Chapter 13

PRINCIPLES OF MEAT PROCESSING

The Science of Poultry and Meat Processing

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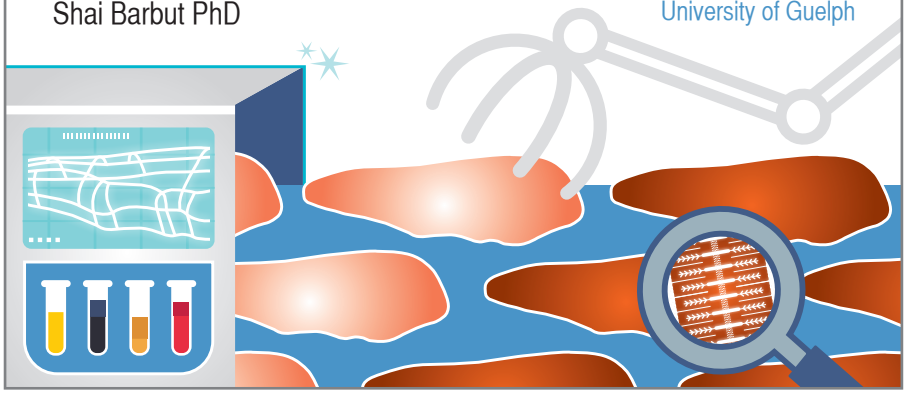

Chapters

* Topics focussing on poultry. Rest of the chapters are related to both red meat and poultry.

Preface

The aim of The Science of Poultry and Meat Processing book is to provide students and industry personnel with a comprehensive view of the modernized primary poultry meat industry and further processing of both red meat and poultry. An emphasis is placed on basic concepts as well as recent advancements such as automation (e.g. increasing poultry line speed from 3,000 to 13,000 birds per hour over the last 40 years) and food safety (e.g. HACCP in primary and the further processing areas). The book also includes chapters explaining basic muscle biology, protein gelation, heat and mass transfer, microbiology, as well as meat colour and texture to help the reader understand the underlying scientific concepts of meat processing. The Science of Poultry and Meat Processing book is based on over two decades of university teaching experiences, and is designed to be used as a course textbook by students, as well as a resource for professionals working in the food industry. The book is available online, at no cost, to any interested learner. Using this format has also allowed me to include many colour pictures, illustrations and graphs to help the reader.

The book is dedicated to my past and current students who have inspired me to learn more and conduct challenging research projects. I see this as an opportunity to give back to the field that I have received so much from as a student and as a faculty member. Looking back, I have learned a great deal from my MSc and PhD advisor, Dr. A. Maurer, who was the student of Dr. R. Baker - the father of poultry processing in North America. I would also like to thank Dr. H. Swatland with whom I worked for almost 20 years, for the many challenging scientific discussions.

Writing The Science of Poultry and Meat Processing book was a long process, which also included having all chapters peer reviewed. I appreciate the help of my colleagues, but I still take responsibility for any inaccuracy in the book. If you have comments or **suggestions,** I would appreciate hearing from you (sbarbut@uoguelph.ca), as I am planning to revise and update a few chapters on a yearly basis.

I would like to thank the many people who have helped me during the writing process. To Deb Drake who entered all of the material for the book, to Mary Anne Smith who assisted in editing, and to ArtWorks Media for the design and desktop publishing of the book. I greatly appreciate the help of my colleagues who reviewed chapters and provided useful discussions. They include Mark B., Ori B., Sarge B., Gregoy B., Joseph C., Mike D., Hans G., Theo H., Melvin H., Myra H., Walter K., Roland K., Anneke L., Massimo M., Johan M., Erik P., Robert R., Uwe T., Rachel T., Jos V., Keith W., and Richard Z. I would also like to thank my family for their love and support during the entire process.

About the Author

Shai Barbut is a professor in the Department of Food Science at the University of Guelph in Ontario, Canada. He received his MSc and PhD at the University of Wisconsin in meat science and food science. He specializes in primary and further processing of poultry and red meat. His research focuses on factors affecting the quality of meat, as well as protein gelation with an emphasis on structure / function relationships, rheological properties and food safety aspects. He has published over two hundred peer reviewed research papers and is the author of the Poultry Products Processing – An Industry Guide textbook. He is a fellow of the Institute of Food Technologists and has received awards from the Meat Science Association, Poultry Science Association, and the Canadian Institute of Food Science and Technology. He is involved in a number of government committees as well as academic and industrial research projects.

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PRINCIPLES OF MEAT PROCESSING

13.1 Introduction

The continuous success of marketing meat depends on the innovation and consistent production of high quality products. Consumers are looking for convenient food products with new/exciting flavours, textures, etc. A simple, inexpensive mix of dry powder containing all essential nutrients can meet our nutritional needs; consumers, however, are looking for diversification and excitement when eating food. As will be discussed in this chapter, the food industry is making and preparing food in different ways and with many ingredients. A simple example of this diversification is the use of white poultry meat in roasts, deep fat fried nuggets, barbequed fillets/wings with honey garlic sauce, or smoked sausages (recipes for all these products are provided at the end of this chapter). Over the past few decades, the meat and poultry industries have been very active in introducing new meat products. Initially, a lot of the products were made from red meat (e.g., salami, pepperoni, ham). However, during the past 30 years the poultry industry has taken the initiative to develop fresh, marinated, as well as fully cooked products, and it has also adopted some red meat recipes. Poultry frankfurters were unheard of 50 years ago; however, after their introduction, they gained widespread popularity and currently represent about a third of the North American market. These new developments have helped to increase consumption and to move away from seasonal meat demands (e.g., in the past, whole turkeys were primarily sold in North America prior to Thanksgiving and Christmas). The industry has also realized that selling large birds, such as whole turkeys, limits its ability to sell meat to all market segments. Therefore, the industry started marketing smaller cuts and further processed products in small packages. Another example that is unique to the poultry industry is the development of the chicken nugget by the fast food industry in the 1970s. This has given the industry a huge boost in sales and has dramatically changed the marketing and processing of chicken meat. This innovation was driven by the industry's need to develop line deboning of poultry as well as find ways to sell the remaining chicken portions (i.e., before nuggets were introduced

the market was mainly set for selling whole birds and some bone-in cut up parts). It also resulted in the introduction of mechanical deboning of the meat left on the frames. All these developments created a market for various innovative further processed meat products (Table 13.1.1; Fig. 13.1.1). Overall, this is an example of the industry successfully responding to consumer demand for more convenient food items including semi and fully prepared items. In this case, the increase in poultry meat consumption (Chapter 2) has been the result of aggressive marketing, the meat's favorable nutrient profile, and its competitive price. As discussed in this book, these developments have been coupled with the introduction of automation, computer assisted programming (e.g., see discussion on Least Cost Formulation below), and increasing line speed.

Table 13.1.1 Categories of the major meat/poultry further processed products on the international market. Note: smoking procedures and cooking recipes for most products are provided at the end of the chapter.

Category	Example	Comment
a. Whole Muscle	Oven roasted turkey breast Smoked chicken/duck/goose fillet	Premium white meat product
b. Restructured	Poultry roll Turkey luncheon roll Cooked duck tenderloins Turkey ham	Large/small meat chunks Pieces of dark thigh meat
c. Ground	Breakfast sausage Pepperoni sticks Salami Chicken hamburger	Sold fresh/frozen to the consumer Fully cooked/frozen ready to eat Semi dried/dried ready to eat
d. Finely Comminuted	Chicken wiener Turkey hot dog Poultry Bologna	Very homogeneous appearance
e. Coated	Nuggets Cordon Bleu Chicken wings BBQ bone in chicken wing/thigh BBQ boneless poultry drum sticks	Battered, breaded and fried Breaded with cheese insert Battered, breaded, par-fried & cooked Marinated and cooked Marinated and cooked

Overall, meat and meat products are mainly composed of protein, water, fat, minerals (salts), and some carbohydrates. Proteins represent the major building blocks of meat products and a major section in this chapter is devoted to protein gelation. Mezzenga and Fischer (2013) indicated that protein aggregation has fundamental relevance not only in the food industry (e.g., providing texture to meat products, gelation of yogurt) but also in the medical field (blood coagulation by

fibrinogen) and others. However, aggregation of food proteins differs substantially from the medical field, where the range of conditions is mostly limited to those found in the human body (e.g., 37ºC, pH – 7.0, ionic strength of about 155mM).

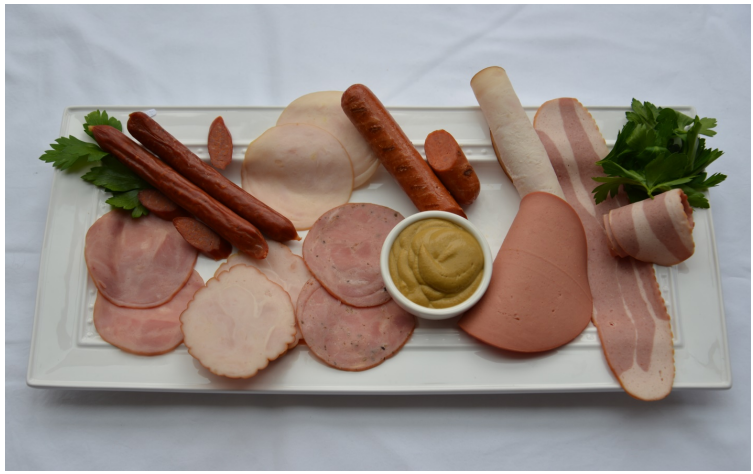


Figure 13.1.1 Examples of different products. Showing chicken roast, turkey roast, turkey pepperoni sticks, poultry wieners, turkey ham and turkey bacon. Photo by Barbut and Jinde.

