949) found that when freezing beef rounds in air blast at -32°C (-25°F), very small intracellular ice crystals on the surface were formed, but large ice crystals were produced between fibers, 10.16 cm (4 in) into the muscle. Large crystals rupture the structure of the cells around them (Bjerklie, 1996). Nusbaum et al. (1983) reported that slower freezing rates increased cooking losses while faster freezing rates decreased cooking losses. These researchers found larger ice crystal size in patties frozen at -10°C (14°F) than in patties frozen at faster rates (-80, -30 and -15°C) (-112, -22, 5°F, respectively). They concluded that larger ice crystals size observed in slower frozen patties might account for higher cooking losses (Nusbaum et al., 1983). Ngapo et al. (1999) studied the effect of freezing and thawing rate on drip loss of pork. Ngapo et al. (1999) reported that at faster freezing rates the drip loss obtained was not significantly different from that obtain from the fresh samples. These results indicate that the freezing process did not affect drip formation. However, at the slower freezing rates studied, drip loss was significantly different from drip loss obtained from the fresh sample.

Nusbaum et al. (1983) reported that sensory tenderness scores were lower and corresponding shear values higher for patties frozen at -10°C (14°F) than for fresh or faster frozen patties. They accounted that difference in sensory characteristics to the large ice crystal size observed in slower frozen patties.

Ngapo et al. (1999) found no evidence to suggest that freezing, frozen storage or thawing results in protein denaturation.

Several researchers have studied the effect of freezing on the color of meat. Ramsbottom et al. (1949) reported that slow-frozen meats are dark, and therefore,
unattractive in appearance. They observed that steaks that were frozen at -29°C (-20°F) in an air blast approached the fresh color. The steaks that were quick-frozen (-79°C/-110°F) were much lighter in color. Steaks that were slow-frozen at -7°C (+20°F) were much darker. Tuma (1971) compared freezing cycles and their effect on beef steaks. Treatments that were composed of higher freezing temperatures (-26, -29 and -40°C) and longer times produced darker color steaks after freezing than the fresh pre-frozen steaks. Rapid short-term systems using -57°C (-70°F) or lower temperatures resulted in brighter red colors immediately after freezing. Guenther and Hendrickson (1962) reported that the colder the freezing temperature, the lighter the frozen steak colors. However, these differences disappeared once the steaks were thawed. The differences in color when the meat is frozen are caused by differences in size and location of the ice crystals (Ramsbottom et al., 1949). According to these researchers, there could be a wide variety of cycles to freeze meat. Ramsbottom et al. (1949) recommended that the rate of freezing should be fast enough so that the color of the lean meat is at least as light as it was before freezing.

Ramsbottom et al. (1949) reported that under the same conditions, beef, pork, lamb and veal freeze at similar rates if their fat content was similar. The total time that well marbled beef, pork and lamb took to go from 4.4°C/40°F to -17.8°C/0°F was 4.7, 4.7 and 4.9 hr, respectively.

**Freezing Methods**

Many methods were used to freeze meats, including freezing in air with low velocity movement, in high velocity air blast, direct contact with refrigerated plates, and
immersion or spraying with sodium chloride brine or other solutions (Ramsbottom et al., 1949). More recently, Berne (1994) reported that there are several methods and a variety of refrigerants used for cooling and freezing. Mechanical systems are used for products of relatively low value but produced in high volumes. Mechanical systems use refrigerants such as ammonia, chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), or liquid carbon dioxide in a closed loop system. The cryogenic technique offers a more precise freezing method. Therefore, they are used for higher value and quality foods. Cryogenic methods are preferred for smaller size food. The cryogenic system utilizes the cooling capabilities of gases such as nitrogen (N₂), carbon dioxide (CO₂), and air. Systems combining the advantages of cryogenics and traditional freezing are becoming more popular. Cryo-mechanical systems combine a cryogenic pre-step followed by mechanical freezing (Berne, 1994). Blast-freezing is the slowest freezing method, but one advantage is that they can also be used for storage (Bjerklie, 1996).

Frozen Storage

Frozen storage of meat takes place at temperatures ranging from −10°C to −30°C. Frozen storage can be detrimental in the quality of meat. According to Calvelo (1981) phenomena that take place during frozen storage are: denaturation of proteins, recrystallization, oxidation of lipids, and/or sublimation (freezer burn). He mentioned that reduction of the latter two depend fundamentally on the use of suitable packing.

The oxidation of lipids is dependent of the access of oxygen and light. If there were adequate protection, rancidity would not appear until after 15 months of storage at −20°C. Ramsbottom (1947) reported that extensive production of peroxides and free
fatty acids occurred after 60 days of storage with pork held at −3°C. Very little evidence of rancidity development was noted at −20°C (Ramsbottom, 1947). After seven years of storage beef steaks resulted in considerable discoloration, dehydration and off-flavor of fat. Ramsbottom (1947) concluded that with proper packaging, meat quality was not reduced even after a year of storage at −29°C.

Sublimation or freezer bum occurs when moisture evaporates from the surface of meat. This takes place as a result of poor packaging were air is allowed in the package. The outcome is a blanched color and a dehydrated layer on the surface of the meat (Cassens, 1994).

Denaturation of proteins involves a change in the protein solubility and is generally evaluated in terms of the quantity of homogenized tissue that can be extracted with a 5% solution of NaCl. The formation of ice crystals during freezing concentrates the remaining solution, which accelerates the denaturation of proteins during storage. The longer the storage time, the smaller the quantity of proteins removed; thus there is an increase in denaturation (Calvelo, 1981). Khan et al. (1963) indicated that during frozen storage chicken muscle proteins became less extractable and the rate of loss of protein extractability increased with storage time and temperature.

Recrystallization consists of the growth of large crystals at the expense of the small ones, leading to a reduction in the number of crystals (Calvelo, 1981).

McBride and Richardson (1979) reported that a trained panel found that for all the sensory attributes (color, texture and flavor) in beef patties, increased storage time resulted in a decrease in acceptability.
Bjerklie (1996) suggested that the key to maintain quality in frozen storage is a constant temperature. Fluctuation of temperature results in crystal thawing and crystal re-formation. This results in cell-structure rupture. This cell-structure damage results in moisture loss and softening of the meat (Bjerklie, 1996). Nichols and MacKintosh (1952) reported increased fragmentation as a result of thawing and freezing cycles. They concluded that both intracellular and intercellular ice crystal formation contributed to the fiber fragmentation. As a result of fiber damage, more drip loss was recorded with each thawing and freezing cycle (Nichols and MacKintosh, 1952).

**Thawing Frozen Meat**

Thawing involves melting all of the ice crystals in the product. Phenomenas such as exudate loss, microbiological growth, evaporation loss and deterioration could occur during thawing (Gonzalez-Sanguinetti et al., 1985; Marriott et al., 1980; Beck and Milone, 1972).

According to Bezanson (1975) from an economic point of view, the drip loss that accompanies the thawing process is of primary significance. Drip loss of frozen/thaw meat could be in the order of 5%. This drip has a protein content of about 10%. In addition to the economic loss, drip loss is related to quality factors such as reduced bind factor, loss of flavor, color changes and dried out texture. Furthermore, if the lost protein gets into the drain, it adds to the BOD load of the wastewater system (Bezanson, 1975).

Calvelo (1981) suggested that meat thawing should be designed to minimize damage. Deterioration reactions reach a maximum rate between –2°C and –10°C. Therefore, it is important that thawing be quick enough to pass through this temperature
range as rapidly as possible (Calvelo, 1981). Thawing should be completed at low temperatures (above 2°C), relatively high heat transfer coefficients and relative humidity between 85% and 95% are used (Calvelo, 1981).

Thawing may be done in cold or warm air. A flow or movement of air will speed the process. Thawing by immersion in water give an improved thawing rate due to the direct contact. Nearly all the meat thawed in processing plants is either air-thawed or water-thawed (Bezanson, 1975). The use of microwave equipment also has appeared to be an applicable way to thaw meat (Cassens, 1994). Water thawing is virtually a standard practice for hams, bellies, briskets, poultry, tuna, and shrimp. It is much faster and consumes less space than air thawing. However, regulations concerning water usage and wastewater quality are making it impractical to water-thaw in an unrestricted manner as was done in the past (Bezanson, 1975).

Some of the disadvantages of the thawing methods include the time that is consumed during the thawing process, the large amounts of floor space required, and the opportunity for undesirable changes to occur to the product (Bezanson, 1975; Satchell and Doty, 1951).

III. Animal production parameters that affect bacon composition

Breed

According to Cisneros et al. (1996) the genetic potential of commercial pigs has changed dramatically over recent years, particularly in terms of lean growth rates.

A study by Tess et al. (1986) reported that at three different ages pigs from a Hampshire X Large White (CX) cross (industry selection based on several traits) were
heaviest and pigs from Beltsville Highfat (HF) (selected for increased backfat thickness) stock were the lightest. The weights were taken on weeks 10, 17 and 24; CX pigs weighed 17.59, 56.10 and 100.59 kg, respectively. Meanwhile HF pigs weighed 13.65, 40.05 and 71.28 kg for 10, 17 and 24 week respectively. Other stocks of pigs was also compared in this study, a Lowfat (LF) (selected for decrease backfat thickness) Duroc-Yorkshire composite. The LF stock had intermediate weights but more similar to HF (14.91, 42.55 and 81.79 kg for 10, 17 and 24 week, respectively). The HF pigs contained the most fat at all three ages, with CX pigs being intermediate (at 10, 17 and 24: HF 2.29, 13.12 and 33.58 kg; LF 1.49, 8.32 and 15.39 kg; CX 1.68, 11.64 and 28.25, respectively). At 24 weeks of age, HF pigs were 13% lighter than LF pigs, while CX pigs were 23% heavier than LF pigs. For non-fat components, CX pigs were heaviest and HF lightest. The fat-free mass weights at week 24 were 37.09, 55.62 and 71.03 kg for HF, LF and CX, respectively. The HF pigs exceeded LF for chemical fat (47 vs 31%) and were lower for protein (11 vs 14%). The CX pigs contained 28% fat and 15% protein. They suggested that selection for rapid lean growth has an effect upon growth and production efficiency. Selection against backfat should decrease total empty body fat, but may also shift the distribution of fat among depots.

Friesen et al. (1994) reported that medium-lean pigs had greater backfat thickness and carcass lipid accumulation than high-lean pigs. High lean pigs had an average backfat thickness of 3.3 cm. Pigs from the medium lean genotype, had an average backfat thickness of 3.5 cm. Lipid accretion was 272.3 vs 226.4 g/d for high-lean and medium-lean pigs, respectively. Friesen et al. (1994) reported that crude protein accretion was greater in high-lean pigs than in medium-lean pigs (106.3 vs 89.7 g/d,
respectively). The differences observed in growth performance up to 104 kg remained evident at 127 kg for both genotypes, although a main effect of genotype was not detected in the finishing phase (from 104 to 127 kg). Their data suggest that high-lean pigs did not produce carcasses superior to those of medium-lean pigs, but that the desired carcass weight was obtained at a faster rate.

Chiba et al. (2002) reported that pigs selected for lean growth efficiency had less 10th rib backfat (22.3 vs 31.5 mm), larger longissimus muscle area (31.6 vs 29.2 cm²) and greater lean accretion rate (273.7 vs 241.6 g/d) when compared with control pigs.

In a study by Gu et al. (1992) it was observed that growth coefficients for lean, fat, bone and skin were not significantly different among genotypes. The genotypes compared in this research were (1) Hampshire x Hampshire Duroc; (2) Synthetic terminal sire line; (3) Hampshire Duroc x Landrace [Yorkshire Duroc]; (4) Landrace x Yorkshire Duroc; (5) Yorkshire x Landrace. The coefficients for lean growth in genotypes 1 to 5 were: .814, .792, .807, .754, .836, respectively. For weight fat growth the average coefficient was 1.584, which indicates that fat tissue grew at a higher rate than did total carcass. Since the coefficients within each trait did not differ among genotypes, it was suggested that growth of these traits, relative to carcass weight, were basically the same in all genotypes. This study is in disagreement with Chiba et al. (2002), Friesen et al. (1994) and Tess et al. (1986). Gu et al. (1992) suggested that the reason for a lack of genotype effect might be due to insufficient numbers and (or) smaller genotype divergence.

Selection by genotype has shown positive results in reducing fat and increasing lean in pig carcasses. Furthermore, selected genotypes tend to grow faster and more
efficiently. The selection for leaner pigs has an effect on bacon production.

Wenther (1999) reported that genetic line had the most dramatic effects on bacon processing parameters and proximate composition. Lines with the higher backfat content and the smallest loin eye area had lower pumping yields. They had the highest percent of fat, the lowest percent of moisture, ash and protein.

Sex

In a study with pigs representing two crossbred genotypes and five slaughter weights barrows grew faster than gilts (Cisneros et al., 1996). They found an interaction between genotype and sex for days on test and daily gain. This interaction resulted from no difference in growth rate (daily gain = .811 kg for barrow and .809 kg for gilts) between the sexes of a three crossbred genotype (Hampshire x [Yorkshire x Duroc]). In the case of a two crossbred genotype (a breeding company hybrid) barrows grew faster than gilts (daily gain = .930 and .817 kg for barrows and gilts respectively). Cisneros et al. (1996) results suggest that sex differences in growth rate may vary with genotype. In relation to the percentage of weight loss from the carcass in the first 24 h postmortem (carcass cooler shrink), Cisneros et al. (1996) reported that the shrink was higher for gilts than for barrows (3.08% and 2.55% loss for gilts and barrows respectively). They also found a genotype x sex interaction for this trait. The breeding company hybrid barrows lost less weight than gilts (2.09 and 3.27%, respectively). However there was no difference between cooler shrink between barrows and gilts for the three crossbred genotype (3.0 and 2.99%, respectively) (Cisneros et al., 1996). Sexes differed for the wholesale cut weight and percentage of ham and carcass trim and the wholesale percentage of shoulder and picnic. But sex did not have an effect on the weight of the
belly (7.70 and 7.54 kg for barrows and gilts respectively). Furthermore there was no difference for the belly on the wholesale cut percentage of barrows and gilts (16.29 and 16.05%, respectively). When curing yields were analyzed, they reported no differences between sexes for belly yield (98.36 and 97.48% for barrow and gilts respectively) (Cisneros et al., 1996). They found no differences between the sexes in some muscle quality traits measured on the longissimus thoracis et lumborum muscle. The traits with no differences were drip loss, cooking loss, tenderness, juiciness, off flavor Warner-Bratzler shear and muscle composition (moisture and fat). However barrows had higher scores for subjective color, firmness and marbling (2.75, 2.85 and 3.07 respectively for barrows; 2.47, 2.55 and 2.63 respectively for gilts).

Larzul et al., (1997) in a study with Large White purebreds, reported that gilts grew more slowly than barrows (average daily gain of 791 g/d for gilts and 836 g/d for barrows). Gilts also had leaner carcasses than barrows. Gilts lean percentage was 52.4 compare to 49.8% of barrows. An average backfat thickness for gilts (29.8 mm) and barrows (31.6 mm) was also reported. Larzul et al. (1997) tested for meat quality traits on the longissimus muscle. They reported that sex had an effect on the intramuscular fat content (1.22 and 1.38% for gilts and barrows respectively). When color was measured, there was no effect of sex on lightness (L* values).

Friesen et al. (1994) reported that dressing percent was lower in barrows than in gilts. An average backfat thickness and 10th rib fat depth were less in gilts than in barrows (2.65 vs. 3.02 and 2.43 vs. 3.15 cm, respectively) for carcasses of 104 kg pigs. Similarly results were reported for carcasses of 127 kg pigs. Gilts had less average backfat thickness (3.28 vs 3.60 cm, respectively) and 10th rib fat depth (3.05 vs. 3.73 cm,
respectively) than barrows. In both of the pigs weights groups, carcasses from gilts had a higher percentage of crude protein (104 kg group: 17.17 vs. 15.77%, respectively; 127 kg group: 15.83 vs. 14.40%, respectively). A difference in ash and lipid content was only found among sexes in the 104 kg pig group. Ash values were 2.85 vs. 2.46%, for gilts and barrows respectively. Values of 27.60 and 31.05% of lipid percent were reported for gilts and barrows respectively.

Wenther (1999) determined that the sex of the animals significantly affected slicing yields and total yield. Barrows had higher slicing yield than gilts.

IV. Composition of the belly

Pringle and Williams (2001) compared pork carcasses varying in fatness and muscling. They reported that side weight was greater in the fattest backfat category than in either of the leaner categories. In the lower 10\textsuperscript{th} rib backfat depth (<2.03 cm) category, the side weight mean was 37.1 kg. The intermediate category (2.03-2.54 cm) had a 38.5 kg mean. Finally, the thick backfat category (>2.54 cm) was significantly higher than the other two side weights with a 43.8 kg mean. However, they found that the belly thickness and belly pocket fat thickness were only different between carcasses in the leanness category. Belly thickness in the leanness category was 1.96 cm in comparison with 2.51 and 2.77 cm for the intermediate and fattest categories respectively. For belly pocket fat depth, the values were 2.49, 3.02 and 2.90 cm for leanness, intermediate and fattest respectively (Pringle and Williams, 2001). The yield of trimmed belly increased as backfat category increased (11.67, 12.37 and 13.21 for leanness, intermediate and fattest respectively).
Wenther (1999) results suggest that the belly composition had an effect on the processing parameters. Leaner bellies exhibited higher pumping yields. Bellies with higher fat content had better smokehouse yields and total yields. These results are in agreement with previous research that reported that the yield of the green and cured belly is inversely related to lean content (Kemp et al., 1969; Freedon et al., 1975a,b; Stiffler et al., 1975; Jabaay et al., 1976; McMillan et al., 1977). In relation to proximal composition Wenther (1999) reported that as the fat in the belly increased moisture, protein and ash decreased (Wenther, 1999).

Fat

Fats are organic chemical compounds made up fatty acids and glycerol. The fatty acids consist of chains of carbon atoms with different amounts of hydrogen and oxygen attached. The most common fatty acids found in food have 16 or 18 carbon atoms in a straight chain. Other are shorter or longer, ranging from 4 to 26 carbon atoms. In food and in the body, fatty acids are usually combined with molecules of glycerol, forming glycerides. One, two, or three fatty acid molecules can be attached to one molecule of glycerol. Most natural fats, from animal and vegetable sources, are triglycerides (Schneeman, 1986).

Fats may also be referred as saturated or unsaturated. These chemical designations refer to the number of double bonds present in the fatty acid chain of the molecule. Unsaturated fatty acids contain one (monounsaturated) or more (polyunsaturated) double bonds. In the case of saturated fatty acids every carbon atom carries the maximum number of hydrogen atoms possible (Schneeman, 1986).
Fat Quality

Consumer demand for cheap lean pork has led to a remarkable improvement of the muscle to fat ratio. This has been achieved by breeding and a reduction in the age and weight of slaughter animals (Kühne, 1984). Unfortunately not only the quality of pork meat but also the properties of fat have change (Cameron and Enser, 1991; Kempster et al., 1986; Wood et al., 1985; Wood and Enser, 1982).