In the food industry, temperature can range from 0 – 300ºC, pH from 1 – 10, and ionic strength spans as many as seven orders of magnitude. Food systems consist of complex mixtures of various proteins, fats, carbohydrates, and salts. In general, food proteins can be divided into different classes based on the amino acid sequence and thermal history. The protein structure may be referred to as either globular or random coil (folded or unfolded, respectively, Fig. 13.1.2). They will be discussed in more detail later in the chapter.

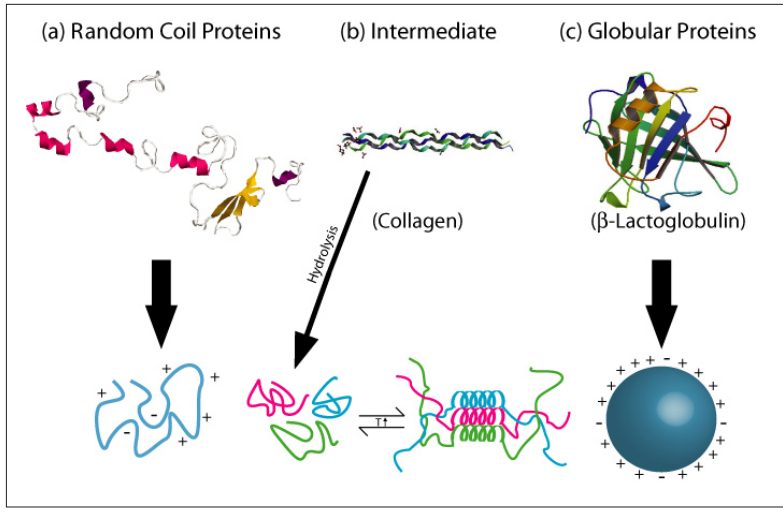


Figure 13.1.2 Schematic representation of the physical description of proteins in soft condensed matter. (a) A hypothetical unfolded protein, interpreted as an ampholytic polyelectrolyte, containing both positive and negative charges. (b) The intermediate case of gelatin, obtained by hydrolysis of the triple-helical collagen: the α-helical structure of gelatin strands can melt by increasing the temperature and reversibly re-constitute upon cooling, with α-helices interacting to induce gelation of the solution. (c) A folded globular protein, such as β-lactoglobulin, viewed as a colloidal sphere with positive and negative charges on its surfaces.
From Mezzenga and Fisher (2013).

13.2 Processing Categories of Meat Products

There is a vast array of meat products available for customers in the supermarket today. Table 13.1.1 shows examples of the main processing categories/groups, but overall there are hundreds of products available on the market, which can be challenging for consumers to understand. To assist them, various systems have been suggested for classifying meat products. For example, one system groups products based on their preparation method (Aberle et al., 2012) and includes six processing categories/groups:

a. Fresh (uncooked) – example: fresh breakfast sausage
b. Uncooked and smoked – example: Italian sausage
c. Smoked and cooked – examples: hot dogs, frankfurters, bologna, mortadella
d. Cooked – examples: liver sausage and pates

e. Dry/semidry or fermented – examples: summer sausage, dry salami
f. Cooked meat specialties – examples: luncheon meats, jellied products and loaves

It should also be mentioned that new technologies have helped to diversify the type of meat products we consume, especially the restructured meat products (e.g., surimi), where small pieces of meat are made into a whole muscle/steak-like product. This can be done by high speed flaking of partially frozen pieces of meat (usually from tougher cuts) that are later recombined under pressure with the addition of hydrocolloid gums (e.g., alginate with a calcium supplement). The surimi technology is based on using minced chicken/fish meat, which is first washed (to remove pigments and enzymes) and later extruded to create a muscle-like fibrous structure and texture.

Section 13.2.1 further discusses the categories of meat products mentioned in Table 13.1.1 and provides an introduction to the unique characteristics of each category. This is followed by an explanation of meat and non-meat ingredients used by the industry (Section 13.3 and 13.4, respectively), protein gel matrix formation (Section 13.5), meat emulsions (Section 13.6), casings (Section 13.7), and recipes for twenty popular, high volume meat products produced by the industry (Section 13.8).

13.2.1 Categories of Meat Products

a. Whole Muscle Products

Some of the largest whole muscle products produced by the industry are a whole ham and a whole oven roasted turkey breast portion (with or without smoke). This is considered a premium product because it is produced from one intact muscle portion. A brine solution (i.e., water, salt, spices, and often gums) is injected into the raw product prior to smoking and cooking. A formula and preparation procedure for this product are provided at the end of the chapter. This specific formulation calls for the addition of 30% brine, but some products on the market are produced with a 50% brine injection, which still results in a high protein level of about 14%. The brine in this case is injected directly into the large diameter product, but in the case of small diameter meat pieces it can be added by tumbling (see Chapter 10). In the case of a whole turkey breast, the meat is massaged or tumbled after brine injection to assist in moisture absorption and help distribute the non-meat ingredients within the muscle. The latter is important in the processing of any meat product as an uneven distribution of ingredients can cause serious flavour, colour and texture problems. Starches and hydrocolloid gums (e.g., carrageenans, see

Section 13.4) are often added to assist in holding the injected brine. Non-meat proteins such as soy concentrate/isolate and whey proteins can also be added for the same purpose (see the recipe at the end of the chapter). The turkey breast muscle can then be placed in a cooking bag or netting (with or without skin) and smoked and cooked in a smokehouse until an internal temperature of at least 71°C is reached.

b. Restructured Products

Poultry rolls can be made from dark meat, white meat, or their combination. The meat portions/trimmings can be obtained from the breast, leg, skin, and mechanically deboned meat (e.g., from poultry, beef, pork). In this product, pieces of muscle tissue ranging in size from 5 – 25 cm are 'glued' together to form a coherent product. This is done with the help of salt, which is used to extract the salt soluble proteins such as actin and myosin (see previous chapters). During mixing, these proteins form a tacky coating on the surfaces of the meat pieces. Later, during cooking they coagulate and the 'glue' is set (similar to the phenomenon seen in a liquid scrambled egg mix turning into an elastic structure during heating). These proteins also contribute to moisture and fat holding within the cooked product, as will be explained later in the chapter. Fat, skin and trimmings are usually finely chopped (the term "emulsified" is often used by the industry, even though no true emulsion is formed) and used to fill the voids between the larger pieces of meat. Moisture is added to compensate for cooking losses and to improve the juiciness of the product. If added moisture exceeds a certain fraction of the raw meat (regulations vary by country), then the product must be labeled accordingly. The meat and non-meat ingredients are then mixed together until the meat batter becomes sticky (an indicator of good protein extraction) and all the added moisture is absorbed. Next, the mix is placed in molds or stuffed into casings and the product is cooked either in water (moisture-proof casings) or an oven (moisture- and smoke-permeable casings), depending on market preference and equipment availability.

Another example of a restructured product is turkey ham, which is manufactured from large pieces of turkey thigh meat. The product is usually lower in fat content than the traditional pork ham and is preferred by some customers. The preparation procedure (see recipe at the end of the chapter) is typical for a product made from medium to large sized meat chunks. In the initial manufacturing step, a brine solution (i.e., water, salt, phosphates, flavourings, and nitrite) is added either by injection and/or by tumbling of the meat chunks. Tumbling is often used when the brine is injected to achieve maximum moisture absorption, distribution of the curing ingredients, and extraction of the salt soluble proteins. The raw meat is then

placed in molds (e.g., 4 × 4" ham molds) or stuffed into large diameter fibrous casings that determine the shape and size of the final product (see Section 13.7). Then the product is smoked and cooked to at least 71°C. If moisture-proof casings or metal molds are used, smoke flavourings can be added to the raw meat batter.

c. Ground Products

Fresh breakfast sausage, pepperoni sticks, cured chicken/turkey/duck sausages, salami and Kolbassa are examples of ground meat products (particle size commonly range from 0.5 to 2.5 cm) that have been stuffed into casings and smoked, cooked, and/or dried. Formulations for five such products are provided at the end of the chapter. These products are usually made from light and dark poultry meat including trimmings, skin, fat, and a small amount of mechanically deboned meat. The meat is first ground and then salt, water, and spices are added. In some products, non-meat proteins (e.g., soy, egg, whey), gums, and/or starches are added to help with water and fat binding. The products can be stuffed into edible casings (e.g., collagen) or non-edible casings (e.g., cellulose or plastic) that must be removed prior to consumption. Fresh sausages need to be cooked by the consumer while products such as pepperoni and salami are fully cooked by the meat processor.

Another unique example of a ground meat product is a poultry/red meat summer sausage, which represents a group of fermented meat products to which a bacterial starter culture has been added. The poultry product is usually made from dark meat, skin, and fat. In the process, lactic acid bacteria are used to lower the pH of the product from about 5.8 to 4.8. This helps to both preserve the product and provide its typical tangy flavour. In the past, microorganisms from previous batches were reintroduced into new batches (this practice is called back-slopping), but today the industry mainly uses starter cultures with a known composition of microorganisms. The industry can select from a variety of cultures that grow at different temperatures and produce distinct flavour notes. During the past 30 years there has been lot of progress in the area of genetic engineering, where desirable characteristics from one bacterial strain are moved to another. Today, the use of a starter culture is highly recommended because it ensures that lactic acid bacteria dominate the fermentation, which both suppresses pathogens (e.g., *E. coli* O157) and produces the desired flavours. The fermentation can be controlled by the quantity of carbohydrate added (i.e., the energy source for the microorganisms) or by continuous pH monitoring and starting a heating cycle when the desired pH is reached. After fermentation, the product is smoked, cooked or dried. If the product is to be sold as a dry product, Canadian government regulations usually require that it be shelf stable with a low pH (around 4.5) and water activity below 0.90.

d. Finely Comminuted Products

Hot dogs, frankfurters, and bologna are examples of emulsified meat products, where the product has been finely chopped and results in a very homogenous appearance. Dark leg meat, trimmings, skin, and/or mechanically deboned meat are commonly used as the starting materials. The meat is then chopped in a bowl chopper or an emulsion mill (see Chapter 10), which efficiently minces the meat particles and emulsifies the fat (i.e., significantly reduces their size and helps coat the small fat globules with proteins; see further explanation below). Salt is used to extract the meat proteins, which are essential in binding the small meat particles and stabilizing the fat globules within the protein matrix (Youssef and Barbut, 2011; Barbut and Findlay, 1989). Nitrite is added to prevent *Clostridium botulinum* growth and provide the typical cured meat colour (Chapters 15 and 16). The meat batter used for small (hot dogs, frankfurters) and large (Bologna) diameter products and is stuffed into cellulose casings, smoked, and cooked in a smokehouse. A newer process is the fully automated co-extrusion casing application, where semi-liquid casing material is extruded onto the meat product as it comes out of the stuffing machine. In this case, an edible casing such as collagen or alginate is applied (see Chapter 10), which does not need to be removed prior to packaging like cellulose casings would. This also helps reduce the potential for cross contamination (e.g., *Listeria*), as product handling by workers is minimized. Since frankfurters are such a popular item, a number of large processors have constructed dedicated lines to continuously make this product (24/7). As with other meat products, low microbial contamination and refrigeration temperatures are essential to the safety and shelf life of these products (some manufacturers guarantee a shelf life of over sixty days).

e. Coated Products

This category includes bone in and boneless products such as poultry drumsticks and wings. The products can be coated with batter and breading (e.g., chicken nuggets) or with a marinade (e.g., honey garlic sauce, BBQ mesquite sauce; see recipes at the end of the chapter) for a few hours prior to cooking to increase juiciness and yield of the fresh meat. The addition of moisture, salt, and spices helps to compensate for evaporation losses during cooking and enhances the flavour and texture of the meat. Coating systems, which include battering and breading, are described in Chapter 14. Chicken nuggets, first introduced in the 1970s, are one of the most successful poultry products. The product was originally prepared from a single piece of slightly marinated breast meat that was battered and breaded. Later, nuggets made from trimmings (including white meat, dark meat, skin, mechanically deboned meat and their combinations) appeared on the

market. These nuggets are usually prepared by marinating and mixing the meat pieces with a brine solution. The meat is then formed into the desired shape, battered, breaded and deep fat fried. Frying preserves the product shape, 'cements' the batter and breading to the product, and provides the typical crunchy texture.

13.3 Meat Ingredients and Least Cost Formulation

A variety of meats can be used for further processing. As has already been mentioned, these meats can come from different cuts (e.g., breast, thigh, belly meat) and states (e.g., fresh, frozen), with or without skin. Formulation of a meat product requires some basic calculations. Most medium and large sized meat companies use a computer program to formulate their products. Two of the main reasons for this are the complexity and time needed to optimize the use of incoming raw materials (i.e., costs are changing on a daily basis) and to formulate products with tight specifications (e.g., protein level, fat content, colour, bind value). In the past, processors commonly used simple formulations with only a few raw meat ingredients. For such recipes the so-called "sausage square" calculation (simple matrix calculation that includes 2-3 meat sources) was sufficient. However, the diversity of raw materials and price fluctuations in the international markets require calculating and optimizing formulations for several products concurrently. In the late 1950s, development of linear programming for sausage manufacturing began. The original term, least cost formulation (LCF), might mislead people who are not familiar with the process into thinking that the goal is to formulate the least expensive product. Instead, the programs are designed to select the lowest cost meat ingredients after all the requirements (protein level, fat content, colour, bind value) have been met. Pearson and Tauber's (1984) description of the advantages of such programs is still true today. The programs:

a. provide the most economical combination of ingredients for a specific product within the limitations placed on each ingredient in the formula
b. permit complicated calculations that would not otherwise be possible
c. save time compared to the more laborious traditional calculation (pencil or a calculator), which can then be devoted to other production problems
d. permit adjustment of formulas on the basis of analysis, using values obtained from pre-blending or other sources
e. maximize the use of available ingredients
f. help reduce inventory
g. supply accurate procurement information
h. allow making real-time management decisions on production, pricing, and labour utilization policies

Today there is a great emphasis on flexibility and traceability, where all data can be kept on file electronically for a program such as HACCP (see Chapters 6 and 12). This is obviously another example of employing automation in the meat industry to help streamline processes, reduce labour costs, and save money. Overall, it should be recognized that computer programming of LCF requires more basic information on ingredient composition (e.g., chemical composition, bind value, water and fat holding capacity values), as well as skilled personnel to operate computers and laboratory equipment. Meat technologists working in the industry need to understand foundational scientific principles such as emulsion stabilization and the functional properties of raw materials. This has become far more important as the number of non-meat ingredients has increased (e.g., dozens of different modified starches are now available on the market). It is important to characterize the ingredients and establish 'constants' that can be used to optimize the quality of the finished product. Two important examples are the bind value and the emulsification capacity value that had to be initially established for running the LCF programs.

Dr. Robert Saffle is generally credited with introducing the concept of meat constants in the early 1960s (LaBudde and Lanier, 1995). The constants were developed based on the meat emulsion stability test and were needed to develop sausage LCF programs. Linear programming requires numerical values that describe each meat's specific properties in order to develop the best combination of raw materials from the few dozen meat cuts/trims available each day to a typical processor. The program's goal is to calculate the best combination of ingredients after satisfying requirements set by the operator. As mentioned previously, the requirements can include protein, fat, and moisture content (Pearson and Tauber, 1984), as well as colour and meat bind values. It is important to note that when Saffle developed his 'constant' emulsification value, at least one major North American company had already developed its own criteria for evaluating meat. Saffle's constant emulsification values were generally based on multiplying the percent salt soluble proteins in a certain cut of meat by the emulsifying capacity results. Today, various medium and large companies continue to use Saffle's values in one form or another, whereas some large meat companies have developed their own proprietary criteria for rating meats and use these values in their in-house developed LCF programs.

13.4 Non-Meat Ingredients

The meat industry also uses various non-meat ingredients in order to:

a. help extract salt soluble proteins
b. provide flavour notes and enhance acceptability
c. help bind moisture through proteins (e.g., soy, dairy) and carbohydrates (e.g., starch, carrageenan)
d. enhance juiciness
e. enhance freeze thaw stability through modified starches
f. improve/modify texture (e.g., gelling of soy proteins, alginate)
g. provide colour (e.g., paprika)
h. lower formulation cost
i. add bulk
j. improve sliceability (e.g., forming a carrageenan gel)
k. extend shelf life (e.g., lactic acid, spice extracts)

To simplify the discussion, non-meat ingredients can be divided into several major groups including water, salts, spices, binders, and fillers.

Limits are imposed on the addition of several non-meat ingredients. The maximum amounts permitted can be found in local regulations/meat inspection guides. An example of a restricted ingredient is nitrite, which is added to prevent the growth of deadly *C. botulinum*. At high levels, however, nitrite can present a health hazard and therefore the level is tightly controlled (e.g., 120-200 ppm in USA and Canada). Other functional ingredients, such as soy protein, are also commonly regulated. For example, up to 3.5% soy can be added, alone or in combination with other binders, to a variety of cooked sausages produced in the USA, However, if this limit is exceeded, the product name must include the words "soy added" or "imitation" to inform the consumer. In most countries, all the ingredients added to a food/meat product must be listed on the label. Below is an example of an ingredient list of a Canadian product showing the additives in a descending order by weight:

> Product name: Chicken Frankfurters. Ingredients: mechanically deboned chicken, chicken, water, wheat flour, salt, modified corn starch, spice, dextrose, sodium erythorbate, sodium nitrite, smoke.

The names and functions of most common non-meat additives used by the meat industry are discussed below:

a. Water – commonly used to compensate for evaporation losses during cooking, increase juiciness, and reduced fat content in products. The latter reflects the trend of combining water with ingredients such as hydrocolloid gums and starch. The amount of added water is regulated in many countries. If the moisture added exceeds a certain level in the finished product (i.e., after cooking and taking into account evaporation loss), it should be mentioned in the product's name (e.g., Chicken Roll with Natural Juices/Added Water). Overall, water is the main component in fresh and processed meats, ranging from 40-80%. Most of the moisture originates from the lean meat portion (e.g., skinless poultry breast meat has 75% moisture, see Chapter 3). Industry and consumers add moisture to products (see recipes at the end of the chapter) because they would have a dry mouth feel if only the original moisture was present. An example is a chicken fillet cooked at home or in an industrial oven. Initially, the raw meat has about 22% protein but it ends up with about 25% protein after cooking and taking into account evaporation loss. This product will be fairly tough and unacceptable to the majority of consumers. Added moisture increases product acceptability by compensating for moisture lost during the heating process. Added moisture also serves as a carrier for spices and other non-meat ingredients and ensures their adequate distribution. In finely comminuted meat products (Table 13.1.1), ice is added during chopping to maintain a sufficiently low temperature so that heat arising from the high friction during cutting will not cause an emulsion breakdown. Additional discussion on this topic is provided below in Section 13.6.