Fat tissue is known to be an important aspect of carcass quality, both in terms of meat processing and consumer acceptability (Whittington et al., 1986). Lack of consistency of adipose tissues is one of the main problems the manufacturers of meat products have to face (Davenel et al., 1999). An example of unacceptable physical characteristics is usually called “Soft fat”. According to Kühne (1984) fat of that consistency cannot be used successfully for the processing of high quality meat products. Soft fat is characterized by defects such as insufficient drying, oily appearance, rancidity development and lack of cohesiveness between muscle and adipose tissue on cutting (Bailey et al., 1973). According to Ellis and McKeith (1999) soft fat is of major concern to the meat processor because it can cause significant problems during cutting, grinding and slicing operations and can result in lower processing yields and reduced value. Therefore, from a processors point of view, firm fat is more desirable.

According to previous studies, lipids make the major contribution to adipose tissue consistency, while other components including collagen and water do not have significant effects (Enser et al., 1984; Whittington et al., 1986). Fat consistency has been attribute to the ratio of monounsaturated to saturated fatty acids (Lea et al., 1970), the percentage of all the unsaturated fatty acids (Elliot and Bowland, 1969) and the
percentage of stearic acid (Wood et al., 1978). Maw et al. (2003) established that the physical characteristics of fat samples are related to their fatty acid composition. In their trial, hardness of the fat samples was related to fatty acid composition with a very high significance. His results show that increased softness was associated with increased linoleic and α-linolenic acid, and a decreased in stearic and palmitic acid percentages.

Research has also been done relating carcass characteristics and fatty acid profile. Wood et al. (1989) compared the composition of the backfat in pigs with different backfat depths and showed that leaner pigs had a higher proportion of polyunsaturated fatty acids (Linoleic and Linolenic). Other studies have linked lean pigs with higher content of unsaturated fatty acids. Chant et al. (1976) evaluated the overall fatty acid composition of bacon. Bellies were classified subjectively based on leanness into five categories. Leanest bellies were scored as 1 and fatter bellies were 5. They reported that the saturated acids (palmitic and stearic) increased as leanness of bacon decreased, whereas linoleic acid increased with bacon leanness. Total saturated fatty acids decreased with leanness of bacon. Their results suggested that leaner bacon had softer, more unsaturated fat with greater susceptibility to rancidity development (Chant et al., 1976). It was also reported that leaner bellies absorb more salt than fatter ones.

According to Enser (1984) the firmness is particularly important in vacuum-packaged rindless bacon slices where soft fat resulted in loss of definition of the individual slice and loss of the firmness of the package.

Sex influence on fat

Geri (1984) reported differences between castrated males and intact females in the cellularity of adipose tissue. In gilts the number of adipocytes in subcutaneous fat was
significantly lower than in barrows from 40 to 200 kg live weight. In the perirenal
deposit adipocytes were significantly larger in barrows than in gilts. There were sexual
differences for total lipid concentration and for water content of the m. logissimus dorsi.
There was lower proportion of water and higher proportion of lipid in barrow muscle
compared with that of gilts (Geri, 1984).

Desmoulin (1984) established that comparison on fatty acid composition must be
made at the same anatomical position between pigs receiving a similar diet. Fatty acid
composition varies with fatness of the carcass and thus may be related to sex and
castration in various breeds. The fatty acid composition of pig fat is more unsaturated
than cattle and sheep. While the level of unsaturation varies between breeds (Wood,
1973), differences in the fatty acid composition of subcutaneous fat from boars, gilts and
castrated males has been shown by many authors (Koch, 1968a; Newel and Bowland,
1972; Smithard et al., 1980). At 90 kg live weight, more than 60% of the total fatty acids
are unsaturated in all three groups although the unsaturation was slightly higher in entire
males. The high level of unsaturation was mainly due to the high concentration of oleic
acid (44%) and linoleic acid (10-12%) (Smithard et al., 1980). Koch et al. (1968b) found
that backfat from barrows contained more palmitic and stearic acids and less linoleic acid
than that of gilts.

Allen (1984) established that there is an effect of sex on the relationship between
fat composition and carcass composition. He suggested that this relationship between fat
composition and carcass composition indicates that very lean carcasses of boars, castrates
or gilts will be more likely to suffer from “floppiness” (soft fat, in which firmness and
cohesiveness has decline) than fatter ones.
This information could impact the bacon industry. If the packer is able to identify lean and fat carcasses and separate them, then it could be that they can supply the bacon manufacturers with more adequate bellies for the production of bacon.
Materials and Methods

A total of 578 bellies from barrow and gilt of six different breeds (Berkshire, Chester White, Duroc, Landrace, Poland China and Yorkshire) were utilized in the study.

Bacon Manufacture

Slaughter and Fabrication

Hogs were slaughtered at Geo, Hormel Inc., Austin, MN. Each carcass was fabricated at Geneva Meats, Inc., Geneva, MN. One belly from each pig was cut to specifications of NAMP #409 – PORK BELLY, SKINLESS (Appendix 1; NAMP, 1997). Fresh bellies were shipped to the Loeffel Meat Laboratory at the University of Nebraska-Lincoln, Lincoln, NE.

Receiving and Storage

Bellies were received at Loeffel Meat Laboratory, University of Nebraska-Lincoln, Lincoln, NE. The bellies were randomly divided into two treatments (Fresh or Frozen). Bellies for the frozen treatment were frozen and stored -15°C (5°F) at UNL Meat Laboratory for processing at a later date. Bellies in the fresh treatment were held in refrigerated (3°C/37°F) storage for curing on the 15th day following slaughter.

Defrosting

Frozen bellies were tempered in a cooler (3°C/37°F) for 2 days prior to manufacture. On the day of production, frozen-tempered bellies were placed in a stainless steel thawing tank, immersed in cold, air agitated water to allow complete thawing. Fresh bellies received similar water treatment. Once thawed, bellies were checked and trimmed for skin and other fabrication defects. After pre-curing assessment,
these bellies were weighed. Prior to pumping, a 7 mm slice of fat from the anterior edge of the belly was removed. The sample was labeled with the belly ID number. It was vacuum packaged and frozen until further analysis.

After collecting the fat sample, the belly dimensions were taken as follows:

Length – measure anterior to posterior dimension at the center of the belly.

Width – measure dorsal to ventral dimension at the center of the belly.

**Pickle Production**

Pickle was prepared fresh each day of bacon production. A batch of 40 bellies required 90 kg (sufficient for pumping operation) of pickle. Ingredients for the pickle were weighed in advance. Table 1 lists the formulation for the pickle solution. The ingredients were mixed using a Rotostat Model 80XP63SS (Admix, Inc., Londonderry, NH). The Rotostat was set at 2500 rpm, the speed reduced to 100 rpm before addition of the liquid smoke, to avoid any production of foam. Ingredients were added one at a time in the following order: water, phosphate, salt, cure, sugar, erythorbate and liquid smoke. The pickle was transferred to the Townsend (Model 1450, Townsend Engineering, Des Moines, IA) pickle injector.

**Pickle Injection**

The bellies were pumped to a target percent of green weight (12.0% pick-up), fat side down on the Townsend multi-needle bacon injection pump. Green weight and post-pump weight were recorded.

Following injection, bellies were hung on a bacon comb at the posterior end, approximately 2.54 cm (1 in) from end. Combed bellies were placed on smokehouse
trucks. The bellies had a resting time of 1 hour before the thermal process to facilitate cure equalization.

**Thermal Processing**

Bellies were thermally processed in an Alkar single truck smokehouse unit (Alkar, Inc., Lodi, WI). The thermal schedule for the smokehouse is shown in Table 2. Following showering and drying, cooked bellies were chilled overnight in a 3°C/37°F cooler.

**Chilling/Tempering**

Following the overnight chilling (3°C/37°F), the individual bellies were weighed to determine smokehouse yield. Bellies were vacuum packaged and stored for subsequent processing in a tempering cooler at -4.4°C/24°F.

**Commercial Pressing**

The vacuum packaged bacon slabs were stacked into pallets. The pallets were transferred to a commercial bacon plant (MPS, Omaha, NE). The slabs were tempered at -4°C/24°F for 24 hrs prior to pressing. The bellies were removed one at a time from the pallets and packaging removed. The tags were removed for pressing and the temperature was recorded (Omega Eng. Inc., Stamford, CT). Bellies were pressed (Anco Model 1411, Cherryburrell, Louisville, KY). They were retagged with the original tag and stacked into new pallets. Pallets were transported back to UNL Meat Laboratory. Pallets with bellies were stored at -4°C/24°F prior to slicing.

**Slicing**

Slabs of bacon were sliced one at a time. The slabs weight and temperature (Omega Eng. Inc., Stamford, CT) were recorded. The slabs were sliced in a Grote Bacon
Slicer (Model 613, Grote Company, Columbus, OH) starting from the posterior end. The bacon slicer was set to slice 10 slices/inch (10 slices/2.54 cm). The following information was recorded for each individual slab: slicing date, slab identification number, slab weight, slab length, slab width, weight of bacon ends and pieces (incomplete slices) and the number of slices in the slab. Slab length corresponded to the measure of the center of the belly from anterior to posterior. Slab width was the measured at the center of the belly from dorsal to ventral.

Belly Evaluation and Sampling

Sliced Bacon Evaluation

After slicing, incomplete slices from both the posterior and anterior ends of the slab were removed. The slices that were affected by the comb (posterior to comb mark and including combing marks) were also removed. End pieces and incomplete slices from posterior and anterior ends of the belly were weighed and recorded separately. The bacon slices were reassembled in original order. Tags were inserted every 20 slices to allow easy counting of the total number of slices in the slab. The slab was divided in 5 zones, each with an even number of slices. The 5 zones were assigned the letters A, B, C, D and E (each representing the next 20% of slices) indicating their location from posterior to anterior.

Each of the five locations were sampled. The first two slices of each zone were evaluated for shattering. Both slices were wrapped in white polyethylene coated, meat wrapping paper (Loxol freezer paper, James River Corp., Parchment, MI) and stored in a cooler (3°C/37°F) for subsequent visioning analysis and proximate analysis. The next
five slices in each zone were assigned for cooking. Slices were vacuum packaged and stored in a cooler (3°C/37°F). The next five slices were also vacuum packaged and kept for backup samples in the freezer (-4°C/24°F).

**Fatty Acid Analysis**

The samples for fatty acid analysis were collected before pickle injection. A thick strip of fresh belly adipose tissue was removed from the anterior edge of the fresh belly. The sample was vacuum packaged and stored in a -4°C (24°F) freezer. They were removed from the freezer and the fatty acid composition of the adipose tissue was determined by gas chromatography. Two samples (0.5-1 g) from the adipose tissue of each fresh belly strip were analyzed. Triglycerol fatty acids were hydrolyzed by saponification and then methylated to form fatty acid methyl ester (FAME). The methyl esters were prepared by an adaptation of the boron trifluoride-methanol procedure of Metcalfe et al. (1966). The gas chromatograph was equipped with an automatic injector (HP 7673) and a flame ionization detector (HP-5890 Series II, Hewlett-Packard Company, Avondale, PA). The methyl esters were separated on a 30 m long x .25 mm internal diameter x .20 μm film thickness Supelco model SP2330 capillary column (Supelco, Bellafonte, PA) utilizing helium gas as a carrier. The injector, oven and detector temperatures were set at 270, 190 and 300°C respectively. The individual methyl esters were identified by their retention time. Peak areas were integrated and analyzed using the HP 3365 Series II ChemStation© Version A.06.98 (Hewlett-Packard Company, Avondale, PA). The results were expressed as a percentage of the total area for all the peaks analyzed. Procedures and analysis conditions are outlined in greater detail in Appendix 3. Commercial standard solutions of FAME (GLC-standard No. 84
and 68D-Check Prep) were used to determine retention times for specific fatty acids, under GLC conditions utilized. The retention times of known FAME were compared to those from belly samples and an in house standard was developed. The standard was used to identify peaks for the rest of the samples and calibrate GLC equipment. The fatty acids studied were: myristic (C14:0), palmitic (C16:0), palmitoleic (C16:1), stearic (C18:0), oleic (C18:1), linoleic (C18:2), linolenic (C18:3), and 11-eicosenoic (C20:1). These fatty acids were selected, since they account for more than 95% of the total amount present (Davanel et al., 1999; Houben and Krol, 1984). Other fatty acids, although present in small quantities, were not considered as important to our objectives, thus, were not identified and were reported as other.

Shattering

Shatter marks were defined as breaks/shatters of the fat portion of the slice that occurred perpendicular to the length of the slice (Salas-Pérez, 2002). Shatter marks did not include the natural separation of fat tissue or the separation between fat and lean tissue.

a. Within Belly Design

In order to obtain information about the variation within the bacon slab as well as geographical location of the shatter marks within the bacon slab, a grid within the sliced bacon slab was made. The grid consisted of dividing the bacon slice into four quadrants (1st, 2nd, 3rd, or 4th), within the five locations (A, B, C, D, or E) (see Appendix 2). Each quadrant represented 1/4 of the distance from the dorsal side to the ventral side of the bacon slice; whereas each zone represents 1/5 of the distance from the anterior to posterior ends of the sliced bacon slab. This procedure was established to accommodate
variable width and length of the bellies. A diagram of this division is presented in Appendix 2.

b. Shatter Recording Considerations

The shatter marks were classified into the following five categories depending on their length: 1-10 mm, 11-20 mm, 21-30 mm, 31-40 mm, >41 mm.

c. Recording Shatter Marks

After recording weights for the sliced bacon slab, the trays were placed on a table with the posterior end closer to the person doing the evaluation, leaving the ventral edge (quadrant 4) to the left side and dorsal to the right side (quadrant 1). The first two slices from each zone were evaluated for shatter marks. Starting from the first complete slice, the slices were separated carefully. Then the slice was rolled over the finger, from quadrant 1 to 4, for a more evident appearance of the shatter marks. Any shatter marks were measured and recorded according to their corresponding quadrant and size category. After shatter marks were recorded for a given slice, the slices were name and wrap appropriately and kept in a cooler until subsequent analysis. The same two slices were packaged and frozen for proximate analysis.

Composition-Proximate Analysis

Proximate analysis was performed for each location of the belly. Ether Extraction-Soxlet determined fat percentage with a modified procedure from AOAC, 1990; section 27.006a, p159. Moisture and Ash were determined using a thermogravimetric analyzer (TGA-601, Leco Corp., St. Joseph, MI). Protein was determined by difference. Detailed procedures are in appendix 4.
Precooked Bacon Processing

Bacon samples were cooked on a Magi-Grill PGB-60 (Magikitch’n, Quakertown, PA) double belt conveyor cooker. Cook yield, dimensional changes in length and width, and distortion scores were determined and recorded for these samples. Preliminary trials were conducted to determine the correct settings for the double belt cooker to yield the proper degree of doneness. The appropriate degree of doneness was determined to be a color described as “golden brown” but not crisp as described by Ross (1999). Cooked yield was required to be less than 40% of raw weight to comply with USDA/FSIS regulations (USDA, 1996). The target cook yield was 37-39% based on cooked color. As a result of these trials, the temperature of the top and bottom platens was set at 204.4°C/400°F with a clearance between platens of 0.33 cm during the cooking process. The preheat temperature was also set at 204.4°C/400°F. The belt speed of the cooker was adjusted to control cooking time. After trials and with the objective to reach the cooked yield and color required, the time was set to 40 seconds from the time the sample entry until its exit from the belt cooker.

Cooked samples were evaluated for percent change in length (at the midpoint of the slice), width (at the midpoint of the slice), and weight from the raw weight. A distortion scale developed by Ross (1999) was used to evaluate the change in bacon shape (Figure 1). The scale has five distortion scores. A distortion score of one characterized a flat piece of bacon with no distortion. A score of five characterized a severely distorted slice. Scores of 2, 3 and 4 represented distortion percentages of 25%, 50% and 75% respectively (Ross, 1999).
The samples were removed from the cooler, the vacuum package was opened and the slices from location A were removed and separated. Their length and width was measured individually. The slices were placed on the paper plate in order from 1 to 5 and weighed. The plate marked “A” was then taken to the belt cooker for cooking. The same procedure was followed for locations B, C, D and E in alphabetical order. The slices were placed on the cooker belt in order from 1 to 5 with spaces of two inches (5 cm). Gaps of eight inches (20.3 cm) were left between locations to prevent any mixing of slices from different locations. As the slices exited the belt cooker, they were placed in numerical order on a clean and identified paper plate. The slices were allowed to cool for 30 seconds before further analysis. All slices from location A were evaluated individually with the distortion scale. Following length and width measures of the five slices were evaluated by video imaging for other parameters of the overall project.

Statistical Analysis

The analysis was a 2 x 2 x 6 factorial treatment design. The experimental unit is the belly from a pig with a given genetic line and sex and with one storage treatment (fresh and frozen). The sample size for each one of the treatments was different. Treatments were allocated in a complete randomize array. Data were analyzed using the Mixed Model procedure of SAS with a level of significance of P<0.05 (SAS, 1999). Means were separated using the Fisher’s least significant difference test.

The effects of genetic line and sex on backfat, loin eye area and carcass length were evaluated using slaughter weight (ranged from 92.98 kg/205 lb – 138.34kg/305lb) as a covariant.
The effects of genetic line, sex and storage treatment on processing parameters were also analyzed for main effects and two-way interactions. Smokehouse yield was analyzed using percent pump (ranged from 6-16%) as a covariant. The slicing yield was analyzed using the temperature (-6°C /21°F - 0°C/32°F) of the belly before slicing as a covariant. When the zone or quadrants were considerate, the analysis splits, or spilt-split plot, respectively were utilized.
Table 1. Brine formulation.

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Percent</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>2.00%</td>
<td>139.21 lb [63145 g]</td>
</tr>
<tr>
<td>Salt</td>
<td>1.00%</td>
<td>33.33 lb [15118 g]</td>
</tr>
<tr>
<td>Sugar</td>
<td>0.15%</td>
<td>16.67 lb [7561 g]</td>
</tr>
<tr>
<td>Natural Smoke Flavoring</td>
<td>0.25%</td>
<td>2.50 lb [1134 g]</td>
</tr>
<tr>
<td>Red Arrow</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sodium Phosphate [BK-450]</td>
<td>0.25%</td>
<td>4.17 lb [1892 g]</td>
</tr>
<tr>
<td>Sodium Erythorbate</td>
<td>550 ppm</td>
<td>0.916 lb [416 g]</td>
</tr>
<tr>
<td>Sodium Nitrite [cure 6.25% NO₂]</td>
<td>120 ppm</td>
<td>3.20 lb [1452 g]</td>
</tr>
</tbody>
</table>

- Phosphate was added to the cold water (≤4°C/40°F) agitated until phosphates are dissolved.
- With continued agitation, the remainder of the non-meat ingredients were added in the following order: salt, sugar, nitrite, natural liquid smoke flavor as required and lastly the ascorbate.