The microbiological and chemical quality of the water is an extremely important issue. From a microbiological standpoint, water should meet the drinking quality standards (e.g., municipal, national standards) at the very least and should be checked on a regular basis (see Chapter 6). From a chemical standpoint, water contaminated with compounds such as nitrate will cause undesirable pinking of products such as oven roasted chicken breast. Nitrite contamination (1-5 ppm) can be common in agricultural areas where the water source is located near fields that are fertilized with nitrates. This is especially of concern after heavy rain (see additional discussion in Chapter 16). Another consideration is the presence of high salt levels. Water with calcium and magnesium salts, also referred to as hard water, can destabilize emulsion-type meat products as well as cause problems within a plant's piping system.

b. Salt – various salts can be added to meat products. The most common salt is table salt (sodium chloride), which is used as a flavouring agent, protein solubilization agent, and anti-microbial agent. Phosphates are another group of salts used to help with meat protein extraction and solubilization (e.g., sodium tri-polyphosphate is used to help extract myosin and actin). Other salts include sodium nitrite (for preservation) and curing accelerators such as sodium erythorbate and sodium ascorbate.

b1. Sodium chloride (NaCl) is the most common ingredient added to meat products because of its three major contributions:

1. Sodium chloride provides a distinct salty flavour, which makes a substantial contribution when added to processed food. The classic salty taste is represented by NaCl and lithium chloride (LiCl), whereas other salts usually have additional flavours associated with them that can include a mixture of sweet, bitter, sour, and salty. Chemically, it appears that cations cause salty tastes, whereas anions inhibit salty tastes (Sebranek and Bacus, 2007).

   Among the anions, Cl^- is the least inhibitory to the salty taste and does not possess a taste of its own. Some anions can not only inhibit the taste of their associated cations, but also contribute tastes of their own. An example is the soapy taste associated with certain phosphates, which results from the specific taste elicited by their anion.

   In general, the most accepted model for describing the mechanism for salty taste perception involves the interaction of hydrated cation-anion complexes with the Shallenberger and Acree AH/B-type receptor site. The individual structures of such complexes vary substantially. In the presence of water, OH groups and salt anions/cations are associated with specific receptor sites. Bitterness in salts involves a different receptor mechanism that seems to be related to the sum of the ionic diameters of the anion and cation components of the salt. Salts with ionic diameters below 6.5 Å are salty in taste (LiCl = 4.98 Å, NaCl = 5.56 Å, KCl = 6.28 Å), although some individuals find KCl somewhat bitter. As the ionic diameter increases (CsCl = 6.96 Å, CsI = 7.74 Å, $MgCl_2$ = 8.50 Å), salts become increasingly bitter.

   In any case, a processor should always try to use the highest quality salt possible. High quality refers to low levels of impurities (e.g., heavy metals such as copper, iron). These trace contaminants are known as pro-oxidants and can trigger fast lipid oxidation during storage, as will be discussed later in the chapter when antioxidants are introduced.

2. Sodium chloride is involved in the protein extraction of the salt soluble fraction (mainly myosin and actin; see also Chapter 3), which is very important in the production of processed meat products as these proteins can bind meat pieces/chunks when heated. Overall, extracting the proteins and bringing them to the surface provides sticky surfaces on the

raw muscle cuts. These proteins also help bind moisture (i.e., increasing the water holding capacity, WHC), assist in emulsifying fat particles in comminuted products (by coating the fat globules), and increasing the raw meat batter viscosity. Later, these extracted proteins coagulate and bind both the meat particles (important for holding the product together) and moisture (important to minimize cooking losses) to form a coherent matrix that is important for texture as well as fat retention during heat processing.

Salt reduction (mainly sodium) in food/meat products was a hot topic in the 1980s and is again today, as more individuals are suffering from hypertension (high blood pressure). Besides the organoleptic effects, an important consideration in replacing NaCl with other chloride salts is the effect on the physical properties of the final product. Sodium chloride reduction by itself will result in lower binding and lower WHC of the proteins. Upon heating, this will result in a softer, drier product with higher cooking losses. If cooking losses are too high the product will be unacceptable to the consumer. The relationship between salt concentration and WHC has been well established and depends on factors such as the amount and type of protein present, pH, and previous storage history. In post-rigor lean poultry meat, an increase in salt results in a concomitant decrease in product shrinkage up to a maximum at around 5% salt (Fig. 13.4.1). Further salt addition will result in a decreased WHC, a phenomenon known as "salting out". This is the result of increasing charges on the protein molecules, which causes them to precipitate.

3. Sodium chloride suppresses microbial growth, as many microorganisms are sensitive to high salt levels. High salt concentration can stop or substantially slow the growth of microorganisms. In the past, high salt levels (10 to 20%) were used as the main means of preservation because these levels can provide shelf-stable meat products. This technique is still used in places where refrigeration is a challenge and/or where the traditional heavily salted products are preferred (i.e., the very high salt content has to be washed out before consumption). However in many markets today, substantially lower salt levels are used (e.g., 1.0 to 2.5%), and it is only in conjunction with other additives (e.g., nitrite, lactic acid) and appropriate refrigerated storage that product safety can be ensured (Barbut and Findlay, 1989; Sebranek and Bacus, 2007).

b2. Sodium Nitrite ($NaNO_2$) and Sodium Nitrate ($NaNO_3$) – also known as curing salts, are added at very low levels (usually 120-200 ppm in the USA) and have four main functions.

1. Prevent *Clostridium botulinum* spore germination. The active compound is nitric oxide (NO) and it inactivates *C. botulinum* spores. Only a very small amount is needed and using the salt form provides an easy and efficient way of introducing the active compound to the meat. It can also be introduced in gas form in a lab setting.

2. Contribute to the development of the typical pink cured meat colour. Again, the active compound is NO. This pink colour is very different from the brown colour of a cooked product such as chicken leg meat, turkey thigh, pork chop, or pork loin. This can be described as the difference between a home-cooked pork chop and a cured pork ham (see additional discussion in Chapter 16). The chemical reaction involved is:

   $$\text{Myoglobin} + \text{NO} \rightarrow \text{Nitrosomyoglobin} \rightarrow \text{Heat} \rightarrow \text{Nitrosohemochrome}$$

   The nitrosohemochrome produces the typical pink pigment found in cured meat products.

3. Protect against lipid oxidation. Nitrite has antioxidant capabilities that can help prolong the shelf life of meat products.

4. Adds some flavour. Nitrite addition results in the development of certain unique flavour notes.

   Overall, the chemical reaction of sodium nitrite (potassium nitrite is also used sometimes by the industry) added to a meat system is shown below. Sodium nitrite is broken down into its components:

   $$NaNO_2 \rightarrow HONO + Na + H_2O$$
   $$3HONO \rightarrow HNO_3 + 2NO + H_2O$$

   The amount of nitrite permitted in meat products is heavily regulated because at high levels it can be toxic. It is very important to note that processed meat products are not necessarily a high source of nitrite in our diet. In comparison, green vegetables such as celery have levels of about 300 ppm nitrate. In addition, bacteria in human saliva and in the gut are capable of producing even higher levels of nitrite. Nitrite added

to meat products is depleted over time, especially during cooking, and a frankfurter with an initial 150 ppm $NaNO_2$ level will end up with about 20-40 ppm or less at the point of purchase. Overall, it is estimated that meat products contribute only 10-20% of the total nitrite in our diet (Sindelar and Milkowski, 2012). There is also a concern in products heated to high temperatures (e.g., bacon) that residual nitrite could react with secondary amines to form nitrosamine compounds, which are potential carcinogens. Therefore, in North America for example, the use of an added curing accelerator (e.g., 500 ppm ascorbate) has been mandated in such products to ensure a fast conversion of nitrite to nitric oxide. This minimizes the chance of nitrosamine formation when the product is exposed to high temperatures (frying at > 100°C). The use of nitrite in processed meat products and its safety has been reviewed by Cassens (1990) and by Sindelar and Milkowski (2012).

b3. Phosphates – salts of phosphoric acid can work together with sodium chloride to enhance muscle protein extraction, which in turn improves the water holding capacity and reduces shrinkage during cooking (Fig. 13.4.1). There are different types of phosphates available on the market. Examples of common polyphosphates and orthophosphates in meat products are shown in Figure 13.4.2. Alkaline polyphosphates such as tripolyphosphate (TPP) are the most popular and by some estimates account for about 80% of the phosphates used by the meat industry. Phosphate use is limited to 0.5% in the finished product in countries such as the USA. This limit is mainly imposed to restrict water addition but greater levels can also result in off flavour problems such as metallic or soapy as reported by consumers. In countries such as Germany, the use of phosphate is not permitted in several products.

The effects of using 0.5% TPP, pyrophosphate, and a commercial blend called KENA (which contains over 50% TPP) are shown in Figure 13.4.1. A synergistic effect is clearly seen when TPP is used with 2-5% salt; i.e, the combined effect of NaCl and TPP is much greater than the simple additive effect of NaCl and TPP. The "salting out" effect, previously discussed, is clearly seen at a salt level above 5%. Pyrophosphate and NaCl show an even greater synergistic effect compared to TPP (Fig. 13.4.1) but pyrophosphates are not commonly used due to their effect on pH and other factors. Hexametaphosphate, for example, results in higher shrinkage during cooking. This raises the point that processors should know exactly what kind of phosphate(s) or blend they are using but this is information that some ingredient companies are not eager to share. However, with the new Material Safety Data Sheet (MSDS) requirements, this information is becoming easier to access by the meat processor.

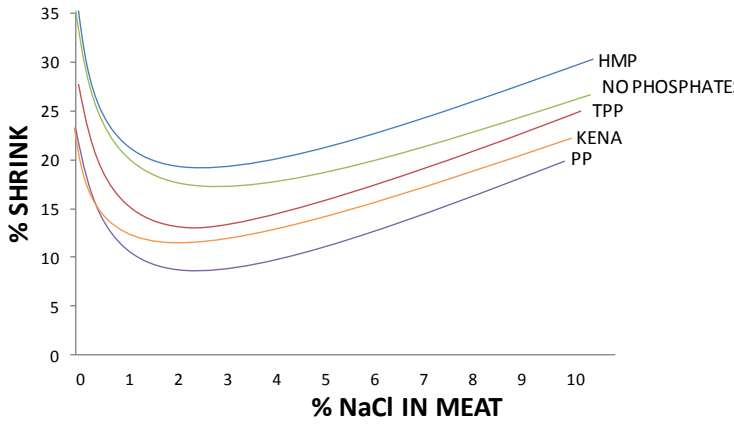


Figure 13.4.1 Effect of NaCl on the shrinking of cooked chicken muscle (70°C) in the presence of salt and different polyphosphates (0.5%). HMP – hexa meta phosphate; TPP – tri poly phosphate; KENA – commercial phosphate blend; PP pyro phosphate (sodium acid). Redrawn from Shults and Wierbicki (1973).

Most phosphates used by the meat industry help enhance the physical and sensory properties of meat products by:

a. Helping extract the salt soluble proteins, hence increasing water holding capacity and meat particle binding.
b. Shifting the pH away from the isoelectric point of the muscle's proteins, hence allowing more charges on the amino acid side chains. This can result in increased repulsion between the proteins, which creates more space for water molecules and more sites for water molecule binding.
c. Assisting in stabilizing meat emulsions due to the hydrophilic/ hydrophobic structure of the molecule
d. Slowing down oxidation due to the chelating effect of phosphate.

Certain phosphates can bind iron and other metals and prevent them from serving as pro-oxidants. This helps extend the shelf life of the meat product in terms of flavour but also protect it from meat pigment oxidation (colour problems).

In general, phosphates act in a food/meat system as polyanions that increase ionic strength, control pH by buffering, and sequester meat ions. Some researchers claim that the increase in water holding is due to an unspecific ionic-strength effect. As indicated above, increasing the net negative charges will result in repulsion of the protein groups, which creates more space for water molecules within the muscle.

However, the effect of a molecule such as pyrophosphate on WHC appears to be greater than would be expected due to its ionic strength alone. Therefore, several researchers have implied a "specific" pyrophosphate effect, where pyrophosphate was reported to dissociate actomyosin into actin and myosin (i.e., pyrophosphate is capable of degrading the actomyosin complex).

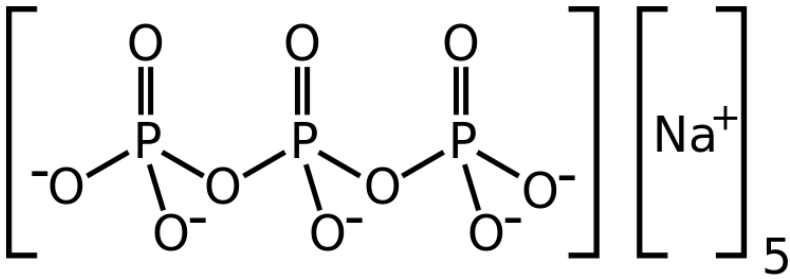


Figure 13.4.2 The chemical structure of sodium tri polyphospate (STPP) commonly used in meat processing (solubility 14.5 g in 100 ml at 25 C; pH of 1% solution is 8.0). From Wikipedia. More detailed information from Material Safety Data Sheet can be found at: http://www.sciencelab.com/msds.php?msdsId=9927608.

b4. Sodium Ascorbate and Sodium Erythorbate – also known as curing accelerators, they are added to increase the rate at which nitrite is reduced to nitric oxide in an aqueous solution. In a meat system, some of the muscle's enzymes help reduce the nitrite. However, in order to speed up the conversion to nitric oxide, curing accelerators that promote reducing conditions are added. Note that they also accelerate the reduction of metmyoglobin to myoglobin. This is especially important in continuous sausage production lines, where the processor's objective is to start cooking the product within an hour of blending and adding the non-meat ingredients. In other cases, such as the manufacture of dry sausages, a slow nitric oxide release is preferred and curing accelerators are not needed. In these cases, processors are actually using sodium nitrate, which takes even longer to breakdown to nitric oxide than sodium nitrite, so they get a prolonged release of nitric oxide.

Sodium ascorbate and sodium erythorbate (or their corresponding acids ascorbic acid and erythorbic acid) are used at low concentrations of about 550 ppm. For products that will be exposed to high temperature cooking (e.g., turkey/pork bacon), a number of countries require that a curing accelerator be added as high temperatures can increase nitrosoamine formation (see previous discussion on nitrite).

c. Spices – used to flavour and colour foods (e.g., paprika) as well as to add some antimicrobial/antioxidant (e.g., rosemary) properties. In several cases they are also used to enhance appearance (e.g., peppercorns on barbequed meat). Various countries restrict the use of artificial food colouring in processed meat products, hence the utility of spices for this purpose.

Examples of spices derived from different plant materials are listed below.

a. seeds – nutmeg (*Myristica fragrans*), mustard (*Brassica nigra*)
b. leaves – sage (*Salvia officinalis*), thyme (*Thymus vulgaris*)
c. bulbs – garlic (*Allium sativum*), onion (*Allium capa*)
d. fruit – pepper (*Piper nigrum*), paprika (*Capsicum annuum*)
e. flowers – clove (*Eugenia caryophyllata*)
f. bark – cinnamon (*Cinnamomum zeylanicum*)
g. roots – ginger (*Zingiber officinale*)

Spices can be added in different forms depending on the product, desired appearance, expected shelf life, etc. In most commercial applications they are added dried or after a heat treatment because they are then easier to handle (e.g., elongated shelf life, inactivated enzymes that can produce off flavours/colours in the meat) and easier to standardize (e.g., strength/heat of pepper). Overall, spices can be added before or after being dried (e.g., onion), whole or ground (e.g., black pepper, mustard seeds), or as extracts (e.g., rosemary oleoresin). The decision as to what form used is based on the meat product type and desired appearance. In coarse ground products such as kielbasa (see recipe at the end of the chapter), whole mustard seeds can be added so the cross section of the product has a nice appearance. However, in a finely comminuted frankfurter whole mustard seeds would not be as attractive.

Spices commonly carry a high number of microorganisms. Therefore, they should be thoroughly cleaned and pasteurized or sterilized. Heat treatment is an option, but is typically not the best approach because it releases many of the volatile flavour/aroma compounds. Therefore, non-heat processes such as ionizing irradiation and chemical pasteurization (e.g., ethylene oxide) are commonly used. Both are considered cold processes that do not volatilize the flavour/aroma compounds. Ionizing radiation is used quite extensively and usually irradiated spices do not have to be identified as irradiated in the meat product ingredient statement, because of the low level of addition. If the whole product is irradiated, however, certain countries require that the international logo for irradiated food appear on the label (see Chapter 11). Chemical sterilization possesses are also commonly used but some consumer groups are concerned with the potential risk of residues.

Large volumes of spice extracts, which contain essential oils and oleoresins extracted from plant material, are sold to the meat industry. The oils can be obtained by pressing, distilling, or solvent extraction, and they are usually concentrated to obtain a more potent solution. The oils will be free of microorganisms if a high distillation temperature or a strong solvent is used. Overall, the advantages of using oil extracts include reduced transportation costs, long shelf life, and they do not change the appearance of the product. In finely comminuted products such as hot dogs and bologna, which have a very homogeneous appearance, this latter point is very important (e.g., adding visible ground black pepper particles would not be acceptable to the consumer). The extracts are usually highly concentrated and are commonly sprayed on to a carrier such as salt or sugar (dextrose) in order to assure an even distribution within the product.

Standardizing the flavour strength is an important consideration when using natural spices or extracts. Spice companies purchase materials from around the world and factors such as growing conditions, climate, and plant variety can result in large variations in taste. To overcome this, spice companies employ trained personnel to standardize flavour profiles and obtain defined strengths (e.g., determine the Scoville Heat Unit for red pepper). This is extremely important to meat processors who want to create a consistent product. When standardizing the flavour of a spice, a technician prepares serial dilutions of the extract and presents them to a trained panel to identify the lowest concentration the panel can detect. This lower threshold can be used to standardize the flavour. Additional sophisticated equipment such as a gas chromatograph can also be used to determine the concentrations of key flavour compounds that contribute to the overall flavour of a spice. In the case of colour standardization of a spice such as paprika, the red colour intensity can be described by the scale developed by the American Spice Trade Association (i.e., measuring absorbance of a sample diluted in acetone at 460nm).

d. Flavour Enhancers – are compounds that act synergistically with meat flavour compounds to enhance the meaty flavour. A few of the most commonly used ones are 5'-ribonucleotides, hydrolyzed yeast proteins, and monosodium glutamate (MSG). When used at levels in excess of their independent detection threshold these compounds contribute to what is called the delicious or umami taste of foods. When used at levels below the independent detection threshold they simply enhance flavours. It is important to recognize that a very small percentage of the population is sensitive to ingredients such as MSG (i.e., they suffer from headaches and nausea when eating MSG). Therefore, MSG should be clearly marked on the package or at a restaurant buffet.

e. Sweeteners and Browning Agents – ingredients commonly used in low amounts to add a sweet flavour, mask saltiness, enhance browning (i.e., the Maillard reaction between proteins and carbohydrates), and provide a substrate for fermentation (e.g., in salami where they are added as an energy source for lactic acid bacteria).

Overall, natural and synthetic sugars vary in their sweetness. The standard for the measurement is sucrose (a disaccharide composed of glucose and fructose that comprises cane sugar), which is assigned a sweetness value of 100. On that scale, dextrose (a monosaccharide of glucose) has a value of 74, fructose has a value of 175, maltose (disaccharide of two glucose monomers) has a value of 40, lactose (or milk sugar) has a value of 16, regular corn syrup solid has a value of 37 (therefore it can also be used as a partial bulking agent; see discussion below), aspartame has a value of 180, and sucralose has a value of 600. There is a wide selection of sugars to choose from and most commonly the meat industry uses natural sugars at about 1 – 3 %. The reason for adding the sugar often determines the type used. Reducing sugars contribute to the Maillard browning reaction when they combine with secondary amines to form a brown pigment during heating. Adding a reducing sugar such as dextrose, fructose, or maltose to a meat product will enhance surface browning. This is important in smoked sausages where a golden/brown colour is desirable (see recipe for smoked flavour turkey sausage at the end of the chapter). Reducing sugars can be also added to fried products where adequate golden/brown colour development during heating prevents overcooking/ burning the sausage.

f. Antioxidants – important compounds used to suppress lipid oxidation. This is a critical issue in meat and meat products as animal fat is prone to lipid oxidation due to its fatty acid profile (including unsaturated fat; see also Chapter 7), there is disruption of cells during processing (e.g., cutting, chopping of meat), and enzymes are released during processing, heat treatments, and prolonged storage. In living tissues there are various natural antioxidants (e.g., tocopherol/vitamin E), however they are not always sufficient to protect the meat/meat products after processing. The process of oxidation is driven by free radical formation and, once started, it accelerates exponentially as one free radical forms two, two then form four, etc. The food industry uses three types of antioxidants:

a. free radical terminators,
b. oxygen scavengers, and
c. chelating agents capable of tying up metal ions.