Wenther, 1999.
Table 2. Smokehouse schedule.

<table>
<thead>
<tr>
<th>Step</th>
<th>Time</th>
<th>Dry Bulb</th>
<th>Wet Bulb</th>
<th>RH%</th>
<th>Dampers /Smoke</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>120 min</td>
<td>60°C</td>
<td>----------</td>
<td>------</td>
<td>Open</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>/140°F</td>
<td>----------</td>
<td>------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>20 min</td>
<td>Heat off</td>
<td>----------</td>
<td>------</td>
<td>Closed</td>
<td>Smoke applied *</td>
</tr>
<tr>
<td></td>
<td></td>
<td>/fans off*</td>
<td>----------</td>
<td>------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>45 min</td>
<td>60°C</td>
<td>21.2°C</td>
<td></td>
<td>Auto</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>/140°F</td>
<td>/100°F</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>IT&gt;53.3°C</td>
<td>65.5°C</td>
<td>48.8°C</td>
<td>40%</td>
<td>Auto</td>
<td>IT&gt;53.3°C</td>
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<tr>
<td></td>
<td>/128°F</td>
<td>/150°F</td>
<td>/120°F</td>
<td></td>
<td></td>
<td>/128°F</td>
</tr>
<tr>
<td>5</td>
<td>10 min</td>
<td>----------</td>
<td>----------</td>
<td>------</td>
<td>Auto</td>
<td>Shower</td>
</tr>
<tr>
<td>6</td>
<td>10 min</td>
<td>----------</td>
<td>----------</td>
<td>------</td>
<td>Auto</td>
<td>Dry</td>
</tr>
</tbody>
</table>

IT= Internal Temperature

* Liquid Smoke Atomization settings as follows: 4.08 atm (60 psi) to nozzle, 2.86 atm (42+ psi) to tank, flow 7.57 L/hr (2.0 gph), 2.11 kg (4.65 lb) Red Arrow “Charsol Supreme Hickory”.

Wenther, 1999.
Figure 1. Distortion scale.

Ross, 1999.
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The effect of fresh and frozen bellies on bacon processing characteristics

C. C. Robles and R. W. Mandigo

Keywords: Bacon, Fresh, Frozen

Department of Animal Science
University of Nebraska, Lincoln
Lincoln, NE 68503-0908

1. Authors Robles and Mandigo are currently affiliated with the University of Nebraska-Lincoln, Lincoln, NE 68503-0908
Abstract

The objective of the study was to evaluate the impact of fresh vs. frozen bellies on bacon parameters. Physical and chemical differences among bellies from pigs of different genetic lines and sexes were evaluated. A population of 578 pork bellies from barrows and gilts of Berkshire, Chester White, Duroc, Landrace, Poland China and Yorkshire lines were processed to sliced bacon and evaluated. Bellies were divided into two storage treatments: fresh (stored at refrigeration temperature, 3°C) or frozen (held at -15°C). Raw bellies were processed into bacon under the same conditions in order to evaluate differences in percent pump (pick-up), smokehouse yield (green weight/cured weight), slicing yield (weight of the slices) and total yield (sliced weight/green weight). Frozen stored bellies were able to pickup 0.73% more pickle (P<0.01) than bellies stored fresh. Fresh bellies had bacon slicing yields 1.74 percent better (P<0.05) than bacon made from frozen bellies. The results for total yield were not different (P>0.05), 82.61% and 82.10% for fresh and frozen, respectively. Genetic line and sex had the most dramatic effects on the bacon processing parameters. Higher yields (smokehouse, slicing and total) were associated with sex and lines containing higher percentage of fat in the bellies. Overall, fresh and frozen bellies had similar characteristics when processing bacon. Although statistical difference among treatments existed, the practical advantages of these values may be slight. Considering that bellies were only stored for 15 d, it is not known if longer periods of storage could result in lower yields.
Introduction

The current surge in popularity of bacon is a factor in the continuing strength in demand for sliced bacon. From 1999 to 2000 supermarket bacon sales increased 45 percent. Restaurant sales grew 7 percent every year from 1997 to 1999. Due to this high demand, the number of U.S. pork bellies in cold storage hit a historic low in April 2001 (National Pork Board, 2001). The live hog market varies due to cyclical and seasonal differences. As a result, the price is determined by supply and demand. Bellies prices also tend to fluctuate throughout the year (National Pork Board, 2002).

The variation in price, supply and demand of bellies can drive manufacturing practices of the bacon industry. The bellies are often stored frozen at times when the prices are low. Bacon is then made as the market demands it.

Freezing provides an excellent means for storing meat for long periods of time, but the quality of meat is not improved by frozen storage. Ice crystals are formed within the food product during freezing. The size and location of the crystals will determine the extent of damage to the tissue. Damage can include changes in the water holding capacity, texture, and surface color (Berne, 1994; Calvelo, 1981; Ramsbottom et al., 1949).

During thawing, other undesirable phenomena such as exudate loss, evaporation loss, oxidative deterioration reactions of lipids and protein denaturation could take place (Gonzalez-Sanguinetti et al., 1985; Marriott et al., 1980; Bezanson, 1975). There is little data that reports the effect of the damage on frozen bellies when processing to sliced bacon.
Other factors influence bacon manufacturing characteristics. It is well known that today’s pigs are bred and fed to be leaner and with less fat, compared to the pig of 1950s. Today’s model is leaner, with 50 percent less fat. Lean-to-fat ratio is one of the biggest factors in a shopper’s selection of bacon. West et al. (1973) reported that consumers would purchase leaner bacon as a premium product. Consequently, packers prefer lean pork and producers are raising leaner, heavier muscled pigs to satisfy these demands (National Pork Board, 2002).

The emphasis on lean hogs has changed bacon. Leaner bellies produce higher percentage of slices, while fatter bellies produce a lower percentage of “premium” bacon slices (Fredeen et al., 1975; Stiffler et al., 1975). However, with the leaner bellies, bacon processing characteristics such as smokehouse yield and total yield are inversely related to carcass characteristics desired by the producer, packer and consumer (Wenther, 1999).

The objective of the study was to determine differences in pump percent, smokehouse yields, slicing yields and total yields when manufacturing bacon from refrigerated and frozen stored bellies. The study also evaluated differences among barrows and gilts from genetic lines consisting of Berkshire, Chester White, Duroc, Landrace, Poland China and Yorkshire lines.

**Materials and Methods**

A total of 578 bellies from barrow and gilt bellies of six different genetic lines (Berkshire, Chester White, Duroc, Landrace, Poland China and Yorkshire) were utilized in the study.
Slaughter and Fabrication

Hogs were commercially slaughtered at Geo. Hormel Inc., Austin, MN. Each carcass was fabricated at Geneva Meats, Inc., Geneva, MN. One belly from each pig was cut to specifications of NAMP #409 - PORK BELLY, SKINLESS (NAMP, 1997), and were shipped to the Loeffel Meat Laboratory at the University of Nebraska-Lincoln, Lincoln, NE, for bacon processing.

Receiving and Storage

Upon receipt, the bellies were divided into two storage treatments: fresh or frozen. Bellies (275) in the frozen treatment were frozen in a still atmosphere freezer at UNL Meat Laboratory and held at -15°C (5°F). Bellies (303) for fresh treatment were held in refrigerated (3°C/37°F) storage for curing on the 15 d following slaughter.

Defrosting

Frozen bellies were tempered in a cooler (3°C/37°F) for 2 d prior to manufacture. Fresh and frozen bellies were then fully thawed in water. The bellies were placed in a stainless steel thawing tank and immersed in cold (≤4°C/40°F), air-agitated water to assure that all frost was removed (usually 30 min). Thawed bellies were re-inspected, trimmed for skin and other fabrication defects, and weighed. Prior to pumping, a 7 mm slice of fat from the anterior edge of the belly was removed. The fat sample was label with the belly ID number. It was vacuum packaged and frozen until further analysis.
After collecting the fat sample, the belly dimensions were taken as follows:

- **Length** – measure anterior to posterior dimension at the center of the belly.
- **Width** – measure dorsal to ventral dimension at the center of the belly.

**Pickle Production**

Fresh pickle was prepared the day of bacon production (Table 1). A batch of 40 bellies required 90 kg of pickle. The water and dry ingredients were mixed using a Rotostat Model 80XP63SS (Admix, Inc., Londonderry, NH). The Rotostat was set at 2500 rpm, the speed reduced to 100 rpm before addition of the liquid smoke, to avoid any production of foam. Ingredients were added one at a time in the following order: water (≤4°C/40°F), phosphate, salt, 6.25% sodium nitrite cure, sugar, erythorbate and liquid smoke. The pickle was transferred to the pickle tank of the Townsend® injector (Model 1450, Townsend Engineering, Des Moines, IA).

**Pickle Injection**

The bellies were pumped to a target percent of green weight (12.0%), fat side down using a multi-needle bacon injection pump (Model 1450, Townsend Engineering, Des Moines, IA). Green weight and post-pump weight were recorded.

Following injection, each belly was hung on a smokehouse truck using a bacon comb approximately 2.54 cm (1 in) from the posterior end. The bellies were allowed to equilibrate 1 h before thermal processing to facilitate brine equalization.
**Thermal Processing**

Bellies were thermally processed in an Alkar single truck smokehouse unit (Alkar, Inc., Lodi, WI). The thermal schedule for the smokehouse is shown in Table 2. Following showering and drying, cooked bellies were chilled overnight in a 3°C/37°F cooler.

**Chilling/Tempering**

Following the overnight chilling (3°C/37°F), individual bellies were weighed to determine smokehouse yield. Bellies were vacuum packaged and stored for subsequent processing in a tempering cooler at -4.4°C/24°F.

**Commercial Pressing**

The vacuum packaged bacon slabs were transferred to a commercial bacon plant (MPS, Omaha, NE) to be pressed. The slabs were held at -4°C/24°F 24 h prior to pressing. Temperature was recorded (Omega Engineering Inc., Stamford, CT) prior to pressing. The slabs were pressed (Anco Model 1411, Cherryburrell, Lousville, KY), stacked on new pallets, then transported and stored at -4°C/24°F at UNL Meat Laboratory.

**Slicing**

Cooked belly weight and temperature (Omega Engineering Inc., Stamford, CT) were recorded prior to slicing. The slab was fed in to the bacon slicer (Model 613, Grote Company, Columbus, OH) starting at the posterior end. The slicer was set to slice 10
slices/inch (10 slices/2.54 cm). The following information was recorded for each individual slab: slab identification number, slab weight, slab length, slab width, weight of bacon ends and pieces (incomplete slices) and the number of slices in the slab. Slab length corresponded to the measure of the center of the belly from anterior to posterior. Slab width was the measured at the center of the belly from dorsal to ventral.

Statistical Analysis

The analysis was a 2 x 2 x 6 factorial treatment design. The experimental unit is the belly from a pig with a given genetic line and sex and with one storage treatment. The sample size for each one of the treatments was different. Treatments were allocated in a complete randomize array. Data were analyzed using the Mixed Model procedure of SAS with a level of significance of P<0.05 (SAS, 1999). Means were separated using the Fisher’s least significant difference test. The effects of genetic line and sex on backfat, loin eye area and carcass length were evaluated using slaughter weight (ranged from 92.98 kg/205 lb – 138.34kg/305lb) as a covariant.

The effects of genetic line, sex and storage treatment (fresh and frozen) on processing parameters were also analyzed for main effects and two-way interactions. Smokehouse yield was analyzed using percent pump (ranged from 6-16%) as a covariant. The slicing yield was analyzed using the temperature (-6°C /21°F - 0°C/32°F) of the belly before slicing as a covariant.
Results and Discussion

Fresh verse Frozen

Frozen bellies retained 0.73% more brine (P<0.01) than fresh bellies (Table 3). These results differ from the expected. It was thought that during storage proteins in frozen bellies would have been damaged. Therefore, fresh bellies would have had the ability to hold more brine than frozen ones.

Ngapo et al. (1999a) studying the cross-sectional areas structure of fresh, frozen, and thawed pork, observed cavities. The areas of the cavities in the frozen samples were approximately ten times larger than similar areas in fresh and thawed samples. Indicating frozen meat had suffered greater damage on its ultrastructure due to freezing.

Damage can possibly be reflected in different ways. Among those, drip loss is considered of economical significance. Previous publications have reported that frozen meat, when thawed, has higher drip loss than fresh meat (Ngapo et al., 1999b; Bjerklie, 1996; Rust and Olson, 1984).

It is suspected that the frozen bellies in this study may have lost more water during thawing than fresh bellies. It is also believed that muscle cells in frozen bellies had suffered distortion during storage. As a result, frozen bellies could have cells that were dryer and more flexible. The bellies were able to hold more brine after pumping.

The difference in pumping percent was small. On a small scale production it may not be of practical significance (10.49 and 11.22% fresh and frozen, respectively). However, considering a large scale of bacon production, this small improvement in yield may translate into economical gain.
To evaluate the thermal processing properties of fresh and frozen bellies, the effect of pump retention was included in the statistical model as a covariate. Fresh and frozen bellies had similar yields after heat process in the smokehouse (Table 3).

Fresh bellies had 1.74% higher (P<0.05) slicing yields than frozen bellies (Table 3). A possible cause of the differences in slicing characteristics could be given for the integrity of the muscle cells in the bacon slab.

A study by Rahelic' and Puac' (1985) observed that the ice crystals formed during freezing meat damaged muscle fibers. They reported that meat frozen at \(-22^\circ C\) was damaged more severe than bacon frozen at \(-10^\circ C\). The distribution of ice crystals and the freezing point may be different. At \(-10^\circ C\) crystal formation seemed to occur intercellularly and at \(-22^\circ C\) the formation was inter and intracellular in their work. The crystals formed between fibers will generate pressure that will separate fibers, while crystals formed intracellularly will exert pressure in the opposite direction. As a result of the opposing pressure, tearing of the fibers will be greater (Rahelic' and Puac', 1985).

In the present study, bellies were frozen at \(-15^\circ C\), an intermediate temperature of those reported by Rahelic' and Puac' (1985). It is possible that a phenomena similar to the one that Rahelic' and Puac' (1985) found at \(-22^\circ C\) could have occurred. Thus, the difference in yields could be given by the less damaged cell structure of fresh bellies. A better integrity of the bacon slab could have a lower tendency to break or shatter during the slicing process, therefore, obtaining more complete slices of bacon.

Total yield measures the overall processing efficiency of the belly from its green weight through to sliced weight and sliced bacon ready to be commercialized. Fresh bellies had higher total yields (82.61%), although, they are not significantly different than
the yields of frozen bellies (82.10%). This difference is very small not statistically different, and might not be of commercial significance. It might suggest that that frozen bellies have lost quality and thus have lower processing characteristics than fresh bellies.

**Genetic Line Effect**

There was a significant effect of genetic line on pumping percent. Bellies from Poland China pigs had greater (P<0.05) pickle retention (11.78%) than Yorkshire, Berkshire, Landrace and Duroc lines (10.78, 10.74, 10.66 and 10.33% respectively). But pump percent in bellies from Poland China was similar to Chester White (10.87%). The ability of the belly to retain pickle has been correlated with the fat and lean content of the carcass. In this study, it was found that Poland China and Chester White barrows had higher (3.40, 3.17 cm) backfat thickness than Landrace, Yorkshire and Duroc barrows (2.61, 2.49 and 2.41 cm, respectively). They also had more backfat than gilts from all genetic lines. Gilts of these two lines (Poland and Chester White) had more backfat when compared to the leaner (Landrace, Yorkshire and Duroc) lines of the study (Table 4). Loin eye area measured from Poland China (37.09 cm²) and Chester White (38.25 cm²) carcasses was smaller than those of Duroc and Yorkshire (41.80 and 40.64 cm², respectively). Overall, our results show that fatter lines had better cure or pickle pick up during pumping. These results are different than work reported by Wenther (1999) who reported that bellies from light muscle and fat lines had the lowest percent pump. Saffle and Bratzler (1959) also reported that bellies from fatter pork carcasses had lower amounts of salt during processing. In this study, the lowest pumping yield was observed in Duroc pigs, which had the largest loin eye area (41.80 cm²), and a heavier muscled
carcass. Pigs in this study were much leaner than those in the Saffle and Bratzler (1959) study. This could possibly explain the differences in these results. It was difficult to compare pigs in this study to those in Wenther (1999) because they reported loin eye area and backfat thickness as rates of change in the live animal and not as final values.

Genetic line had an effect (P<0.01) on smokehouse yields (Table 3). Bellies from Berkshire pigs had the highest yield (98.20%) (P<0.05) as compared to all other lines. Previous studies report that yield is positively related to fat content in the belly. Table 4 illustrates that within sex, Berkshire pigs had the highest backfat content (3.40 and 2.66 cm for barrows and gilts, respectively). Landrace hogs had the lowest smokehouse yields, 2.29% lower than the highest yield achieved with the Berkshires (Table 3). Comparing backfat of Landrace barrows and gilts (2.61 and 2.28) with the rest of the breeds were similar to the leaner Yorkshire (2.41 barrows and 2.05 gilts) and Duroc pigs (2.49, 1.95 barrow and gilts, respectively). These results suggest that fatter bellies have better yield during cooking in the smokehouse. The results are in agreement with previous studies that reported that fatter bellies tended to lose less weight during the heating process (Wenther, 1999; Kemp et al., 1969; Carpenter et al., 1963; Saffle and Bratzler, 1959).

Total yield provides an estimate of the losses during bacon manufacturing from the green weight of the belly to the total number of marketable slices of bacon. The bellies with better performance in the study were those that belong to carcasses with thicker backfat (Tables 3 and 5). Bellies from Berkshire pigs had the highest yield with 85.90%. Poland China followed, with similar yields (83.44%). Chester White hogs had yields (83.14%) that were similar to Poland China, but they were significantly different
than Berkshire pigs (Table 3). Results suggest that fat content is positively related to total yield. Results are in agreement with Wenther (1999), Carpenter et al., (1963) and Saffle and Bratzler (1959).

The length and width of the bellies (Table 6) were affected by genetic line (P<0.05). Genetic lines that had longer bellies tended to have smaller widths, Chester White pigs had the longest bellies (52.07 cm) and the smallest width (25.37 cm). Yorkshire bellies resulted in the widest width (26.44 cm). Their length was among the shortest of the study (50.39 cm). The differences in dimension of the bellies did not seem to have an effect on slicing yield or total yield. Lines with longer bellies did not necessarily have higher yields.

**Sex effect**

The sex of the pig did not have an impact on the percent pump injection solution retained by the belly (Table 3). The data also indicated no significant effect of sex in bacon smokehouse yields.