Because governments have certain restrictions on using synthetic antioxidants and some are not permitted, natural antioxidants such as rosemary oleoresin are an attractive option and are also label-friendly. In this case, they are only listed by the spice name. Products such as a low-flavour rosemary oleoresin are also available, where most of the flavour compounds have been removed so that the amount of the oleoresin added to the product can be increased. Citric acid is another example of a molecule that is an oxygen scavenger (i.e., can tie up free oxygen).

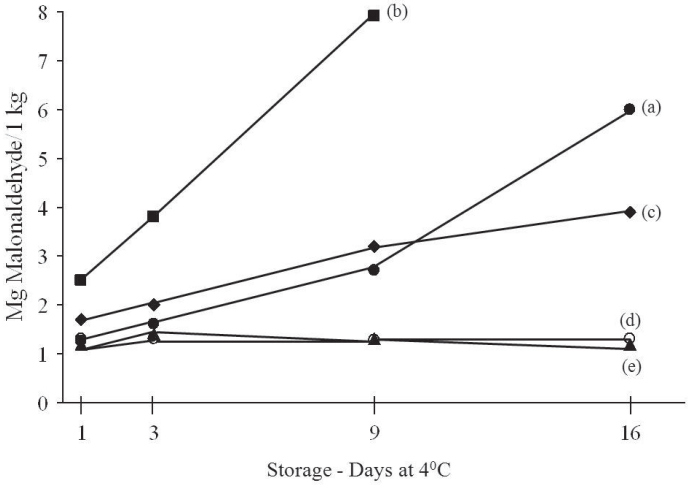


Figure 13.4.3 Oxidation byproduct values of raw turkey sausage. Legends: a) no additives (●); b) 1.7% salt (■); c) spice only (♦); d) spice + rosemary (O); e) spice + BHA/BHT (▲). Adapted from Barbut et al. (1985).

The industry also uses synthetic antioxidants such as butylated hydroxy toluene (BHT), butylated hydroxy anisole (BHA), and propyl gallate (PG). These compounds are free radical terminators, as they have a cyclic carbon ring structure that is capable of accepting a free radical molecule. These three compounds are fat soluble and their usage level (where permitted) is commonly limited to 200 ppm of the fat content. Figure 13.4.3 shows the beneficial effects of using a BHA/BHT mixture (200 ppm) and natural rosemary oleoresin on delaying lipid oxidation in a turkey sausage produced with 25% mechanically deboned meat, which is highly susceptible to oxidation (see Chapter 9). Both the mixture and the rosemary oleoresin were very effective in suppressing oxidation in the stored product. The

spice mix used in isolation also resulted in some antioxidant activity as compared to the meat control treatment. Figure 13.4.3 also illustrates the effect of salt, which can accelerate lipid oxidation due to a small amount of heavy metal (e.g., iron) contamination. The data is reported as the amount of malonaldehyde (i.e. an oxidation byproducts from the breakdown product of oxidized fatty acids), which is commonly used in the literature to follow lipid oxidation. The publication also lists the amounts of other byproducts (e.g., hexanal, heptanal, penanol; measured by gas chromatography) that contribute to off odours that can be detected by a sensory panel.

g. Starter Culture – bacteria capable of producing lactic acid are added to fermented sausages, such as pepperoni and summer sausage. *Lactobacillus plantarum* and *Pediococcus acidilactici* are used to ferment the added sugars and produce lactic acid, which decreases the pH of the product. This helps to make the product shelf-stable and provides unique flavours and textures. Processors should add a simple sugar source (e.g., mono, disaccharide) to prevent bacterial utilizing of fat and proteins which will result in the formation of oxidized compounds and putrefied odours. In the past, processors relied on the naturally occurring lactic acid bacteria or an innoculum from a previous batch of products for the fermentation. Today, however, many use a standardized, controlled starter culture produced by specialized companies. When using starter cultures the inoculation level is 10^7 bacteria per gram meat of the "good lactic acid bacteria" so it dominates the fermentation. Concerns with *E. coli* O157:H7 have also driven the industry to use starter cultures to assure fast and efficient fermentation.

h. Mold inhibitors – are used to inhibit growth on the surface of dry and semi-dry sausages that are not vacuum packed (molds are aerobic). This can be a problem as these products have a water activity that supports mold (but not bacterial) growth. Mold inhibitors are applied by dipping or spraying the outside casings. Common chemical inhibitors include potassium sorbate and sorbic acid. These compounds are permitted for use in some countries (e.g., USA), but not others (e.g, Canada). In countries where these compounds are not permitted processors can use a cold smoke treatment that contains natural antimicrobial compounds (see discussion below) that help prevent mold growth.

i. Binders – are ingredients used to help bind meat particles and increase water holding capacity (see also Section 13.5). These ingredients usually consist of proteins that can form a gel system or participate in meat protein gelation. It is obviously advantageous if they act synergistically with the meat proteins (see Fig 13.5.1, Aguilera and Kessler, 1989). These ingredients can be expensive so when processors consider using them they should look for added values such as:

a. texture enhancement
b. water holding; i.e., reducing shrinkage during processing
c. improved product's formulation
d. emulsification capabilities
e. reduction of formulation cost

The meat industry commonly uses dairy binders (e.g., milk powders and their derivatives), vegetable proteins (soy, pea), and meat proteins (collagen, blood plasma).

Examples of dairy binders:

a. Whey proteins – a by-product of cheese manufacturing, and very effective in meat products. After gentle drying (i.e., to prevent protein denaturation) they are sold as a powder with about 70% protein (marketed as whey protein concentrates) and with about 90% protein (marketed as isolates).
b. Caseinate – sold after drying as a highly functional ingredient that has 80-90% protein content. One of its main uses is in emulsified products.
c. Non-fat dry milk – contains about 35% protein (80% is casein) and about 50% lactose.
d. Calcium reduced non-fat dry milk – used for finely chopped/emulsified products where high levels of calcium can be detrimental to emulsion stability.

Examples of vegetable protein binders:

Soy proteins – commonly used as binders in products such as meat patties, meat loaves, and sausages. In a number of countries their presence is limited to $\leq 2\%$ soy protein isolate or else the product name should include the word "soy". Other vegetable proteins such as pea are also used but to a lesser extent. The vegetable proteins are also marketed under certain categories:

a. Soy/pea protein flour (fine particles with 40-60% protein)
b. Soy/pea grits – coarse particles with 40-60% protein
c. Soy/pea protein concentrates – with 70% protein and bland flavour
d. Soy/pea protein isolate – with 90% protein, bland flavour, and high water/fat binding capacity
e. Textured soy/vegetable protein – cooked and extruded particles sized to order, with or without flavour and/or colour added

It should be noted that vegetable protein flours and grits usually have a distinct flavour (beany) if used at a high concentration. Much work has been done over the past decade to minimize this problem and today the standards for low beany off flavours are much higher.

j. Fillers – are non-meat ingredients, usually made with complex sugars (e.g., starch) and low protein, that help bind water but not meat particles and are usually considered to be good as bulking agents.

Fillers can be divided based on their cereal source (wheat, corn, starch) and are added to the meat product either as flours or extruded/texturized particles. When starch is heated past its gelatinization temperature in the presence of water it opens up to bind water (e.g., can be 1:2 up to 1:10 ratio). At high temperatures the solution becomes more viscous and when temperature is lowered (e.g., cooling food/meat products after heating) the texture will become even more viscous. The meat industry also uses pre-gelatinized starches where the starch manufacturer has heated the product (in a solution) and then dried it. This creates a product that is capable of binding water at lower temperatures, which is advantageous for the meat industry because as meat proteins are heated (and denatured) they bind less water. Please note that another popular application of flour and starches is in coated products (see Chapter 14).

k. Hydrocolloid gums – are unique compounds that are capable of forming a high water gel matrix at low concentrations (e.g., at 1% carrageenan forms a very firm gel after heating, which nicely binds the rest of the 99% water). Such gums are added to meat products at relatively low concentrations to bind added brine/water (see Turkey Pastrami recipe at the end of the chapter). In this case the firm gel (upon cooling) also helps enhance the texture. Many gums are obtained from seaweed, some are extracted from seeds, and others are the result of microbial fermentation. Below are a few examples of common hydrocolloid gums:

a. Alginate – is extracted from brown algae (*Phaeophyta*) that is usually harvested off the coasts of Ireland (Davis et al., 2003). Alginate is composed of manmuronic and guluronic acid monomers; the ratio between them determines the brittleness of the gel, water holding, etc. Since the algae are harvested at different places and during different seasons, there are variations in the gelling performance. Therefore, it is important that the meat processor uses a supplier who is reputable and can control and standardize the gel performance. One of the unique characteristics of alginate is its ability to gel at room/refrigerated temperature instantly when a small amount of calcium ions is added.

The meat industry uses it for binding raw meat particles in products such as restructured cutlets (Fig. 13.4.4) in order to provide binding of the smaller meat trimmings and hold the product together prior to cooking. It is also used today to make casings (Harper et al., 2013) that are co-extruded directly onto the product (see discussion in Chapter 10).

Figure 13.4.4 Meat trimmings bound with an alginate gum to form a restructured product. The binding is done at low temperature with the help of $CaCl_2$ which causes cold gelation of the alginate. Showing raw chicken and beef products, as well as the resulting cooked beef product. Photo by S. Barbut.

b. Carrageenan – gum that is extracted from Irish moss (*Chondrus crispus Stackh*.) found along the Atlantic coast of the British Isles, Europe and North America. It is composed of monomers of sulfated galactose and anhydro-D-galactose. The gum is a complex mixture of about ten different polymers. The main ones used by the meat industry are kappa and iota (note: some lambda is also used to increase viscosity but it is a non-gelling component). The type of gel formed depends on refining the raw material (Fig. 13.4.5), the dominant polymer in the mixture and the cation used to induce gelation during heating. Carrageenan forms a reversible gel (i.e., can be remelted and reformed), is very effective at binding water, and is added to products where water is used to replace fat such as oven roasted turkey/chicken breast products and low fat sausages.

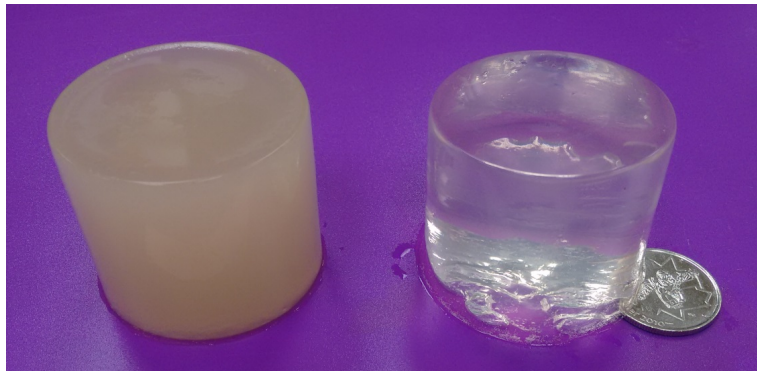


Figure 13.4.5 Carrageenan gels (1%) made by the addition of hot water (85 °C) followed by cooling (see text for explanation). The gel on the left was made from non-refined carrageenan and the one on the right from refined carrageenan. The latter produced a clearer, harder, and more elastic gel, but with more syneresis. Photo by S. Barbut.

c. Xanthan gum – is produced by microbial biosynthesis and is an extracellular polysaccharide. It is composed of cellulose chains with attached oligosaccharide groups. Low xanthan concentrations produce a highly viscous solution. Together with locust bean gum, xanthan can produce a thermo-reversible gel.

l. Acids/Acidulants – used to reduce pH, add flavour, extend the self-life and/or produce a fermented-like meat product. A common example of an acid is vinegar and an example of an acidulant is glucono delta lactone (GDL; introduced in the 1960s), which can yield a more rapid and improved colour development to cooked comminuted meat products. An important advantage of using GDL is its slow acid release that does not cause a problem with later protein binding (note: adding a large amount of liquid acid to a meat product at the beginning of the process will result in early protein denaturation, poor binding, and decreased WHC). Although GDL was introduced to accelerate raw meat processing operations, it has been later used in the production of fermented-like meat products (e.g., pepperoni for a pizza topping and other industrial acidified products).

Encapsulated acids (e.g., lactic, citric) are another way to add acids to produce a fermented-like products. The encapsulation material (wall component) is usually made of hydrogenated vegetable oil with a melting point that has been adjusted to be slightly higher than denaturation temperature for major meat proteins (e.g.,

60-65ºC). Other sensitive compounds can also be encapsulated (e.g., flavours) to protect them until needed (e.g., coating material can be designed to be broken by saliva, enzymes or mechanical shear). Overall, the market for encapsulated flavour, sensitive oils, and vitamins has been growing at a tremendous rate over the past three decades.

In the food ingredient business, the area of nanotechnology including encapsulation, is becoming an important topic. Currently there is quite a lot of use of encapsulation technology, but not so much at the nano scale. As mentioned above, encapsulation is used to protect food additives such as flavour compounds, vitamins, sensitive omega-3-fatty acids, and microorganisms (e.g., to protect some probiotics from the stomach's low acidity and only release them later on in the gut). This topic is beyond the scope of this book, but further information can be found in Prakash et al. (2013) and Graffagnini (2010).

m. Natural and Liquid Smoke – are mainly used to provide flavour, colour (Maillard reaction), antimicrobial protection, and antioxidant compounds to the surface of the product. Historically, smoking meat cuts over an open fire was used to preserve different products. The exposure to mild/high temperature for an extended period of time (e.g., several days; not currently used in the industry) also resulted in significant drying. Today, smoking is commonly employed for a short period of time (e.g., 10 - 90 min) and is mainly done to add flavour and colour and to help increase the shelf life to the product.

There are several hundred different compounds in natural smoke. Maga (1989) and Toledo (2007) reported over 300 in some of the commonly used hard woods (maple, cherry). The compounds can be divided into four groups:

a. carbonyls – contribute to flavour and colour development
b. organic acids – help in preservation and coagulate surface proteins (i.e., assist in casings peeling)
c. phenols – contribute to colour and flavour development, preservation, and retard oxidation
d. polycyclic hydrocarbons – are created when high burning temperatures are employed; some of the compounds, such as benzopyrene, are potentially carcinogenic.

Smoke can be applied by burning the sawdust or pieces of hard woods (e.g. maple, cherry) or as a liquid smoke solution. The former is achieved with the help of a special generator outside the smokehouse. As the moist sawdust is slowly burned, the smoke is circulated into the smokehouse by a fan system usually for

10 – 30 min. During this process, the exhaust duct must be closed so smoke can accumulate and is not wasted. The product's surface must be dry (it could be wet due to condensate) or else the smoke will drip off. Liquid smoke is a newer product that is prepared in dedicated facilities where smoke compounds from burning wood are captured by letting the smoke rise inside a tall chimney equipped with a counter flow water shower. The smoke compounds can later be concentrated and the preparation is applied to meat products as a dip, spray, or atomized mist. An advantage of this process is the ability to separate some/most of the polycyclic hydrocarbons by allowing then to settle out. In addition, some liquid smoke products can be added directly to the raw product after the pH has been adjusted.

n. Enzymes – several groups of enzymes can be added to meat products for a variety of reasons. The two main groups are used for binding meat particles/surfaces and for tenderizing tough meat cuts. Transglutaminase is an example of commercially available enzyme used to bind meat pieces at low temperature (i.e., prior to cooking) in products such as those that have been restructured. This specific enzyme has been used for hundreds of years in the production of fish surimi, although the chemistry was not understood until recently. Transglutaminase is able to catalyze acyl transfer reactions and introduce covalent cross links between proteins. It is now commercially harvested from microbial fermentations.

The other major group of enzymes used is the one that can break down connective tissue. Papain and ficin extracted from pineapples and figs respectively are able to break down collagen and are sometimes used to tenderize meat. However, their activity should be stopped at a certain point as extensive proteolysis can turn the meat into mush.

13.5 Meat Protein Gelation and Binding

Note that sections 13.5 and 13.6 contain more detailed reviews of the protein gelation, binding, and emulsification topics to help the reader understand the relationships between the science and practical application of meat processing principles.

Proteins are the main building blocks of meat products. Thus protein type (e.g., myofibrullar, sarcoplasmic, stromal proteins; see Chapter 3), configuration (Fig. 13.1.2), quantity, and quality (e.g., fresh vs. frozen) have major impact on the final meat product characteristics. The product is also affected by processing parameters such as the size of the meat pieces (small vs. large), addition of ingredients (e.g., salts, acidulants, gums), and cooking method (e.g., hot air vs frying). Overall, the

proteins interact with other components in the meat batter/product to form a gel matrix. In any case, it should be recognized that proteins are the main functional ingredient in meat products while the other two main components, water (30-75%) and fat (5-30%), are important but do not directly contribute to structure building. When discussing protein's contribution to structure it is useful to look at its interactions with the other components in the meat product:

a. Protein-protein interactions: this is one of the main mechanisms that contribute to the formation of an elastic gel upon heating of meat products. As discussed in Chapter 3, there are over 50 different muscle proteins. The amount and type of extracted salt soluble proteins (myofibrillar) and their later associations during heat processing has a strong effect on the meat product's characteristics. As will be highlighted in the following comment, not all meat proteins can form a gel and some proteins such as collagen actually melt when cooked (e.g., 65-72ºC) and will only form a gel upon cooling (e.g., the basis of Jell-O ® manufacturing). This example is mentioned here so the reader can understand that the production of an acceptable meat product is complex. As much as possible, the meat processor should understand the mechanisms involved and be aware of potential positive and negative effects (e.g., using meat with too much connective tissue is less expensive, but can destabilize the gel matrix). Processors should also be aware of the compatibility (e.g. similar gelation temperature) of added non-meat proteins (e.g., soy, whey) and how they will interact with meat proteins.

b. Protein-water interactions: water retention within a lean cut of meat or a ground/finely comminuted meat product is extremely important in creating a product that is acceptable to the consumer (e.g., juicy, not too tough) and profitable to the producer (e.g., reasonable yield). A lean meat chicken fillet portion contains 75% water. In some products added water (e.g., 10-50%; see recipes at the end of the chapter) should also be held within the product.

c. Protein-fat interactions: meat proteins' associations with oils/fats present in fat cells, membranes, or that have been added to the product are very important in providing a mechanism to keep the fat within the product. This is extremely important for sensory and economic reasons.