Sex had an effect on slicing yield parameter (Table 3). Barrows had significantly higher (P<0.05) slicing yields than gilts (86.86 and 85.36%, respectively). Results in this study are consistent with prior reports that indicate barrows tend to be fatter than gilts (Wenther, 1999; Cisneros et al., 1996; Lonergan et al., 1992). They also had smaller (P<0.01) loin eye area (36.25 cm²) than gilts (40.77 cm²). This suggests barrow carcasses had less muscle content than gilts (Table 5). Although due to interactions between sex and genetic line, main effects cannot be analyzed. A view of the means for back fat thickness of barrows and gilts for each line are given in Table 4.
From these results it can be seen that within a genetic line, barrows had higher backfat content than gilts.

Sex had a significant effect (P<0.05) on total yield (Table 3). Barrows had higher (P<0.05) yields than gilts. Since barrows had higher slicing yields, it was expected that they would have higher total yields. This can also be attributed to the fact that barrows were fatter than gilts.

The effect of sex on belly dimension was also analyzed. Sex had no effect on the length, but had an effect on the width of the belly. Gilts had wider bellies than barrows by an average of 0.48 cm (Table 6). This is in agreement with Freeden (1980) who found that bellies from females were greater in the dorso-ventral dimension. However, the difference in belly width did not seem to have had an effect on the any of the parameters analyzed in this study.

**Conclusions**

Bacon has become an important part of the increased consumer preferences due to flavor and texture. A number of factors influence bacon processing characteristics. Commercial bacon processors consider sliced yield, smokehouse yield and total yield important in the overall profitability of bacon manufacture.

These results suggest that the use of fresh or frozen bellies in the manufacture of bacon would have very similar processing characteristics and yields. In the present study bellies were in frozen storage for only 15 days prior to processing. Perhaps longer periods of storage could lead to significant processing differences. These differences
could have greater impact in bacon processing operations, where volumes of production are much larger.

Genetic line and sex had great impact on processing yields of bacon. The present study agrees with previous reports that indicate that the yield of the green and cured bellies are inversely related to the lean content of the pork carcass. Thus the potential economic benefits associated with improved lean content in live hogs may come with a reduction in yield when manufacturing bacon (Wenther, 1999; Freeden, 1980; Jabaay et al., 1976; Stiffler et al., 1975).
Reference


Table 1. Brine formulation.

<table>
<thead>
<tr>
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<tr>
<td>Water</td>
<td></td>
<td>139.21 lb [63145 g]</td>
</tr>
<tr>
<td>Salt</td>
<td>2.00%</td>
<td>33.33 lb [15118 g]</td>
</tr>
<tr>
<td>Sugar</td>
<td>1.00%</td>
<td>16.67 lb [7561 g]</td>
</tr>
<tr>
<td>Natural Smoke Flavoring</td>
<td>0.15%</td>
<td>2.50 lb [1134 g]</td>
</tr>
<tr>
<td>Red Arrow</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sodium Phosphate [BK-450]</td>
<td>0.25%</td>
<td>4.17 lb [1892 g]</td>
</tr>
<tr>
<td>Sodium Erythorbate</td>
<td>550 ppm</td>
<td>0.916 lb [416 g]</td>
</tr>
<tr>
<td>Sodium Nitrite [cure 6.25% NO₂]</td>
<td>120 ppm</td>
<td>3.20 lb [1452 g]</td>
</tr>
</tbody>
</table>

a. Phosphate was added to the cold water (≤4°C/40°F) agitated until phosphates are dissolved.
b. With continued agitation, the remainder of the non-meat ingredients were added in the following order: salt, sugar, nitrite, natural liquid smoke flavor as required and lastly the ascorbate.

Wenther, 1999.
Table 2. Smokehouse schedule.

<table>
<thead>
<tr>
<th>Step</th>
<th>Time</th>
<th>Dry Bulb</th>
<th>Wet Bulb</th>
<th>RH%</th>
<th>Dampers /Smoke</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>120 min</td>
<td>60°C/140°F</td>
<td>----------</td>
<td>------</td>
<td>Open</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>20 min</td>
<td>Heat off/fans off*</td>
<td>----------</td>
<td>------</td>
<td>Closed</td>
<td>Smoke applied *</td>
</tr>
<tr>
<td>3</td>
<td>45 min</td>
<td>60°C/140°F</td>
<td>21.2°C/100°F</td>
<td>Auto</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>IT&gt;53.3°C/128°F</td>
<td>65.5°C/150°F</td>
<td>48.8°C/120°F</td>
<td>40%</td>
<td>Auto</td>
<td>IT&gt;53.3°C/128°F</td>
</tr>
<tr>
<td>5</td>
<td>10 min</td>
<td>----------</td>
<td>----------</td>
<td>------</td>
<td>Auto</td>
<td>Shower</td>
</tr>
<tr>
<td>6</td>
<td>10 min</td>
<td>----------</td>
<td>----------</td>
<td>------</td>
<td>Auto</td>
<td>Dry</td>
</tr>
</tbody>
</table>

IT= Internal Temperature  
* Liquid Smoke Atomization settings as follows: 4.08 atm (60 psi) to nozzle, 2.86 atm (42+ psi) to tank, flow 7.57 L/hr (2.0 gph), 2.11 kg (4.65 lb) Red Arrow “Charsol Supreme Hickory”.  
Wenther, 1999.
Table 3. Least Square Means ± S.E. of Percent Pump, Smokehouse Yield, Slicing Yield and Total Yield as affected by Line, Sex and Storage Treatment.

<table>
<thead>
<tr>
<th>Effect</th>
<th>Percent pump (%)</th>
<th>Smokehouse yield (%)</th>
<th>Slicing yield (%)</th>
<th>Total yield (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Line</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Berkshire</td>
<td>P&lt;0.05*</td>
<td>P&lt;0.01*</td>
<td>P&gt;0.05*</td>
<td>P&lt;0.01*</td>
</tr>
<tr>
<td>10.74 ± 0.15bc</td>
<td>98.20 ± 0.17a</td>
<td>87.25 ± 0.51</td>
<td>85.90 ± 0.52a</td>
<td></td>
</tr>
<tr>
<td>Chester White</td>
<td>10.87 ± 0.30abc</td>
<td>97.34 ± 0.33b</td>
<td>88.29 ± 0.98</td>
<td>83.14 ± 1.00bd</td>
</tr>
<tr>
<td>Duroc</td>
<td>10.33 ± 0.14c</td>
<td>97.48 ± 0.15b</td>
<td>85.24 ± 0.46</td>
<td>80.49 ± 0.47d</td>
</tr>
<tr>
<td>Landrace</td>
<td>10.66 ± 0.38bc</td>
<td>95.91 ± 0.42c</td>
<td>85.65 ± 1.25</td>
<td>80.41 ± 1.28cd</td>
</tr>
<tr>
<td>Poland China</td>
<td>11.78 ± 0.40a</td>
<td>97.30 ± 0.44b</td>
<td>86.49 ± 1.31</td>
<td>83.44 ± 1.34abc</td>
</tr>
<tr>
<td>Yorkshire</td>
<td>10.78 ± 0.16b</td>
<td>97.31 ± 0.17b</td>
<td>85.73 ± 0.53</td>
<td>80.79 ± 0.54cd</td>
</tr>
<tr>
<td><strong>Sex</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barrows</td>
<td>P&gt;0.05*</td>
<td>P&gt;0.05*</td>
<td>P&gt;0.05*</td>
<td>P&lt;0.01*</td>
</tr>
<tr>
<td>10.80 ± 0.17</td>
<td>97.32 ± 0.19</td>
<td>86.86 ± 0.57a</td>
<td>83.83 ± 0.58a</td>
<td></td>
</tr>
<tr>
<td>Gilts</td>
<td>10.92 ± 0.14</td>
<td>97.19 ± 0.16</td>
<td>85.36 ± 0.47b</td>
<td>80.89 ± 0.48b</td>
</tr>
<tr>
<td><strong>Storage Treatment</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fresh</td>
<td>P&lt;0.01*</td>
<td>P&gt;0.05*</td>
<td>P&lt;0.05*</td>
<td>P&gt;0.05*</td>
</tr>
<tr>
<td>10.49 ± 0.15a</td>
<td>97.07 ± 0.17</td>
<td>86.98 ± 0.51a</td>
<td>82.61 ± 0.53</td>
<td></td>
</tr>
<tr>
<td>Frozen**</td>
<td>11.22 ± 0.16b</td>
<td>97.44 ± 0.18</td>
<td>85.24 ± 0.53b</td>
<td>82.10 ± 0.55</td>
</tr>
</tbody>
</table>

abcd Means within the same column and within a main effect with similar superscripts are not significantly different (P>0.05).

* P values from Analysis of Variance for each main effect within a variable.

** Frozen stands for bellies that were frozen at -15°C prior to processing.

c Percent pump = (weight of the pumped belly / initial belly weight) x 100.

t Smokehouse yield = (weight of the cooked belly / initial belly weight) x 100.

g Slicing yield = (weight of the center of the sliced bacon slab / weight bacon slab) x 100.

h Total yield = (weight of the center of the sliced bacon slab / weight of the belly) x 100.
Table 4. Least Square Means of the Genetic Line x Sex interaction for Backfat (cm).

<table>
<thead>
<tr>
<th>Line</th>
<th>Barrows</th>
<th>Gilts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Berkshire</td>
<td>3.40&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.66&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Chester White</td>
<td>3.17&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.56&lt;sup&gt;bc&lt;/sup&gt;</td>
</tr>
<tr>
<td>Duroc</td>
<td>2.41&lt;sup&gt;c&lt;/sup&gt;</td>
<td>2.05&lt;sup&gt;de&lt;/sup&gt;</td>
</tr>
<tr>
<td>Landrace</td>
<td>2.61&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>2.28&lt;sup&gt;cd&lt;/sup&gt;</td>
</tr>
<tr>
<td>Poland China</td>
<td>3.40&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.54&lt;sup&gt;bc&lt;/sup&gt;</td>
</tr>
<tr>
<td>Yorkshire</td>
<td>2.49&lt;sup&gt;c&lt;/sup&gt;</td>
<td>1.95&lt;sup&gt;*&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Means within the column and row with similar superscripts are not significantly different (P>0.05).
Table 5. Least Square Means for Loin eye area (LEA), Carcass length (CL) and Backfat (BF).

<table>
<thead>
<tr>
<th>Effect</th>
<th>LEA (cm²)</th>
<th>CL (cm)</th>
<th>BF (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Line</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Berkshire</td>
<td>P&lt;0.01*</td>
<td>P&lt;0.01*</td>
<td></td>
</tr>
<tr>
<td>Chester White</td>
<td>36.06d</td>
<td>82.24bc</td>
<td>3.05</td>
</tr>
<tr>
<td>Duroc</td>
<td>38.25c</td>
<td>82.47bc</td>
<td>2.88</td>
</tr>
<tr>
<td>Landrace</td>
<td>41.80a</td>
<td>82.65b</td>
<td>2.24</td>
</tr>
<tr>
<td>Poland China</td>
<td>37.48cd</td>
<td>84.50a</td>
<td>2.46</td>
</tr>
<tr>
<td>Yorkshire</td>
<td>37.09d</td>
<td>81.71c</td>
<td>2.98</td>
</tr>
<tr>
<td></td>
<td>40.64b</td>
<td>84.58a</td>
<td>2.22</td>
</tr>
<tr>
<td><strong>Sex</strong></td>
<td>P&lt;0.01*</td>
<td>P&lt;0.01*</td>
<td></td>
</tr>
<tr>
<td>Barrows</td>
<td>36.25a</td>
<td>82.39a</td>
<td>2.92</td>
</tr>
<tr>
<td>Gilts</td>
<td>40.77b</td>
<td>83.64b</td>
<td>2.35</td>
</tr>
</tbody>
</table>

Means within the same column within a main effect with similar superscripts are not significantly different (P>0.05).

* P values from analysis of variance for each main effect within a variable.

LEA Loin eye area.
CL Carcass length.
BF Backfat measured at the 10th rib.
Table 6. Least Square Means ± S.E. of the Belly Length and Belly Width as affected by Line, Sex and Storage Treatment.

<table>
<thead>
<tr>
<th>Effect</th>
<th>Belly Length (cm)**</th>
<th>Belly Width (cm)***</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Berkshire</td>
<td>P&lt;0.01*</td>
<td>P&lt;0.05*</td>
</tr>
<tr>
<td></td>
<td>50.85 ± 0.09b</td>
<td>26.21 ± 0.06abc</td>
</tr>
<tr>
<td>Chester White</td>
<td>52.07 ± 0.17a</td>
<td>25.37 ± 0.12b</td>
</tr>
<tr>
<td>Duroc</td>
<td>50.44 ± 0.08bc</td>
<td>25.88 ± 0.05bc</td>
</tr>
<tr>
<td>Landrace</td>
<td>50.77 ± 0.22abc</td>
<td>25.88 ± 0.15abc</td>
</tr>
<tr>
<td>Poland China</td>
<td>49.50 ± 0.23c</td>
<td>26.36 ± 0.16ab</td>
</tr>
<tr>
<td>Yorkshire</td>
<td>50.39 ± 0.09bc</td>
<td>26.44 ± 0.06a</td>
</tr>
<tr>
<td>Sex</td>
<td>P&gt;0.05*</td>
<td>P&lt;0.05*</td>
</tr>
<tr>
<td>Barrows</td>
<td>50.87 ± 0.10</td>
<td>25.78 ± 0.10a</td>
</tr>
<tr>
<td>Gilts</td>
<td>50.44 ± 0.08</td>
<td>26.26 ± 0.08b</td>
</tr>
<tr>
<td>Storage Treatment</td>
<td>P&gt;0.05*</td>
<td>P&gt;0.05*</td>
</tr>
<tr>
<td>Fresh</td>
<td>50.72 ± 0.09</td>
<td>25.90 ± 0.62</td>
</tr>
<tr>
<td>Frozen</td>
<td>50.59 ± 0.09</td>
<td>26.13 ± 0.65</td>
</tr>
</tbody>
</table>

* Means within the same column and within a main effect with similar superscripts are not significantly different (P>0.05).

* P values from the Analysis of Variance for each main effect within a variable.

** Length corresponds to the measure at the center of the belly from anterior to posterior.

*** Width corresponds to the measure at the center of the belly from dorsal to ventral.
The effect of breed, sex and storage treatment on the fatty acid profile of bellies and bacon quality

C. C. Robles and R. W. Mandigo

Keywords: Bacon, Fresh, Frozen, Fatty Acids

Department of Animal Science
University of Nebraska, Lincoln
Lincoln, NE 68503-0908

1. Authors Robles and Mandigo are currently affiliated with the University of Nebraska-Lincoln, Lincoln, NE 68503-0908
Abstract

The objective of the study was to evaluate the effect of genetic line, sex and storage treatment (fresh vs. frozen) of bellies on bacon quality. A population of 578 pork bellies from barrows and gilts of Berkshire, Chester White, Duroc, Landrace, Poland China and Yorkshire lines were processed to cooked bacon. Bellies were divided into two storage treatments: fresh (stored at refrigeration temperature, 3°C) or frozen (held at -15°C for 15 d). Before treatments were processed into bacon, fat samples were collected from each belly in order to establish a fatty acid profile. The bacon slabs were sliced and cooked in order to evaluate differences in fatty acid content, shattering, cooking yield, distortion and proximal composition. No differences (P>0.05) were found in the saturated and unsaturated fatty acid profile of the bellies due to treatment. Fresh bellies revealed values of 61.69 and 37.44 percent, saturated (SFA) and unsaturated fatty acids (UFA), respectively, compared to 62.24 and 36.86 percent of SFA and UFA for frozen bellies. Bellies from pigs of leaner genetic lines had higher (P<0.01) percentages of unsaturated fatty acids. The effect of sex was observed by differences in the content of SFA and UFA. Gilts had a profile with a 1.08 percent higher unsaturated fatty acid profile when compared to barrows (P<0.05). Shattering of the bacon slice was influenced by location. Slices from the center portion (location B, C and D) of the frozen bellies had a higher total shatter mark length (P<0.05). Correlation suggests that 22 percent of the variation in the total number of shatter marks in the belly is explained by the total content of saturated fatty acid. Genetic lines with higher fat content (Berkshire and Poland China) had lower (P<0.05) cooking yields (31.90 and 31.14 percent). Fresh and frozen bellies had differences on distortion (P<0.05) of the cooked bacon slices with least square
means of 2.35 and 2.43, respectively. Distortion was affected by an interaction (P<0.05) among line and sex. Overall, fresh and frozen bellies resulted in bacon with similar quality. Although statistical differences existed, the practical advantages of these values may be slight.
Introduction

It is well accepted that consumers in prefer to purchase meat with lower levels of fat. This trend has certainly extended to cured bacon. One of the major reasons is the possible association between high levels of saturated fat and heart disease (Wood and Fisher, 1990). There is a strong body of evidence which maintains that fat in meat contributes to eating quality and that reducing fat to low levels will reduce satisfaction at a time when consumer interest in the quality of food in general is increasing (Wood and Fisher, 1990).

Recent studies have shown that consumers are demanding more flavorful foods. According to the Food Marketing Institute (2000), the factors that consumers feel are important when making food purchasing decisions, ranked in descending order of importance, were: (1) taste; (2) nutrition; (3) food safety; (4) cost; (5) storability. It appears that despite continued health consciousness, people seem to be enjoying more full-flavored foods in moderation (Salvage, 2002).

Although bacon could hardly be called a new food category, it is far from been mature. In fact, bacon is enjoying a renaissance in retail and foodservice markets, driven by an explosion of innovation that includes new flavors, thickness variations and packaging (Salvage, 2002). Bacon is the fastest growing foodservice pork product, at a 5 to 7 percent annual growth (Salvage, 2002; National Pork Board, 2001). Ranging from sandwich toppings to garnishing salads, bacon has delivered versatility to the menu, as a side dish or ingredient for all meals. Bacon has added flavor to a wide array of dishes and is now often considered a condiment. The most unique new products are the
microwaveable products and salad toppings that are actual bacon slices instead of dried bits.

Quality defects represent lost revenue opportunities for the pork industry and potentially the entire pork marketing chain. Estimates of 10% of the total value of the live animal are cost related to quality nonconformity (Cannon et al., 1996). Problems associated with bacon include separation of fat from lean, color of fat, color of lean, consistency and flavor.

The problem of marketing a uniform, highly acceptable product has become increasingly important to both producer and packer (Chant et al., 1976). Packers are improving their processing techniques (selecting, trimming and grading) with the goal of delivering a more consistent consumer experience (Salvage, 2002).

Understanding the role of fat on bacon success starts with an understanding of the variables that impact the amount and quality of the lean and fat found in the bacon. Previous studies have analyzed the effect of genetics, sex and nutrition on the quality of backfat and longissimus muscle, as well as the palatability of longissimus muscle and palatability of bacon (Bryhni et al., 2002; Cameron et al., 2000; Mazhar et al., 1990; Carpenter et al., 1963). However, there have been few attempts to evaluate the quality of fat in the belly and its effect on bacon slicing and cooking. The fatty acid profile of the fat found in the belly will potentially impact the processing of the belly, the slicing of the bacon and the cooking and eating quality of the bacon. Many factors can influence the fat content as well as the fatty acid profile including the breed and sex of the pigs as well as other management strategies.
The purpose of this study was to identify and study the relationship of chemical characteristics of bacon to determine how they influence the structure of the bacon slice and its cooking characteristics.

**Materials and Methods**

A total of 578 bellies from barrow and gilt bellies of six different genetic lines (Berkshire, Chester White, Duroc, Landrace, Poland China and Yorkshire) were utilized in the study.

*Bacon Fabrication*

Bellies were cut to specifications of NAMP #409 – PORK BELLY, SKINLESS (NAMP, 1997) during fabrication at Geneva Meats, Inc., Geneva, MN. Fresh bellies were shipped to the Loeffel Meat Laboratory at the University of Nebraska-Lincoln, Lincoln, NE. They were received and divided into two treatments (fresh or frozen). Bellies for the frozen treatment were frozen and stored at -15°C (5°F) 15 d at UNL Meat Laboratory for processing at a later date. Bellies in the fresh treatment were held in refrigerated (3°C/37°F) storage for curing on the 15th day following slaughter.

Two days prior to manufacture, frozen bellies were tempered in a cooler (3°C/37°F). On the day of production, frozen-tempered bellies were placed in a stainless steel thawing tank, and immersed in cold, air-agitated water (≤4°C/40°F) to allow complete thawing. Fresh bellies received similar water treatment. When completely thawed, bellies were checked and trimmed for skin and other fabrication defects. Prior to pumping, a 7 mm slice of the fresh belly was removed from the anterior edge of the belly,
to obtain a fatty acid profile analyses of the belly. The sample was label with the belly ID number, vacuum packaged and frozen.

Pickle was prepared fresh each day of bacon production (Table 1). The ingredients were mixed using a Rotostat Model 80XP63SS (Admix, Inc., Londonderry, NH). The bellies were pumped to a target percent of green weight (12.0% pick-up), fat side down on the Townsend multi-needle bacon injection pump (Model 1450, Townsend Engineering, Des Moines, IA).

Following injection, bellies were hung on a smokehouse truck by a bacon comb at the posterior end of the belly, approximately 2.54 cm (1 in) from the end. The bellies had a holding time of 1 hour before the thermal process to facilitate cure equalization. Bellies were thermally processed in and Alkar single truck smokehouse unit (Alkar, Inc., Lodi, WI). The thermal schedule for the smokehouse is shown in Table 2. Following showering and drying, cooked bellies were chilled overnight in a 3°C/37°F cooler. The slabs were vacuum packaged and stored for subsequent processing in a tempering cooler at -4.4°C/24°F. The bacon was transferred to a commercial plant (MPS, Omaha, NE) to be pressed. The slabs were tempered at -4°C/24°F for 24 hrs prior to pressing. Bacon slabs were pressed using an Anco machine (Model 1411, Cherryburrell, Lousville, KY). Pressed bellies were transported back to UNL Meat Laboratory and stored at -4°C/24°F for subsequent slicing.

Slabs of bacon were weighed and temperatures (Omega Engineering Inc., Stamford, CT) were recorded. The slabs were sliced in a Grote Bacon Slicer (Model 613, Grote Company, Columbus, OH) starting from the posterior end. The bacon slicer was set to slice 10 slices/inch (10slices/2.54 cm). The following information was recorded for
each individual slab: slicing date, slab identification number, slab weight, slab length, slab width, weight of bacon ends and pieces (incomplete slices) and the number of complete slices in the slab. Slab length corresponded to the measure of the center of the belly from anterior to posterior. Slab width was the measured at the center of the belly from dorsal to ventral.

_Bacon Evaluation and Sampling_

After slicing, incomplete slices from both the posterior and anterior ends of the slab were removed. The slices that were affected by the comb (posterior to comb mark and including combing marks) were also removed. End pieces and incomplete slices from posterior and anterior ends of the belly were weighed and recorded separately. The bacon slices were reassembled in original order. Tags were inserted every 20 slices to allow easy counting of the total number of slices in the slab. The slab was divided in 5 locations, each with an equal number of slices, by the 5 locations, which were assigned the letters A, B, C, D and E (each representing the next 20% of slices); A at the most posterior and E being anterior (Appendix 2).

Each of the five locations was sampled. The first two slices of each location were evaluated for shattering. Both slices were wrapped in white polyethylene coated, meat wrapping paper (Loxol freezer paper, James River Corp., Parchment, MI) and stored in a cooler (3°C/37°F) for subsequent visioning analysis and proximate analysis. The next five slices in each zone were assigned for cooking; they were vacuum packaged and stored in a cooler (3°C/37°F). The next five slices were also vacuum packaged and kept for backup samples in the freezer (-15°C/5°F).
Fatty Acid Analysis

The samples for fatty acid analysis were collected before pickle injection. A thick strip of fresh belly adipose tissue was removed from the anterior edge of the fresh belly. The sample was vacuum packaged and stored in a -15°C (5°F) freezer. They were removed from the freezer and the fatty acid composition of the adipose tissue was determined by gas chromatography. Two samples (0.5-1 g) from the adipose tissue of each fresh belly strip were analyzed. Triglycerol fatty acids were hydrolyzed by saponification and then methylated to form fatty acid methyl esters (FAME). The methyl esters were prepared by an adaptation of the boron trifluoride-methanol procedure of Metcalfe et al. (1966). The gas chromatograph was equipped with an automatic injector (HP 7673) and a flame ionization detector (HP-5890 Series II, Hewlett-Packard Company, Avondale, PA). The methyl esters were separated on a 30 m long x .25 mm internal diameter x .20 μm film thickness Supelco model SP2330 capillary column (Supelco, Bellafonte, PA) utilizing helium gas as a carrier. The injector, oven, and detector temperatures were set at 270, 190, and 300°C respectively. The individual methyl esters were identified by their retention time. Peak areas were integrated and analyzed using the HP 3365 Series II ChemStation© Version A.06.98 (Hewlett-Packard Company, Avondale, PA). The results were expressed as a percentage of the total area for all the peaks analyzed. Commercial standard solutions of FAME (GLC-standard No. 84 and 68D-Check Prep) were used to determine retention times for specific fatty acids, under GLC conditions utilized. The retention times of known FAME were compared to those from belly samples and an in-house standard was developed. The standard was used to identify peaks for the rest of the samples and calibrate GLC equipment. The fatty
acids studied were: myristic (C14:0), palmitic (C16:0), palmitoleic (C16:1), stearic (C18:0), oleic (C18:1), linoleic (C18:2), linolenic (C18:3), and 11-eicosenoatic (C20:1). These fatty acids were selected, since they account for more than 95% of the total amount present (Davanel et al., 1999; Houben and Krol, 1984). Other fatty acids, although present in small quantities, were not considered as important to our objectives, thus, were not identified.

Shattering

Shatter marks were defined as breaks/shatters of the fat portion of the slice that occurred perpendicular to the length of the slice (Salas-Peréz, 2002). Shatter marks did not include the natural separation of fat tissue or the separation between fat and lean tissue.

a. Within Belly Design

In order to obtain information about the variation within the bacon slab as well as geographical location of the shatter marks within the bacon slab, a grid within the sliced bacon slab was made. The grid consisted of dividing the bacon slice into four quadrants (1st, 2nd, 3rd, or 4th), within the five locations (A, B, C, D, or E) (see Appendix 2). Each quadrant represented 1/4 of the distance from the dorsal side to the ventral side of the bacon slice; whereas each location represents 1/5 of the distance from the anterior to posterior ends of the sliced bacon slab. This procedure was established to accommodate variable width and length of the bellies.

b. Shatter Recording Considerations
The shatter marks were classified into the following five categories depending on their length: 1-10 mm, 11-20 mm, 21-30 mm, 31-40 mm, >40 mm.

c. Recording Shatter Marks

After recording weights for the sliced bacon slab, the trays were placed on a table with the posterior end closer to the person doing the evaluation, leaving the ventral edge (quadrant 4) to the left side and dorsal to the right side (quadrant 1). The first two slices from each zone were evaluated for shatter marks. Starting from the first complete slice, the slices were separated carefully. Then the slice was rolled over the finger, from quadrant 1 to 4, for a more evident appearance of the shatter marks. Any shatter marks were measured and recorded according to their corresponding quadrant and size category. After shatter marks were recorded for a given slice, the slices were labeled for proximate analysis.

Due to very low values of shattering, shatter was statistically analyzed as the value of the length of the shatter marks. To obtain such a value, the number of marks within a length category (1-10 mm, 11-20 mm, 21-30 mm, 31-40 mm, 41-+mm) were multiplied by the average size within the category (5.5 mm, 15.5 mm, 25.5 mm, 35.5 mm). The resulting value was called the Total Length of the Shatter Mark (TLS).

The Total Belly Shatter Marks values were obtained by adding all the shatter marks recorded for a particular belly, disregarding zone, quadrant and size categories.

Composition Proximate Analysis

Proximate analysis was performed for each location of the belly. Ether Extraction (Soxlet) determined fat percentage (Modified procedure from AOAC, 1990; section
Moisture and ash were determined using a thermogravimetric analyzer (TGA-601, Leco Corp., St. Joseph, MI). Protein was determined by difference.

**Precooked Bacon Processing**

Bacon samples (five slices per location) were cooked on a Magi-Grill PGB-60 (Magikitch’n, Quakertown, PA) double belt conveyor cooker. Cook yield, dimensional changes in length and width, and distortion scores were determined and recorded for these samples. Preliminary trials were conducted to determine the correct settings for the double belt cooker to yield the proper degree of doneness. The appropriate degree of doneness was determined to be a color described as “golden brown” but not crisp as described by Ross (1999). Cooked yield was required to be less than 40% of raw weight to comply with USDA/FSIS regulations (USDA, 1996). The target cook yield was 37-39% based on cooked color. As a result of these trials, the temperature of the top and bottom platens was set at 204.4°C/400°F with a clearance between platens of 0.33 cm during the cooking process. The preheat temperature was also set at 204.4°C/400°F. The belt speed of the cooker was adjusted to control cooking time. After trials and with the objective to reach the cooked yield and color required, the time was set to 40 seconds from the time of sample entry until its exit from the belt cooker.

Cooked samples were evaluated for percent change in length (at the midpoint of the slice), width (at the midpoint of the slice), and weight from the raw weight. A distortion scale developed by Ross (1999) was used to evaluate the change in bacon shape (Figure 1). The scale has five distortion scores. A distortion score of one characterized a flat piece of bacon with no distortion. A score of five characterized a
severely distorted slice. Scores of 2, 3 and 4 represented distortion percentages of approximately 25%, 50% and 75% respectively (Ross, 1999).

The samples were removed from the cooler (3°C/37°F), the vacuum packages were opened and the two slices from location A were removed and separated from each sample. Their length and width was measured individually. The slices were placed on the paper plate in order from 1 to 5 and weighed. The plate marked “A” was then taken to the belt cooker for cooking. The same procedure was follow for locations B, C, D and E in alphabetical order. The slices were placed on the belt cooker in order from 1 to 5 with spaces of two inches (5 cm). Gaps of eight inches (20.3 cm) were left between locations to prevent any mixing of slices from different locations. As the slices exited the belt cooker, they were placed in numerical order on a clean and labeled paper plate. The slices were allowed to cool for 30 seconds before being evaluated. All slices from location A were evaluated individually with the distortion scale. Following length and width measures, the five slices were evaluated by video imaging for another project.

Statistical Analysis

The analysis was a 2 x 2 x 6 factorial treatment design. The experimental unit is the belly from a pig with a given genetic line and sex and with one storage treatment (fresh and frozen). The sample size for each one of the treatments was different. Treatments were allocated in a complete randomize array. Data were analyzed using the Mixed Model procedure of SAS (SAS, 1999) with a level of significance of P<0.05. Means were separated using the Fisher’s least significant difference test. When the zone or quadrants were considerate, the analysis splits, or spilt-split plot, respectively were
utilized. The effect of genetic line, sex and treatment on fatty acid profile, shatter marks, cooking characteristics and composition of bacon was tested. The model for the fatty acid analysis consisted of genetic line, sex and treatment. When analyzing cooking characteristics and composition, the design was a split-plot (the belly was the whole plot and locations were the split). When analyzing shattering the design was a split-split plot (the belly was the plot, and the quadrants within location were the split-split). The model statement included pig id, line, sex, treatment location and quadrant. The random statement terms were pig identification (line|sex|treatment). Significant main effects and two-way interactions were analyzed.

Results and Discussion

Fatty Acid Profile

Treatment (Fresh vs. Frozen) Effect

There were no significant differences in the saturated and unsaturated fatty acid profile of the bellies due to storage treatment (Table 3). Fresh bellies contained values of 61.69 and 37.44 percent unsaturated fatty acids (UFA) and saturated fatty acids (SFA), respectively. Frozen bellies contained 62.24 unsaturated fatty acids (UFA) and 36.86 saturated fatty acids (SFA) percent content (Table 3). Individually, fresh or frozen bellies did not differ in the individual fatty acid profile of Myristic, Palmitoleic, Stearic, Oleic, Linoleic, Linolenic and Eicosenoatic (Table 4). Fresh bellies had a 0.37 % higher (P<0.05) Palmitic acid content than frozen bellies (Table 4). These results suggest that frozen storage of 15 days or less will not change significantly the fatty acid profile of bellies.
Genetic Line Effect

Yorkshire pigs from this study had a higher percentage of unsaturated fatty acids, compared to all breeds (P<0.05), with a least square mean of 64.35% (Table 3). Duroc and Landrace pigs followed with the next highest UFA levels, 62.89 and 62.40%, respectively. Breeds with the lowest percents of unsaturated fatty acids were Poland China, Chester White and Berkshire (61.46, 60.50 and 60.20%, respectively). As expected, these breeds had higher saturated fatty acid levels than Landrace, Duroc and Yorkshire (Table 3).

In most cases individual fatty acid content (Myristic, Palmitic, Palmitoleic, Stearic, Oleic, Linoleic, Linolenic and Eicosenoatic) was also affected by genetic line (Table 4). Individual profile of each genetic line followed similar patterns of the total content of UFA and SFA.

The current study data are in disagreement with Villegas et al. (1973) who reported the backfat content for Yorkshire and Duroc pigs. They reported Yorkshire with 40.04% saturated (Myristic, Palmitic and Stearic) and 57.06% unsaturated (Palmitoleic, Oleic, Linoleic, Linolenic and Eicosenoatic) fatty acid content. Durocs were reported at 39.87% saturated fatty acid and 57.38% of unsaturated fat. Pigs in Villegas et al. (1973) had higher overall total unsaturated fatty acids. These differences could be due to the fact that in the last 30 years pig production (including genetic improvement and diet changes) has altered the characteristics of the carcass including fatty acid composition.

Based on our results, it appears that production changes have had a greater impact on Yorkshire pigs than on Duroc pigs. Our study suggests that Yorkshire pigs tended to have 1.49% higher UFA content than Duroc hogs.
**Sex Effect**

The effect of sex was demonstrated by a difference in the saturated and unsaturated fatty acid content of the bellies (Table 3). Barrows had 1.12% higher (P<0.05) of saturated fatty acids than gilts. Gilts had a 1.08% higher (P<0.05) unsaturated fatty acid content than barrows. The difference in the saturated versus unsaturated profile may be explained by the difference in the content of Palmitic acid. Barrows had a 24.04% of Palmitic versus 23.17% of Palmitic for gilts. The content of the remaining fatty acids was not different (P>0.05) for gilts vs. barrows; although, a similar pattern can be observed: barrows had higher content of the saturated fatty acids than gilts (Table 4).

Villegas et al. (1973) reported that the backfat of gilts contained more linoleic acid (18:3) than barrows. These results suggest that gilts deposit a higher percentage of unsaturated fatty acids than barrows. However, this disagrees with Geri (1984). Their study examined lipid extracted from the longissimus muscle and reported no differences between sexes for fatty acid composition of single fatty acids or the sum of saturated or unsaturated constituents. The discrepancy among the present study and Geri (1984) might also be due to anatomical differences of the fat sample.

Maw et al. (2003) established that the physical characteristics of fat samples are related to their fatty acid composition. Unsaturated fatty acids are responsible for soft fat in the belly (Ellis and McKeith, 1999; Enser et al., 1984; Chant et al., 1976). The differences we found in content of unsaturated fatty acids in the belly among breed and sex could have an effect on bacon production, soft fat could have negative impacts on slicing yields, shelf life and texture of the final product.
**Shatter Analysis**

*Treatment (Fresh vs. Frozen) Effect*

There was an interaction ($P<0.01$) between treatment and location (Table 5). In both treatments (fresh, frozen), locations to the posterior end of the belly (A and B) possessed the highest total length of the shatter mark. The length of the shatter mark within a slice of bacon is expressed as total length of the shatter mark (TLS). Fresh bellies had a TSL of 2.76 mm for both locations. Frozen bellies had TLS of 3.72 mm and 2.59 mm for locations on the anterior end of the slab (D and E, respectively). Frozen bellies at locations in the center of the slab (B, C and D) had larger ($P<0.05$) shatter values than fresh bellies (Figure 2). Although, fresh vs. frozen treatments were not significantly different for locations on the most posterior and most anterior part of the belly (A and E), it appears that frozen bellies tended to shatter more than fresh bellies. It was discovered that frozen bellies at location D had the highest incidence of shattering (3.72 mm). The lowest incidence of shattering was found in location A, fresh (0.46 mm) and frozen bellies (0.50 mm) (Table 6).

Past reports suggest that freezing and frozen storage may affect the quality of the meat (Bjerklie, 1996; Calvelo, 1981; Jeremiah, 1980; Miller et al., 1980). The formation of ice crystal during freezing is an inevitable process. These ice crystals are believed to be responsible for the rupturing of the cells around them (Bjerklie, 1996). These studies have looked at muscle fiber. However, there is little data on the effects of freezing on fat cells. Base on the higher incidence of shatter marks in the frozen bellies, it could be speculated that adipose tissue in these bellies was damage during freezing.
Genetic Line Effect

Separation of LS Means was not conducted due to significant two-way interactions. The interactions for the total length of the shatter mark were for, Line x Sex (P<0.05) and Line x Location (P<0.01) (Table 5).

Lines with the highest fat content based on proximate analysis results, (Berkshire, Poland China and Chester White) had the highest incidence of shatter marks (Figure 3). For all lines, barrows had greater (P<0.05) TLS than gilts (Table 7).

These results are in agreement with Salas-Perez (2002), who reported that in their study genetic lines with higher fat content had higher scores for all variables analyzed for shattering of the bacon slice (percentage of bacon slices affected, occurrence of shatter marks, total shattering and size of the shatter mark).

Sex Effect

There was an interaction (Table 5) between sex and location (P<0.01). Location D had the highest level of TLS with 4.53 mm and 1.95 mm for barrows and gilts, respectively (Table 6). Bacon from barrows had more TLS in all locations than bacon made from gilt bellies (Table 6). These may be attributed to the fact that bellies from barrows were fatter than gilts. These results are in agreement with Salas-Perez (2001). He reported that fatter bellies tended to shatter more often.

There was an interaction between sex and slice quadrant (P<0.01) (Table 5). Barrows had a greater TLS in each quadrant as compared to gilts (Table 7). From these results it appears that within sex, quadrants 1 and 2 are more susceptible to shattering. This may be explained by the way bellies were handled during slicing. The machine may have exerted greater stress on quadrants 1 and 2 as it moved through the belly.
The highest value of shattering is found in quadrant 2, which is 1.46 mm more than the lowest reported value for TLS (which is in quadrant 4) (Table 7). Although, it is difficult to assess the practical value of shatter marks with this small measurement.

Correlations were run comparing the level of fatty acid saturation in the belly with the total number of shatter marks in the whole belly. It was thought that higher saturation of the fat would have higher tendency to disrupt and break during slicing, therefore resulting in shatter marks in the sliced bacon. Because saturated fat that is refrigerated appears to be harder. According to Table 8, there is an $r = .22$. Suggesting that 22% of the variation in total number of shatter marks is due to the percentage content of saturated fatty acids.

Overall results for shattering suggested that the occurrence of shattering in the present study was less than in the study conducted by Salas-Perez (2002). These may be due to the difference in the slicing method.

**Cooked Bacon Analysis**

*Treatment (fresh vs. frozen) Effect*

There was a significant interaction on Treatment x Location ($P<0.05$) for cooking yield of the bacon slices (Table 9). Bacon slices from locations A and B had higher cooking yields than C, D and E (Fig. 4). Location D had the lowest yields (32.00 and 31.80 % for fresh and frozen, respectively). Except for location A, within location, fresh bellies had better yields than frozen bellies (Fig. 4).
Treatment had an effect on the distortion (P<0.05) of the cooked bacon slices (Table 9). Frozen bellies had higher least square mean for distortion than fresh bellies. Frozen bellies had an average score of 2.43 compare to a 2.35 of fresh bellies (Table 10).

According to the results, bacon made from fresh bellies had better performance during cooking than the one made from frozen bellies. Perhaps structural changes took place in the bellies during frozen storage. Several theories could explain the nature of the damage to the muscle. One of these theories establishes that the formation of ice crystals during freezing could damage the cell membrane resulting in moisture loss (Ngapo et al., 1999; Nusbaum et al., 1983; Nichols and MacKintosh, 1952.). A second theory suggests that frozen storage induces deterioration of muscle thru chemical reactions, resulting in denaturation of muscle proteins (Miller et al., 1980). The results in the present study demonstrated differences between the cooking abilities among bacon from fresh and frozen bellies, although further research should be conducted to investigate the reasons.

**Genetic Line Effect**

All cooking parameters were affected by genetic line (Table 9). Table 10 illustrates differences among lines for cooking yield. Berkshire and Poland China pigs had the lower (P<0.05) cooking yields (31.90 and 31.14, respectively) (Table 10). Of all lines, Berkshire and Poland China had the highest percent of fat in the belly (45.09 and 45.01%, respectively) (Table 11). Leaner pigs such as Duroc and Yorkshire had the highest yields (36.69 and 37.49, respectively). These results support previous data that established that cooking yields are inversely related to the fat content of the bacon slice (McEver, 2000; Kemp et al., 1969; Carpenter et al., 1963; Saffle and Bratzler, 1959).
Jabaay et al. (1976) found that bacon cooking losses were due to lipid cooked out. A study by Stanley et al. (1980) reported that 95% of the moisture and 75% of the lipid in the bacon slices is lost during cooking.

Distortion was affected by an interaction (P<0.05) among line and sex (Table 9). The highest distortion with an average score of 2.56 corresponded to Chester White gilts. Followed by Duroc gilts, which had an average of 2.53 (Figure 5). For the rest of the lines, bacon from barrows exhibited more distortion than that from gilts.

**Sex Effect**

There was an interaction (P<0.0001) between sex and location for cooking yield (Table 9). Gilts had higher (P<0.05) yields for four (B, C, D and E) of the five locations on the bacon slab (Figure 6). Slices from the most posterior locations of the bacon slab (A and B) had higher (P<0.05) yields when cooking than the rest of the locations (Figure 6). The higher yields could be attributed to lower fat content of the slices. As seen in Table 11, the posterior end of the slab (locations A and B) had lower means for percent fat.

The percent shrink in width was affected by an interaction (P<0.0001) between sex and location (Table 9). For barrow and gilts, location A had the lowest shrink in width, while locations D and E observed the highest shrink in width of the bacon slice (Figure 7). Difference (P<0.05) between barrows and gilts were only notice in location D where barrows shrank more than gilts.
Proximate Analysis

Genetic Line Effect

Bellies from Berkshire and Poland China pigs had higher (P<0.05) fat percent content (Table 11). Bacon made from Duroc and Yorkshire bellies had the lowest (P<0.05) fat percentage content (Table 11). Genetic lines with lower fat percentage had the highest moisture content (46.78% and 46.70% for Duroc and Yorkshire, respectively). These genetic lines also had higher protein percentage content (14.38% and 14.28% for Duroc and Yorkshire, respectively).

Sex Effect

Barrows had higher (P<0.05) fat percentage content when compared to gilts (Table 11). Inversely, barrows exerted lower (P<0.05) moisture percentage than gilts (41.64% and 45.58% for barrows and gilts, respectively) (Table 11).

Location Effect

Locations on the most anterior end of the belly (D and E) had higher (P<0.05) fat percentage and lower moisture content than locations on the center and posterior (A, B and C) end of the slab (Table 11).

Conclusion

Demand for bacon has increased due to consumer preference for flavor and texture. A number of factors influence bacon processing and cooking characteristics. Commercial bacon processors consider shattering of the fat on a bacon slice and
distortion of the cooked slice as quality defect. Along with these two, fatty acid composition, cooking yield and size shrinkage are important in the overall profitability and consumer satisfaction of bacon.

Freezing pork bellies prior to curing has been a common practice in bacon production. Freezing provides an excellent means for storing meat for long periods of time. Science has proved that freezing and storage of meat could damage muscle tissue. There is little data that reports the effect of the damage on frozen bellies when processing to sliced bacon.

The results suggest that very similar processing characteristics and yields would be obtained when manufacturing bacon from fresh or frozen bellies. In the present study bellies were in frozen storage for 15 days prior to processing. This period of time had little effect on the fatty acid profile of the bellies. Genetic line and sex had greater impact on the percentage of saturated and unsaturated fatty acids in the pork bellies. The effects of frozen storage on shattering of the bacon slice appear to be less significant than that of genetic line, sex, location and quadrant. However, results suggest a relationship between fat content and shattering; therefore, it could be speculated that adipose tissue in the bellies was damage during freezing. Results from the cooking analysis suggest that genetic line, sex and location had greater impact on cooking parameters than treatment (fresh, frozen).

The results do not reveal a great difference on processing characteristics of bacon when using frozen bellies. Although, findings might suggest that longer periods of storage could lead to significant processing and cooking differences. These differences
could have greater impact in bacon processing operations, were volumes of production are much larger.

The fat content as well as the fatty acid composition appear to play an important role in the manufacturing characteristics of the belly. In bacon production, bellies with soft fat could have negative impact on slicing yields, shelf life and texture of the final product.

Finally, it appears that genetic line and sex had the greatest impact on processing characteristics and yields of bacon.
Reference


Table 1. Brine formulation.

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Percent</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>2.00%</td>
<td>139.21 lb</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[63145 g]</td>
</tr>
<tr>
<td>Salt</td>
<td>1.00%</td>
<td>33.33 lb</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[15118 g]</td>
</tr>
<tr>
<td>Sugar</td>
<td>0.15%</td>
<td>16.67 lb</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[7561 g]</td>
</tr>
<tr>
<td>Natural Smoke Flavoring</td>
<td>0.25%</td>
<td>2.50 lb</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[1134 g]</td>
</tr>
<tr>
<td>Red Arrow</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sodium Phosphate [BK-450]</td>
<td>0.25%</td>
<td>4.17 lb</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[1892 g]</td>
</tr>
<tr>
<td>Sodium Erythorbate</td>
<td>550 ppm</td>
<td>0.916 lb</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[416 g]</td>
</tr>
<tr>
<td>Sodium Nitrite [cure 6.25% NO₂]</td>
<td>120 ppm</td>
<td>3.20 lb</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[1452 g]</td>
</tr>
</tbody>
</table>

a. Phosphate was added to the cold water (<4°C/40°F) agitated until phosphates are dissolved.

b. With continued agitation, the remainder of the non-meat ingredients were added in the following order: salt, sugar, nitrite, natural liquid smoke flavor as required and lastly the ascorbate.

Wenther, 1999.
Table 2. Smokehouse schedule.

<table>
<thead>
<tr>
<th>Step</th>
<th>Time</th>
<th>Dry Bulb</th>
<th>Wet Bulb</th>
<th>RH%</th>
<th>Dampers /Smoke</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>120 min</td>
<td>60°C</td>
<td>---------</td>
<td></td>
<td>Open</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>/140°F</td>
<td>---------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>20 min</td>
<td>Heat off</td>
<td>---------</td>
<td></td>
<td>Closed</td>
<td>Smoke applied *</td>
</tr>
<tr>
<td></td>
<td></td>
<td>/fans off *</td>
<td>---------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>45 min</td>
<td>60°C</td>
<td>21.2°C</td>
<td></td>
<td>Auto</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>/140°F</td>
<td>/100°F</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>IT&gt;53.3°C</td>
<td>65.5°C</td>
<td>48.8°C</td>
<td>40%</td>
<td>Auto</td>
<td>IT&gt;53.3°C</td>
</tr>
<tr>
<td></td>
<td>/128°F</td>
<td>/150°F</td>
<td>/120°F</td>
<td></td>
<td></td>
<td>/128°F</td>
</tr>
<tr>
<td>5</td>
<td>10 min</td>
<td>---------</td>
<td>---------</td>
<td></td>
<td>Auto</td>
<td>Shower</td>
</tr>
<tr>
<td>6</td>
<td>10 min</td>
<td>---------</td>
<td>---------</td>
<td></td>
<td>Auto</td>
<td>Dry</td>
</tr>
</tbody>
</table>

IT= Internal Temperature
* Liquid Smoke Atomization settings as follows: 4.08 atm (60 psi) to nozzle, 2.86 atm (42+ psi) to tank, flow 7.57 L/hr (2.0 gph), 2.11 kg (4.65 lb) Red Arrow “Charsol Supreme Hickory”.

Wenther, 1999.
Table 3. Least Square Means ± S.E. of Percent Unsaturated Fatty Acid (% UFA) and Percent of Saturated Fatty Acids (% SFA) for Sex, Line and Storage Treatment Effects.

<table>
<thead>
<tr>
<th>Effect</th>
<th>% UFA</th>
<th>% SFA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barrows</td>
<td>61.43 ± 0.26a</td>
<td>37.71 ± 0.27a</td>
</tr>
<tr>
<td>Gilts</td>
<td>62.51 ± 0.22b</td>
<td>36.59 ± 0.23b</td>
</tr>
<tr>
<td>Berkshire</td>
<td>60.20 ± 0.23c</td>
<td>39.05 ± 0.24a</td>
</tr>
<tr>
<td>Chester White</td>
<td>60.51 ± 0.46c</td>
<td>38.57 ± 0.47a</td>
</tr>
<tr>
<td>Duroc</td>
<td>62.89 ± 0.21b</td>
<td>36.22 ± 0.22c</td>
</tr>
<tr>
<td>Landrace</td>
<td>62.40 ± 0.57b</td>
<td>36.64 ± 0.59bc</td>
</tr>
<tr>
<td>Poland China</td>
<td>61.46 ± 0.60c</td>
<td>37.82 ± 0.62ab</td>
</tr>
<tr>
<td>Yorkshire</td>
<td>64.35 ± 0.24a</td>
<td>34.60 ± 0.25d</td>
</tr>
<tr>
<td>Fresh</td>
<td>61.69 ± 0.23</td>
<td>37.44 ± 0.23</td>
</tr>
<tr>
<td>Frozen</td>
<td>62.24 ± 0.24</td>
<td>36.86 ± 0.25</td>
</tr>
</tbody>
</table>

abcd Means within the same column within a main effect with similar superscripts are not significantly different (P>0.05).
Table 4. Least Square Means ± S.E. of the Fatty Acid Profile for Sex, Line and Treatment Effects.

<table>
<thead>
<tr>
<th>Effect</th>
<th>14:0</th>
<th>16:0</th>
<th>16:1</th>
<th>18:0</th>
<th>18:1</th>
<th>18:2</th>
<th>18:3</th>
<th>20:1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barrows</td>
<td>1.35 ± 0.01</td>
<td>24.04 ± 0.15(^a)</td>
<td>2.64 ± 0.03</td>
<td>11.59 ± 0.13</td>
<td>44.98 ± 0.27</td>
<td>11.27 ± 0.31</td>
<td>0.69 ± 0.03</td>
<td>0.80 ± 0.01</td>
</tr>
<tr>
<td>Gilts</td>
<td>1.32 ± 0.01</td>
<td>23.17 ± 0.13(^b)</td>
<td>2.58 ± 0.03</td>
<td>11.36 ± 0.11</td>
<td>45.27 ± 0.23</td>
<td>12.06 ± 0.26</td>
<td>0.69 ± 0.02</td>
<td>0.77 ± 0.00</td>
</tr>
<tr>
<td>Berkshire</td>
<td>1.36 ± 0.01(^b)</td>
<td>25.09 ± 0.14(^a)</td>
<td>2.88 ± 0.03(^b)</td>
<td>11.89 ± 0.12(^ab)</td>
<td>45.78 ± 0.27(^bc)</td>
<td>9.45 ± 0.27(^b)</td>
<td>0.42 ± 0.03(^b)</td>
<td>0.76 ± 0.00(^b)</td>
</tr>
<tr>
<td>Chester White</td>
<td>1.49 ± 0.02(^a)</td>
<td>24.84 ± 0.27(^ab)</td>
<td>3.07 ± 0.06(^a)</td>
<td>11.45 ± 0.24(^b)</td>
<td>45.48 ± 0.48(^c)</td>
<td>9.74 ± 0.54(^b)</td>
<td>0.45 ± 0.06(^b)</td>
<td>0.80 ± 0.01(^bc)</td>
</tr>
<tr>
<td>Duroc</td>
<td>1.30 ± 0.01(^c)</td>
<td>22.27 ± 0.12(^d)</td>
<td>2.13 ± 0.02(^a)</td>
<td>11.99 ± 0.11(^e)</td>
<td>41.90 ± 0.22(^c)</td>
<td>15.66 ± 0.25(^a)</td>
<td>1.15 ± 0.02(^a)</td>
<td>0.78 ± 0.00(^b)</td>
</tr>
<tr>
<td>Landrace</td>
<td>1.28 ± 0.02(^ad)</td>
<td>23.20 ± 0.33(^c)</td>
<td>2.61 ± 0.07(^c)</td>
<td>11.27 ± 0.30(^b)</td>
<td>47.28 ± 0.66(^ab)</td>
<td>10.17 ± 0.67(^b)</td>
<td>0.46 ± 0.07(^b)</td>
<td>0.77 ± 0.02(^bc)</td>
</tr>
<tr>
<td>Poland China</td>
<td>1.30 ± 0.03(^cd)</td>
<td>24.31 ± 0.35(^b)</td>
<td>2.66 ± 0.08(^c)</td>
<td>11.54 ± 0.32(^ab)</td>
<td>47.35 ± 0.63(^a)</td>
<td>9.25 ± 0.71(^b)</td>
<td>0.46 ± 0.08(^b)</td>
<td>0.80 ± 0.02(^bc)</td>
</tr>
<tr>
<td>Yorkshire</td>
<td>1.26 ± 0.01(^d)</td>
<td>21.95 ± 0.14(^d)</td>
<td>2.30 ± 0.03(^d)</td>
<td>10.69 ± 0.12(^c)</td>
<td>42.98 ± 0.25(^d)</td>
<td>15.73 ± 0.28(^a)</td>
<td>1.18 ± 0.03(^a)</td>
<td>0.81 ± 0.01(^ac)</td>
</tr>
<tr>
<td>Fresh</td>
<td>1.33 ± 0.01</td>
<td>23.79 ± 0.13(^e)</td>
<td>2.63 ± 0.03</td>
<td>11.59 ± 0.12</td>
<td>45.12 ± 0.25</td>
<td>11.36 ± 0.27</td>
<td>0.67 ± 0.03</td>
<td>0.78 ± 0.00</td>
</tr>
<tr>
<td>Frozen</td>
<td>1.34 ± 0.01</td>
<td>23.42 ± 0.14(^b)</td>
<td>2.59 ± 0.03</td>
<td>11.35 ± 0.12</td>
<td>45.14 ± 0.26</td>
<td>11.97 ± 0.28</td>
<td>0.70 ± 0.03</td>
<td>0.78 ± 0.00</td>
</tr>
</tbody>
</table>


\(^{abcd}\) Means within the same column and within main effect with similar superscripts are not significantly different (P<0.05).
Table 5. Analysis of Variance of the Total Length of the Shatter Mark, Main Effects and Two-Way Interactions.

<table>
<thead>
<tr>
<th>Effect</th>
<th>Interaction</th>
<th>Total Length</th>
<th>F</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line</td>
<td></td>
<td></td>
<td>8.55</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td></td>
<td>Line * Sex</td>
<td></td>
<td>2.31</td>
<td>0.0433</td>
</tr>
<tr>
<td></td>
<td>Line * Treatment</td>
<td></td>
<td>2.21</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>Line * Location</td>
<td></td>
<td>8.15</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td></td>
<td>Line * Quadrant</td>
<td></td>
<td>1.19</td>
<td>NS</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td>30.05</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td></td>
<td>Sex * Treatment</td>
<td></td>
<td>0.02</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>Sex * Location</td>
<td></td>
<td>21.89</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td></td>
<td>Sex * Quadrant</td>
<td></td>
<td>12.63</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Storage Treatment</td>
<td></td>
<td></td>
<td>2.58</td>
<td>NS</td>
</tr>
<tr>
<td>Treatment *</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Treatment * Location</td>
<td></td>
<td>7.36</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td></td>
<td>Treatment * Quadrant</td>
<td></td>
<td>0.80</td>
<td>NS</td>
</tr>
<tr>
<td>Location**</td>
<td></td>
<td></td>
<td>88.69</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td></td>
<td>Location * Quadrant</td>
<td></td>
<td>24.84</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Quadrant***</td>
<td></td>
<td></td>
<td>20.08</td>
<td>&lt; 0.0001</td>
</tr>
</tbody>
</table>

NS Not statistically significant (P>0.05).
* Fresh (3°C) or frozen bellies (-15°C)
** Location: sampling location of the bacon slab from posterior to anterior. Each location represents 20% of the slices of the slab (see appendix 2).
*** Quadrant: sampling location of the bacon slice representing 25% of the slice from dorsal to ventral (see appendix 2).
Table 6. Least Square Means and S.E. for Total Length of the Shatter Mark for the Interactions* with Location**.

<table>
<thead>
<tr>
<th>Effect</th>
<th>Location A</th>
<th>Location B</th>
<th>Location C</th>
<th>Location D</th>
<th>Location E</th>
<th>S.E.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh</td>
<td>0.46d</td>
<td>0.86d</td>
<td>1.71c</td>
<td>2.76b</td>
<td>2.76b</td>
<td>0.23</td>
</tr>
<tr>
<td>Frozen</td>
<td>0.50d</td>
<td>1.47c</td>
<td>2.44b</td>
<td>3.72a</td>
<td>2.59b</td>
<td>0.24</td>
</tr>
<tr>
<td>Barrows</td>
<td>0.73fg</td>
<td>1.66de</td>
<td>2.96c</td>
<td>4.53a</td>
<td>3.76b</td>
<td>0.26</td>
</tr>
<tr>
<td>Gilts</td>
<td>0.22h</td>
<td>0.67g</td>
<td>1.18ef</td>
<td>1.95d</td>
<td>1.59de</td>
<td>0.23</td>
</tr>
<tr>
<td>Yorkshire</td>
<td>0.27</td>
<td>0.60</td>
<td>1.75</td>
<td>2.38</td>
<td>1.62</td>
<td>0.26</td>
</tr>
<tr>
<td>Duroc</td>
<td>0.29</td>
<td>0.43</td>
<td>1.51</td>
<td>2.00</td>
<td>1.77</td>
<td>0.23</td>
</tr>
<tr>
<td>Chester White</td>
<td>0.95</td>
<td>1.83</td>
<td>2.17</td>
<td>2.74</td>
<td>2.37</td>
<td>0.48</td>
</tr>
<tr>
<td>Poland China</td>
<td>0.69</td>
<td>1.86</td>
<td>2.83</td>
<td>4.43</td>
<td>2.94</td>
<td>0.64</td>
</tr>
<tr>
<td>Berkshire</td>
<td>0.48</td>
<td>1.37</td>
<td>2.56</td>
<td>4.66</td>
<td>4.83</td>
<td>0.25</td>
</tr>
<tr>
<td>Landrace</td>
<td>0.18</td>
<td>0.90</td>
<td>1.61</td>
<td>3.20</td>
<td>2.52</td>
<td>0.60</td>
</tr>
<tr>
<td>Quadrant 1</td>
<td>0.53klm</td>
<td>1.40fgij</td>
<td>3.27cd</td>
<td>4.05ab</td>
<td>1.92ef</td>
<td>0.24</td>
</tr>
<tr>
<td>Quadrant 2</td>
<td>0.34lm</td>
<td>0.96ijkl</td>
<td>2.15e</td>
<td>4.30a</td>
<td>4.04ab</td>
<td>0.24</td>
</tr>
<tr>
<td>Quadrant 3</td>
<td>0.40lm</td>
<td>0.89klm</td>
<td>1.28ghi</td>
<td>2.77d</td>
<td>3.65bc</td>
<td>0.24</td>
</tr>
<tr>
<td>Quadrant 4</td>
<td>0.65klm</td>
<td>1.41ghi</td>
<td>1.58gh</td>
<td>1.82efg</td>
<td>1.08hiijk</td>
<td>0.24</td>
</tr>
</tbody>
</table>

* Superscripts may be compared in row and column for the effects (storage treatment, sex and quadrant). However comparisons cannot be made between two interactions.

** Location: sampling location of the bacon slab from posterior to anterior. Each location represents 20% of the slices of the slab (see appendix 2).

*** Quadrant: sampling location of the bacon slice representing 25% of the slice length from dorsal to ventral (see appendix 2).
Table 7. Least Square Means and S.E. Total Length of Shatter Mark (mm) for Line x Sex Interaction and Quadrant x Sex Interactions*

<table>
<thead>
<tr>
<th>Effects</th>
<th>Barrows</th>
<th>S.E.</th>
<th>Gilt</th>
<th>S.E.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Berkshire</td>
<td>3.78\textsuperscript{a}</td>
<td>0.25</td>
<td>1.77\textsuperscript{b}</td>
<td>0.31</td>
</tr>
<tr>
<td>Chester White</td>
<td>3.35\textsuperscript{a}</td>
<td>0.45</td>
<td>0.66\textsuperscript{bc}</td>
<td>0.62</td>
</tr>
<tr>
<td>Duroc</td>
<td>1.51\textsuperscript{bc}</td>
<td>0.24</td>
<td>0.88\textsuperscript{c}</td>
<td>0.27</td>
</tr>
<tr>
<td>Landrace</td>
<td>2.25\textsuperscript{abc}</td>
<td>0.84</td>
<td>1.11\textsuperscript{b}</td>
<td>0.50</td>
</tr>
<tr>
<td>Poland China</td>
<td>3.67\textsuperscript{a}</td>
<td>0.84</td>
<td>1.43\textsuperscript{bc}</td>
<td>0.58</td>
</tr>
<tr>
<td>Yorkshire</td>
<td>1.78\textsuperscript{b}</td>
<td>0.25</td>
<td>0.86\textsuperscript{c}</td>
<td>0.34</td>
</tr>
<tr>
<td>Quadrant 1**</td>
<td>3.26\textsuperscript{a}</td>
<td>0.25</td>
<td>1.21\textsuperscript{c}</td>
<td>0.22</td>
</tr>
<tr>
<td>Quadrant 2</td>
<td>3.42\textsuperscript{a}</td>
<td>0.25</td>
<td>1.29\textsuperscript{c}</td>
<td>0.22</td>
</tr>
<tr>
<td>Quadrant 3</td>
<td>2.45\textsuperscript{b}</td>
<td>0.25</td>
<td>1.14\textsuperscript{cd}</td>
<td>0.22</td>
</tr>
<tr>
<td>Quadrant 4</td>
<td>1.78\textsuperscript{c}</td>
<td>0.25</td>
<td>0.84\textsuperscript{d}</td>
<td>0.22</td>
</tr>
</tbody>
</table>

* Superscripts may be compared in row and column for line x sex and quadrant x sex. However comparisons cannot be made between the two interactions.

** Quadrant: sampling location of the bacon slice representing 25% of the slice from dorsal to ventral.
Table 8. Correlation of the Total Shatter Marks of the Belly and Fatty Acid Content.

<table>
<thead>
<tr>
<th></th>
<th>TBS</th>
<th>14:00</th>
<th>16:00</th>
<th>18:00</th>
<th>TSF</th>
<th>16:1</th>
<th>18:1</th>
<th>18:2</th>
<th>18:3</th>
<th>20:1</th>
<th>TUF</th>
</tr>
</thead>
<tbody>
<tr>
<td>TBS</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14:00</td>
<td>0.18926</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16:00</td>
<td>0.28746</td>
<td>0.51843</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18:00</td>
<td>0.08295</td>
<td>0.02069</td>
<td>0.56964</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TSF</td>
<td>0.22828</td>
<td>0.38800</td>
<td>0.92824</td>
<td>0.83045</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16:1</td>
<td>0.20816</td>
<td>0.62945</td>
<td>0.49978</td>
<td>-0.3016</td>
<td>0.20840</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18:1</td>
<td>0.15706</td>
<td>0.04560</td>
<td>0.48560</td>
<td>-0.0985</td>
<td>0.07260</td>
<td>0.43088</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18:2</td>
<td>-0.2694</td>
<td>-0.3666</td>
<td>-0.7601</td>
<td>-0.3970</td>
<td>-0.6927</td>
<td>-0.5888</td>
<td>-0.7499</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18:3</td>
<td>-0.2018</td>
<td>-0.3472</td>
<td>-0.6988</td>
<td>-0.3736</td>
<td>-0.6448</td>
<td>-0.5410</td>
<td>-0.7530</td>
<td>0.96808</td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20:1</td>
<td>0.10881</td>
<td>-0.0779</td>
<td>-0.0996</td>
<td>-0.0357</td>
<td>-0.0801</td>
<td>-0.1025</td>
<td>0.44309</td>
<td>-0.2444</td>
<td>-0.2260</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>TUF</td>
<td>-0.2193</td>
<td>-0.3920</td>
<td>-0.9233</td>
<td>-0.8290</td>
<td>-0.9974</td>
<td>-0.2047</td>
<td>-0.0554</td>
<td>0.68199</td>
<td>0.63899</td>
<td>0.09027</td>
<td>1.000</td>
</tr>
</tbody>
</table>


TBS = Total Shatter Marks in the Belly.
TSF = Total Saturated Fatty Acids.
TUF = Total Unsaturated Fatty Acids.
Table 9. Analysis of Variance of Percentage of Shrink in length, Percentage of Shrink in Width and Distortion of Cooked Bacon Slices and their Two-Way Interactions.

<table>
<thead>
<tr>
<th>Effect</th>
<th>Cooking Yield</th>
<th>% Shrink-Length</th>
<th>% Shrink-Width</th>
<th>Distortion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>P-value</td>
<td>F</td>
<td>P-value</td>
</tr>
<tr>
<td>Line</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Line * Sex</td>
<td>0.63</td>
<td>NS</td>
<td>0.23</td>
<td>NS</td>
</tr>
<tr>
<td>Line * Treatment</td>
<td>1.85</td>
<td>NS</td>
<td>0.44</td>
<td>NS</td>
</tr>
<tr>
<td>Line * Location</td>
<td>1.42</td>
<td>NS</td>
<td>0.77</td>
<td>NS</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sex * Treatment</td>
<td>0.16</td>
<td>NS</td>
<td>0.43</td>
<td>NS</td>
</tr>
<tr>
<td>Sex * Location</td>
<td>6.98</td>
<td>&lt;0.0001</td>
<td>0.22</td>
<td>NS</td>
</tr>
<tr>
<td>Treatment</td>
<td>0.2</td>
<td>NS</td>
<td>0.05</td>
<td>NS</td>
</tr>
<tr>
<td>Treatment * Location</td>
<td>2.55</td>
<td>0.0376</td>
<td>0.97</td>
<td>NS</td>
</tr>
<tr>
<td>Location</td>
<td>120.2</td>
<td>&lt;0.0001</td>
<td>59.03</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

*a* Cooking Yield = \( \frac{\text{cooked slice wt} \times \text{initial slice wt}}{100} \).

*b* % Shrink-Length = \( \frac{\text{cooked slice length} - \text{initial slice length}}{\text{cooked slice length}} \) * 100.

*c* % Shrink-Width = \( \frac{\text{cooked slice width} - \text{initial slice width}}{\text{cooked slice width}} \) * 100.

*d* Distortion = Score from 1 to 5 assigned to the cooked slices (see Fig. 1) (Ross, 1999).

NS = Not statistically significant (P>0.05).
Table 10. Least Square Means ± S.E. of Cooking Yield, % of Shrink in Length, % Shrink in Width and Distortion score for all Main effects. *

<table>
<thead>
<tr>
<th>Effect</th>
<th>Cooking Yield (%)</th>
<th>% Shrink-Length</th>
<th>% Shrink-Width</th>
<th>Distortion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barrows</td>
<td>33.17 ± 0.38</td>
<td>32.84 ± 0.50</td>
<td>19.36 ± 0.86</td>
<td>2.40 ± 0.03</td>
</tr>
<tr>
<td>Gilts</td>
<td>35.52 ± 0.32</td>
<td>31.63 ± 0.45</td>
<td>18.22 ± 0.73</td>
<td>2.39 ± 0.02</td>
</tr>
<tr>
<td>Berkshire</td>
<td>31.90 ± 0.34*</td>
<td>33.10 ± 0.48a</td>
<td>23.16 ± 0.78a</td>
<td>2.41 ± 0.03</td>
</tr>
<tr>
<td>Chester White</td>
<td>33.90 ± 0.67b</td>
<td>33.66 ± 0.94a</td>
<td>19.95 ± 1.52ab</td>
<td>2.48 ± 0.05</td>
</tr>
<tr>
<td>Duroc</td>
<td>36.69 ± 0.31cd</td>
<td>32.26 ± 0.43a</td>
<td>14.84 ± 0.70c</td>
<td>2.44 ± 0.02</td>
</tr>
<tr>
<td>Landrace</td>
<td>34.94 ± 0.85bc</td>
<td>31.64 ± 1.19a</td>
<td>16.24 ± 1.92bc</td>
<td>2.37 ± 0.06</td>
</tr>
<tr>
<td>Poland China</td>
<td>31.14 ± 0.87a</td>
<td>31.92 ± 1.23a</td>
<td>21.74 ± 1.98a</td>
<td>2.37 ± 0.07</td>
</tr>
<tr>
<td>Yorkshire</td>
<td>37.49 ± 0.36d</td>
<td>30.81 ± 0.50b</td>
<td>16.82 ± 0.81bc</td>
<td>2.28 ± 0.03</td>
</tr>
<tr>
<td>Fresh</td>
<td>34.45 ± 0.34</td>
<td>32.16 ± 0.48</td>
<td>18.19 ± 0.77</td>
<td>2.35 ± 0.03a</td>
</tr>
<tr>
<td>Frozen</td>
<td>34.24 ± 0.35</td>
<td>32.31 ± 0.49</td>
<td>19.39 ± 0.79</td>
<td>2.43 ± 0.03b</td>
</tr>
<tr>
<td>Location A</td>
<td>37.07 ± 0.31</td>
<td>38.35 ± 0.68a</td>
<td>4.63 ± 0.78</td>
<td>2.79 ± 0.03a</td>
</tr>
<tr>
<td>Location B</td>
<td>36.23 ± 0.31</td>
<td>28.17 ± 0.68c</td>
<td>15.94 ± 0.78</td>
<td>2.26 ± 0.03b</td>
</tr>
<tr>
<td>Location C</td>
<td>33.96 ± 0.31</td>
<td>27.48 ± 0.68c</td>
<td>23.29 ± 0.78</td>
<td>2.19 ± 0.03c</td>
</tr>
<tr>
<td>Location D</td>
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<td>30.35 ± 0.68b</td>
<td>25.37 ± 0.78</td>
<td>2.22 ± 0.03bc</td>
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<tr>
<td>Location E</td>
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<td>36.82 ± 0.68a</td>
<td>24.74 ± 0.78</td>
<td>2.52 ± 0.03d</td>
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</tbody>
</table>

* Mean differences within a column are shown for those main effects that are not involved in any interaction.

Means within the same column and within a main effect with similar superscripts are not significantly different (P>0.05).

Cooking Yield = (cooked slice wt / initial slice wt) * 100.

% Shrink-Length = (cooked slice length - initial slice length) * 100 / cooked slice length.

% Shrink-Width = (cooked slice width - initial slice width) * 100 / cooked slice width.

Distortion Score from 1 to 5 assigned to the cooked slices (see Fig. 1) (Ross, 1999).

Location Sampling location of the bacon slab from posterior to anterior. Each location represents 20% of the slices of the slab (see appendix 2).
Table 11. Least Square Means ± S.E. Proximal Composition of the Raw Bacon for all Main Effects.

<table>
<thead>
<tr>
<th>Effect</th>
<th>% Fat</th>
<th>% Moisture</th>
<th>% Ash</th>
<th>% Protein</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barrows</td>
<td>43.51 ± 0.57&lt;sup&gt;a&lt;/sup&gt;</td>
<td>41.64 ± 0.42&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.18 ± 0.04&lt;sup&gt;b&lt;/sup&gt;</td>
<td>12.71 ± 0.19&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Gilts</td>
<td>38.29 ± 0.47&lt;sup&gt;b&lt;/sup&gt;</td>
<td>45.58 ± 0.35&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.30 ± 0.03&lt;sup&gt;a&lt;/sup&gt;</td>
<td>13.80 ± 0.16&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Berkshire</td>
<td>45.09 ± 0.50&lt;sup&gt;a&lt;/sup&gt;</td>
<td>40.93 ± 0.37&lt;sup&gt;c&lt;/sup&gt;</td>
<td>2.13 ± 0.03&lt;sup&gt;b&lt;/sup&gt;</td>
<td>11.72 ± 0.17&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Chester White</td>
<td>40.51 ± 0.96&lt;sup&gt;c&lt;/sup&gt;</td>
<td>44.26 ± 0.71&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.17 ± 0.06&lt;sup&gt;b&lt;/sup&gt;</td>
<td>13.16 ± 0.33&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Duroc</td>
<td>36.44 ± 0.44&lt;sup&gt;d&lt;/sup&gt;</td>
<td>46.78 ± 0.33&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.44 ± 0.03&lt;sup&gt;a&lt;/sup&gt;</td>
<td>14.38 ± 0.15&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Landrace</td>
<td>41.76 ± 1.28&lt;sup&gt;b&lt;/sup&gt;</td>
<td>42.54 ± 0.95&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>2.13 ± 0.08&lt;sup&gt;b&lt;/sup&gt;</td>
<td>13.59 ± 0.44&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>Poland China</td>
<td>45.01 ± 1.27&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>40.45 ± 0.94&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.16 ± 0.08&lt;sup&gt;b&lt;/sup&gt;</td>
<td>12.40 ± 0.44&lt;sup&gt;bc&lt;/sup&gt;</td>
</tr>
<tr>
<td>Yorkshire</td>
<td>36.60 ± 0.51&lt;sup&gt;d&lt;/sup&gt;</td>
<td>46.70 ± 0.38&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.41 ± 0.03&lt;sup&gt;a&lt;/sup&gt;</td>
<td>14.28 ± 0.18&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Fresh</td>
<td>40.89 ± 0.49</td>
<td>43.66 ± 0.36</td>
<td>2.17 ± 0.03&lt;sup&gt;b&lt;/sup&gt;</td>
<td>13.29 ± 0.17</td>
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<tr>
<td>Frozen</td>
<td>40.92 ± 0.51</td>
<td>43.56 ± 0.38</td>
<td>2.32 ± 0.03&lt;sup&gt;a&lt;/sup&gt;</td>
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<td>Location A*</td>
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<td>2.37 ± 0.03&lt;sup&gt;a&lt;/sup&gt;</td>
<td>12.99 ± 0.18&lt;sup&gt;c&lt;/sup&gt;</td>
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<td>Location B</td>
<td>38.90 ± 0.42&lt;sup&gt;c&lt;/sup&gt;</td>
<td>45.86 ± 0.31&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.34 ± 0.03&lt;sup&gt;a&lt;/sup&gt;</td>
<td>12.90 ± 0.18&lt;sup&gt;c&lt;/sup&gt;</td>
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<td>Location C</td>
<td>41.14 ± 0.42&lt;sup&gt;b&lt;/sup&gt;</td>
<td>42.82 ± 0.31&lt;sup&gt;c&lt;/sup&gt;</td>
<td>2.18 ± 0.03&lt;sup&gt;b&lt;/sup&gt;</td>
<td>13.85 ± 0.18&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Location D</td>
<td>43.17 ± 0.42&lt;sup&gt;a&lt;/sup&gt;</td>
<td>41.26 ± 0.31&lt;sup&gt;d&lt;/sup&gt;</td>
<td>2.16 ± 0.03&lt;sup&gt;b&lt;/sup&gt;</td>
<td>13.42 ± 0.18&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Location E</td>
<td>43.42 ± 0.42&lt;sup&gt;a&lt;/sup&gt;</td>
<td>41.36 ± 0.31&lt;sup&gt;d&lt;/sup&gt;</td>
<td>2.16 ± 0.03&lt;sup&gt;b&lt;/sup&gt;</td>
<td>13.12 ± 0.18&lt;sup&gt;bc&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>abcd</sup> Means within the same column and within a main effect with similar superscripts are not significantly different (P>0.05).

<sup>*</sup> Sampling location of the bacon slab from posterior to anterior. Each location represents 20% of the slices of the bacon slab (see appendix 2).
Table 12. Least Square Means ± S.E. Proximal Composition of the Cooked Bacon for all Main Effects.

<table>
<thead>
<tr>
<th>Effect</th>
<th>% Fat</th>
<th>% Moisture</th>
<th>% Ash</th>
<th>% Protein</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barrows</td>
<td>36.66 ± 0.68&lt;sup&gt;a&lt;/sup&gt;</td>
<td>19.87 ± 0.40&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.45 ± 0.07</td>
<td>38.04 ± 0.57</td>
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<tr>
<td>Gilts</td>
<td>34.45 ± 0.57&lt;sup&gt;b&lt;/sup&gt;</td>
<td>21.79 ± 0.33&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.34 ± 0.06</td>
<td>38.42 ± 0.47</td>
</tr>
<tr>
<td>Berkshire</td>
<td>38.09 ± 0.59&lt;sup&gt;a&lt;/sup&gt;</td>
<td>19.31 ± 0.35&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.18 ± 0.06&lt;sup&gt;c&lt;/sup&gt;</td>
<td>37.43 ± 0.50</td>
</tr>
<tr>
<td>Chester White</td>
<td>34.33 ± 1.18&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>20.30 ± 0.69&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.24 ± 0.12&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>40.12 ± 0.99</td>
</tr>
<tr>
<td>Duroc</td>
<td>32.54 ± 0.54&lt;sup&gt;c&lt;/sup&gt;</td>
<td>23.47 ± 0.31&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.41 ± 0.06&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>38.59 ± 0.45</td>
</tr>
<tr>
<td>Landrace</td>
<td>37.39 ± 1.46&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>19.33 ± 0.83&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.43 ± 0.15&lt;sup&gt;abc&lt;/sup&gt;</td>
<td>37.89 ± 1.22</td>
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<td>Poland China</td>
<td>38.01 ± 1.57&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>18.26 ± 0.92&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.68 ± 0.16&lt;sup&gt;c&lt;/sup&gt;</td>
<td>38.05 ± 1.32</td>
</tr>
<tr>
<td>Yorkshire</td>
<td>32.99 ± 0.62&lt;sup&gt;c&lt;/sup&gt;</td>
<td>24.30 ± 0.36&lt;sup&gt;c&lt;/sup&gt;</td>
<td>5.43 ± 0.06&lt;sup&gt;ab&lt;/sup&gt;</td>
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<tr>
<td>Fresh</td>
<td>35.64 ± 0.59</td>
<td>21.48 ± 0.34&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.27 ± 0.06&lt;sup&gt;b&lt;/sup&gt;</td>
<td>37.62 ± 0.49</td>
</tr>
<tr>
<td>Frozen</td>
<td>35.47 ± 0.62</td>
<td>20.17 ± 0.36&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.52 ± 0.06&lt;sup&gt;a&lt;/sup&gt;</td>
<td>38.85 ± 0.52</td>
</tr>
<tr>
<td>Location A&lt;sup&gt;*&lt;/sup&gt;</td>
<td>33.53 ± 0.51&lt;sup&gt;d&lt;/sup&gt;</td>
<td>23.26 ± 0.28&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.41 ± 0.06&lt;sup&gt;b&lt;/sup&gt;</td>
<td>37.80 ± 0.44</td>
</tr>
<tr>
<td>Location B</td>
<td>34.17 ± 0.52&lt;sup&gt;c&lt;/sup&gt;</td>
<td>22.34 ± 0.28&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.29 ± 0.06&lt;sup&gt;c&lt;/sup&gt;</td>
<td>38.21 ± 0.44</td>
</tr>
<tr>
<td>Location C</td>
<td>35.84 ± 0.52&lt;sup&gt;b&lt;/sup&gt;</td>
<td>20.57 ± 0.28&lt;sup&gt;c&lt;/sup&gt;</td>
<td>5.26 ± 0.06&lt;sup&gt;c&lt;/sup&gt;</td>
<td>38.34 ± 0.44</td>
</tr>
<tr>
<td>Location D</td>
<td>37.10 ± 0.52&lt;sup&gt;a&lt;/sup&gt;</td>
<td>18.94 ± 0.28&lt;sup&gt;d&lt;/sup&gt;</td>
<td>5.45 ± 0.06&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>38.53 ± 0.44</td>
</tr>
<tr>
<td>Location E</td>
<td>37.15 ± 0.52&lt;sup&gt;a&lt;/sup&gt;</td>
<td>19.02 ± 0.28&lt;sup&gt;d&lt;/sup&gt;</td>
<td>5.56 ± 0.06&lt;sup&gt;a&lt;/sup&gt;</td>
<td>38.28 ± 0.44</td>
</tr>
</tbody>
</table>

<sup>a</sup> Means within the same column and within a main effect with similar superscripts are not significantly different (P>0.05).

<sup>b</sup> Sampling location of the bacon slab from posterior to anterior. Each location represents 20% of the slices of the slab (see appendix 2).
Figure 1. Distortion scale.

Ross, 1999.
Figure 2. Total Length of the Shatter Mark Least Square Means for Treatment x Location.

abcd Means sharing a superscript are not significantly different; P>0.05.
Figure 3. Total Length of the Shatter Mark Least Square Means for Line x Sex.

abc Means sharing a superscript are not significantly different; \( P > 0.05 \).
Figure 4. Cooking Yield Least Square Means for Treatment x Location Interaction. *

Means with a similar superscript are not significantly different (P>0.05).

* Cooking Yield = (cooked slice wt / initial slice wt) * 100.
Means with a similar superscript are not significantly different \((P > 0.05)\).

Distortion Score refers to the value assigned to the cooked slices (see Fig. 1) (Ross, 1999).
Figure 6. Cooking Yield Least Square Means for Sex x Location Interaction.*

Means with a similar superscript are not significantly different (P > 0.05).

* Cooking Yield = (cooked slice wt / initial slice wt) * 100.
Figure 7. Percent Shrink in Width (% Shrink-Width) Least Square Means for Sex \times Location Interaction.

Means with a similar superscript are not significantly different (P > 0.05).

* \% Shrink-Width = \frac{\text{cooked slice width - initial slice width}}{\text{cooked slice width}} \times 100

\text{ \textsuperscript{a,b,c,d,e} Means with a similar superscript are not significantly different (P > 0.05).}

* \% Shrink-Width = (\text{cooked slice width - initial slice width}) \times 100/\text{cooked slice width}.
Appendix 1: Belly Specifications

Reston, Va.

NAMP # 409- Pork Belly, Skinless

“The skinless belly is as described for NAMP No. 408, except that the skin is removed, leaving a smooth skinned surface which is practically free of hair roots and scores. The belly is prepared from the side after removal of the ham, shoulder, loin, fat back and spareribs. All bones and cartilage shall be removed. The fat back shall be removed by a straight cut no more than 1 ½ inches (38 mm) from the outermost dorsal curvature of the scribe line. The anterior (shoulder) and posterior (ham) ends of the belly shall be reasonable straight and parallel. No side of the belly shall be more than 2 inches (51 mm) longer than its opposite side. The width of the flank muscle (rectus abdominas) shall be at least 25% of the width of the belly on the ham end. The fat on the ventral side of the belly and adjacent to the flank shall be trimmed to with ¼ inch (19 mm) from the lean. The area ventral to the scribe line shall be free of scores and snowballs (exposed areas of fat) which measure 3 square inches (194 sq. mm) or more. The belly shall be free of enlarged, soft, porous, dark or seedy mammary tissue. The scribe line is not considered a score, but shall not be more than ¼ inch (6 mm) in depth at any point.”
## Appendix 2: Sampling Diagram for Draft of Sliced Bacon

<table>
<thead>
<tr>
<th>Posterior</th>
<th>Dorsal</th>
<th>Anterior</th>
<th>Incomplete Slices</th>
</tr>
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<tbody>
<tr>
<td><strong>Comb End</strong></td>
<td><strong>A</strong></td>
<td><strong>B</strong></td>
<td><strong>C</strong></td>
</tr>
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<td>12345....</td>
</tr>
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<td></td>
</tr>
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<td>Quad 2</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Quad 3</td>
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<td>0</td>
<td></td>
</tr>
<tr>
<td>Quad 4</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

### Ventral

Five locations for sampling in each bacon slab as follows:

a. After all incomplete slices have been removed, measure the complete draft (slices tightly compacted) in mm. Divide by 5, and determine the distance (mm) between each of the five sampling locations. This procedure accommodates variable weight and length bellies.

1. Sample A - Posterior edge of the draft of sliced bacon.
2. Sample B - 1/5 distance from posterior edge of draft of sliced bacon.
3. Sample C - 2/5 distance from posterior edge of draft of sliced bacon.
4. Sample D - 3/5 distance from posterior edge of draft of sliced bacon.
5. Sample E - 4/5 distance from posterior edge of draft of sliced bacon.
Four quadrants in each bacon slice as follows:

1. Quadrant 1 – Dorsal edge of the bacon slice.
2. Quadrant 2 – 1/4 distance from dorsal to ventral of the bacon slice.
3. Quadrant 3 – 2/4 distance from dorsal to ventral of the bacon slice.
4. Quadrant 4 – 3/4 distance from dorsal to ventral of the bacon slice.
Appendix 3: Fatty Acid Procedures

Modified procedure of:

GC sample preparation.

Saponification / Methylation
1. Transfer 10-1000mg of fatty tissue to a 13 x 100 mm (or 16 x 100 mm) screw cap test tube.
2. Add 0.5 mL 0.5 N NaOH in Methanol, purge with nitrogen, cap tightly, mix thoroughly, and heat 5 minutes at 100°C in boiling water bath or heating block.
3. Remove from heat and cool to room temperature. Add 0.5 mL boron trifluoride in methanol, purge with nitrogen, cap tightly, mix thoroughly, and heat and additional 5 minutes at 100°C in boiling water bath or heating block.
4. Remove from heat and cool to room temperature. Add 1.0 mL hexane (or other injection solvent) and mix thoroughly.
5. Add 1 mL saturated NaCl, cap tube, and shake vigorously for 30 seconds.
6. Centrifuge at 1500 rpm for 5 minutes to separate phases.
7. Transfer the organic layer containing the fatty acid methyl esters to a GC vial for injection. Be careful not to transfer any water to the vial. Samples may be "dried" prior to injection by adding about 0.5 g Na2SO4 and mixing. Allow the Na2SO4 to settle about 20 minutes, then transfer the solvent to a clean vial.

Reagents
1. Fatty acid methyl ester standards.
2. 0.5 NaOH in methanol
3. Boron trifluoride in methanol (14%), Sigma B-1252
4. Saturated NaCl in H2O
5. Hexane (methylene chloride or isoctane can also be used as injection solvent)
Appendix 4: Proximate Analysis Procedures

Sample Preparation

Bacon samples were stored in a freezer (-20°C) prior to analysis. The sample was removed from the plastic bag with tweezers and frozen in liquid nitrogen for approximately 1-2 minutes. The sample was then removed with tweezers and put into a blender cup (250 ml cup for location samples in 1 L cup for composite samples) that had been supercooled in liquid nitrogen. Composite samples were divided into three subsets for ease of powdering. The sample was then powdered in a Waring Commercial Blender (Dynamics Corporation of America, New Hartford, CT) for approximately 1 minute or until the samples was completely homogenized. The powdered sample was then transferred into a clean plastic bag. An additional bag with the identification tag was placed over the sample bag and ultra-low freezer (-80°C) for storage.

Fat (Modified procedure from AOAC, 1990; section 27.006a, p.159)

Powdered samples were removed from the ultra-low freezer and prepared for extraction. Prior to each use, the balance (Mettler-Toledo, Inc., Highstown, NJ) was cleaned and checked for level. After zeroing the balance, a labeled filter paper and a paper clip were weighed. This weigh was entered into the computer. Two grams of powdered sample was then added to the weigh paper with a supercooled spatula. The sample weight was then entered into the computer. After removing the sample from the balance, the filter paper with sample, was folded and secure with the paper clip. Each sample was weighed in duplicate. The samples were then ready for extraction. If the extraction was not performed immediately, samples were stored in the freezer (-80°C).

Extraction Procedure

A thin film of silicone grease was applied to the ground joints of the extraction tube. The boiling flask was filled with anhydrous ether until it was approximately ¾ full. A boiling stone was placed in each flask. The extraction tube was then placed on the flask. The joints were checked for firm attachment by rotating the tube ¼ turn and back
again. Weighed samples were placed in the extraction tube. Each tube held twenty samples. The flask and extraction tube were setup in the extraction room and connected to the condenser. The apparatus was checked for a firm connection. The distillation water was turned on by turning the spigot ¼ of a turn. The temperature on the hot plate was set between 4 ½ and 5, and the solution was allowed to distill for 72 h. All connection were checked daily. After the extraction was complete, the hot plate was turned off and allowed to cool before the flask and extraction setup were moved back into the fume hood (1 ½ h). The water was turned off, and the ether was poured back into the recovery container for reuse or re-distillation. The finished samples were left in the hood for 2 h to vent off any remaining ether. Samples from each distillation setup were kept in a separate pan. The samples were then transferred to the drying oven (105°C) for 24 h before recording weights. This procedure removed fat and moisture from each sample.

Fat percentage was calculated using the following equation:

\[
\text{Fat \%} = \left(\frac{\text{original sample weight} - \text{extracted sample weight}}{\text{sample weight} - \text{moisture}}\right) \times 100
\]

**Moisture and Ash** (Thermogravimetric Analyzer (TGA-601) Leco Corp., St. Joseph, MI)

This method measures the weight loss of the samples as a function of temperature in a controlled environment. The analyzer consists of an electronic chassis for furnace control and data management and a multiple sample furnace, which allows up to 19 samples to be analyzed simultaneously.

After the analysis method was selected, empty crucibles were loaded into the furnace carousel. This method controls the carousel, furnace, and balance operation. Once the crucibles were tare, each crucible was individually presented to the operator for sample loading. The starting sample weight was measured and stored automatically. Once all the crucibles were loaded, the analysis began. The weight loss of each sample was monitored, percent weight loss in each sample for each analysis step was printed at the end of the analysis as the carousel turned and lowered the sample onto the balance. The analyzer contains a menu-driven program, which allowed analysis methods to be
customized. Temperature, temperature ramp rate, and atmosphere could be adjusted and saved in the TGA-601 computer.

Powered samples were removed from the ultra-low freezer. Samples were stored in small styro-foam cooler containing liquid nitrogen to prevent thawing while loading the liquid nitrogen. Sample identification numbers were entered into the computer. The method of operation was then selected (User defined). Setting for Leco:

<table>
<thead>
<tr>
<th>Name</th>
<th>Covers</th>
<th>Ramp Rate</th>
<th>Ramp Time</th>
<th>Start Temp</th>
<th>End Temp</th>
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</thead>
<tbody>
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<td>Moisture</td>
<td>Off</td>
<td>6 d/m</td>
<td>:17 min</td>
<td>25°C</td>
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<tr>
<td>Ash</td>
<td>Off</td>
<td>20 d/m</td>
<td>:30 min</td>
<td>130°C</td>
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<table>
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<tr>
<th>Name</th>
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<td>High</td>
<td>:00 min</td>
<td>0.05%</td>
<td>:09 min</td>
</tr>
<tr>
<td>Ash</td>
<td>O</td>
<td>High</td>
<td>:00 min</td>
<td>0.05%</td>
<td>:09 min</td>
</tr>
</tbody>
</table>

General Setting

- Crucible Density: 3.00
- Cover Density: 3.00
- Sample Density: 1.00

Equations

- Initial Wt. \( W(\text{initial}) \)
- Moisture \( W(\text{initial}) - \frac{W(\text{moisture})}{W(\text{initial})} \times 100 \)
- Ash \( \frac{W(\text{ash})}{W(\text{initial})} \times 100 \)
- Ash Dry Basis \( W(\text{ash}) \times \frac{100}{(100 - W(\text{moisture}))} \)

Select “Analysis” and click on “collect”. Next choose the furnace to be used. Load empty crucibles into select furnace. TGA-601 will weigh all crucibles to obtain a tare weight. After tare is obtained the machine will call to load each sample (1g). Return samples to ultra-low freezer. After all samples are loaded the machine will automatically start. When analysis is finished click the “save” icon on toolbar and print a hard copy of results. Remove crucibles after they have cooled down for 30 minutes. Wash them in
soapy water and allow to dry in drying oven for 4h. Remove dry crucibles and transfer them to desiccator until future use. Before doing another run, machine must cool down to 25°C. Margin of error for fat samples is 1.5% difference between duplicate samples. Margin of error for moisture is 2% difference between duplicate samples. Margin of error for ash is .5% difference between duplicate samples.

Recommendations for Future Research

Further research should be conducted to better understand the effect of freezing and storing frozen bellies. Previous research has suggested that freezing methods as well as freezing rates have different effects over muscle cell structures. Therefore, bellies should be freeze by different methods to obtain different freezing rates, and evaluate the quality of the final product.

Beside the method and rate by which the belly could be freeze, frozen storage times could also play an important role. Research should look at longer storage times. Similar evaluations of the belly performance should be measured over time, as well as changes in the fatty acid composition of the belly during frozen storage.

In the present study, fat samples were collected to evaluate fatty acid composition. The sampling was conducted on one anatomical point of the belly. To obtain a better idea of the fatty acid composition of the whole belly, sampling should be design to include different locations on the belly. Since the results suggested that percentage of saturation of fat appear to have an effect on shattering, it could also be beneficial to obtain fatty acid profiles of the belly by location.

Attention should be directed towards the structure of the connective tissue, to the quantity of the proteins comprising it, as well as to its degree of maturation. Analysis could be conducted to compare collagen content with the level of distortion of the cooked slices.

The present study did not establish a direct relationship between shattering of the bacon slicing and the potential effect on cooked bacon. Further analysis could be conducted to evaluate a possible relation between shattering and distortion scores.
Finally, a successful grading system could serve to efficiently direct carcasses and bellies into an appropriate niche (supermarket, restaurant, further processing, etc). In its simplest form, grading is an attempt to separate a commodity into lots, each lot having a relatively high degree of uniformity in certain traits associated with market preferences and value.