The binding of meat proteins during cooking involves extensive protein-protein interactions as a result of heat denaturation. Overall, a meat gel matrix can be described in terms of a composite structure. Figure 13.5.1.a shows various possibilities for the production of simple, mixed, filled, and filled-mixed gels with different results in terms of compatibility or incompatibility (i.e., possible enhancement or disruption when two proteins are used). For a mixed gel system a

synergistic effect can result from the cooperation of two proteins/components. As will be discussed in the following comments, another component in the gel matrix can be fat particles/globules in a meat emulsion (e.g., frankfurter). When present as small particles fat can significantly increase the gel's hardness.

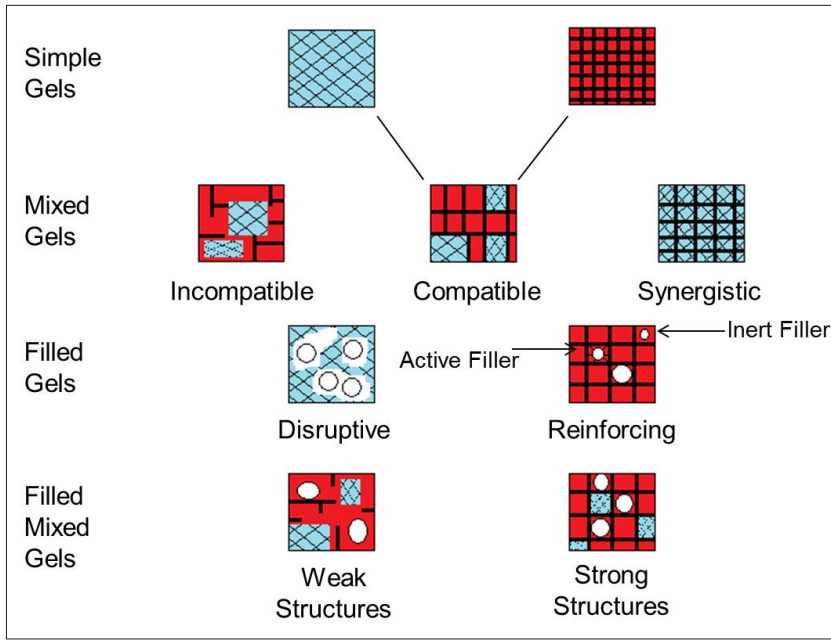


Figure 13.5.1.a Possibilities for engineered structures of simple, mixed, filled and filled – mixed gels. Redrawn from Aguilera and Kessler (1989).

In general, a meat product is composed of various soluble and non-soluble proteins, fat, water, and carbohydrates. Together they can form composite materials that strengthen the polymetric matrix due to volumetric and/or surface phenomena. A non-food example is rubber, a polymer that can be described as a filled gel system. When the so called carbon-black particles are added, there is a great increase in the mechanical moduli. In such a case both the size of the carbon black particles and their strong surface adsorption properties contribute to the gel strength. Aguilera and Kessler (1989) have also shown this strengthening phenomenon in a mixed dairy gel containing small fat globules with modified membranes.

Gravelle et al. (2015) have reported on the physical and mechanical properties of particle-filled composite gels prepared from chicken breast meat proteins. They

examined the effects of solid filler with varying size (1.0-1.4, 0.50-0.60, 0.15-0.21, 0.045-0.090, and < 0.50 mm) and surface properties (hydrophobic rice bran wax particles and hydrophilic glass beads). All composites were found to be stable up to 0.5 volume fraction (φ) filler, based on post-gelation liquid loss, light microscopy and cryo-SEM analyses. Both filler type and size were found to influence the Young's modulus and stress at 50% strain (Fig. 13.5.1.b). The recoverable energy and post-compression height recovery were found to be predominantly influenced by the filler volume fraction, and were less influenced by particle/gel interactions. Interestingly, filler type and size range were observed to have no effect on the cohesiveness of the composites, as this parameter was found to be solely dependent on the volume fraction of the elastic filler present. The behavior of the Young's modulus was compared to that predicted by particle-reinforcement theories proposed by van der Poel and Kerner, each with subsequent extensions (Fig. 13.5.1 b).

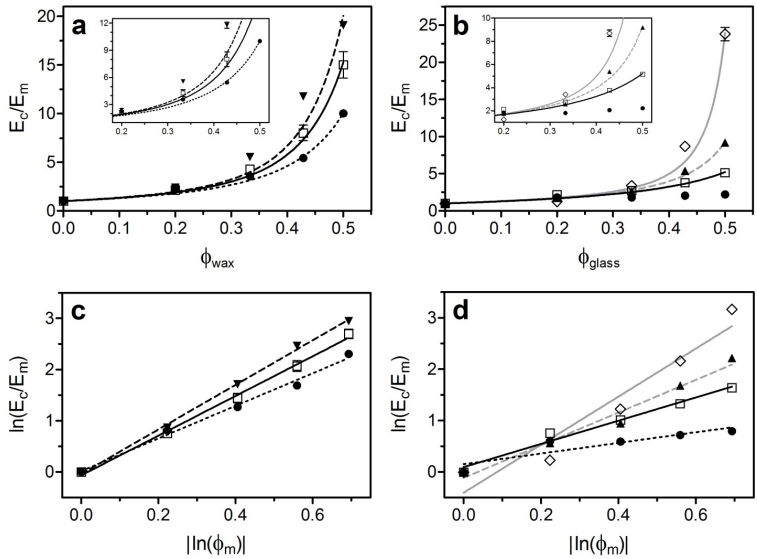


Figure 13.5.1.b Effect of filler type, size, and volume fraction filler (φ) on the Young's modulus (Ec) of particle-filled comminuted meat protein gels. (a,c) Rice bran wax; strongly bound filler (insets show greater separation in the y-axis). (b,d) Glass beads; weakly bound filler. Experimental data in (a) and (b) were fit to the exact solution of the van der Poel model and the Kerner model, respectively. Fitted parameters are presented in the actual paper. The data presented in (c) and (d) is a ln-ln transformation of that shown in (a) and (b), respectively. Note: φm in panels c and d denote the volume fraction of the gel matrix. Particle size ranges ●: 1.0-1.4 mm, □: 0.50-0.60 mm, ▲: 0.15-0.21 mm, ◊: 0.045-0.090 mm, ▼: < 0.50 mm. From Gravelle et al. (2015).

Protein gelation can be defined as an aggregation of denatured protein molecules with a certain degree of order, which results in the formation of a continuous network. This can be described as a two-step process: denaturation and aggregation (see review by Totosaus et al., 2002). Gelation can be induced by physical means (e.g., heat, high pressure) as well as chemical means (e.g., salt ions, acid, urea, and enzymes such as transglutaminase). Phillips et al. (1994) and later Totosaus et al. (2002) classified the factors that affect gelation as extrinsic or intrinsic factors.

Extrinsic factors are the environmental conditions surrounding the proteins and include:

a. pH – affects the net charge of a protein. At its isoelectric point the protein's charge is equal to zero but the further the environment is from the isoelectric point, the more charged the protein becomes.
b. Protein concentration – in general, the cross-linking of macromolecules of an arbitrary initial size distribution is required for gelation and is proportional to the protein concentration. There must also be a minimal concentration of the protein itself, below which a continuous three-dimensional structure cannot be formed. Gel strength and deformability is highly dependent upon protein concentration.
c. Ionic strength– affects water absorption, swelling, and solubility of proteins as competitive linkages are created. Ionic strength has an effect on the microstructure of the gel matrix; at low ionic strengths (<0.1 M) of monovalent cations a fine-stranded matrix is formed, whereas at high ionic strengths (>0.1 M) the matrix becomes mixed (Foegeding et al., 1995).
d. Type of salt – chloride monovalent ions (e.g., Li^{+}, K^{+}) form a fine stranded matrix at ionic strengths less than 0.1 M. The salt concentration required to affect gel microstructure depends on the salt's position in the Hofmeister series. Matrix formation also occurs when low concentrations (10–20 mM) of divalent cations (e.g., Ca^{2+}, Mg^{2+}) of chloride salts are present (Foegeding et al., 1995).
e. Temperature– one of the most important factors because it is a driving force behind protein unfolding. When the gelling temperature coefficient is high, the first gelation step (denaturation) is completed faster than the second (aggregation).
f. Pressure – can affect the sol–gel transition of protein solutions. High pressures (e.g., 200-500 MPa) modify the native volume of proteins, which is composed of the volume of constituent atoms (compositional volume), the volume of internal cavities, and a contribution due to solvation (e.g., presence of water). The native structure governs the

biological activity of proteins and is a delicate balance between the stabilizing and destabilizing interactions within the polypeptide chain and the solvent.

Intrinsic factors are related to the protein itself and include:

a. Amino acid composition – proteins that contain less than 31.5% mol of hydrophobic residues (i.e., proline, leucine and tryptophan) form a coagulum-type gel, whereas proteins with more than 31.5% hydrophobic residues form a translucent gel. Some suggest that a more appropriate parameter might be the ratio of the net charge to hydrophobicity rather than hydrophobicity alone (Totosaus et al., 2002).
b. Electrostatic interactions – are related to the net charge of the protein molecule as influenced by attractive and repulsive forces. They affect protein–protein and protein–solvent interactions (Phillips et al., 1994). These electrostatic interactions are promoted by changes in ionic strength and/or pH (extrinsic factors).
c. Hydrophobicity – when non-polar amino acids are grouped together, they form a hydrophobic nucleus surrounded by a polar residue layer that remains in contact with the solvent (e.g., water). This plays an important role in protein organization and should be taken into account in any protein-folding consideration. Effective hydrophobicity refers to the value representing the interactions between the proteins and surrounding medium.
d. Molecular weight – differences in the average molecular weight and the hydrodynamic size of polypeptide species could be related to variations in the formation of self-supporting gel network and gel strength. The polypeptide critical molecular weight for gel formation is about 23 000 Da.
e. Disulphide bonds and thiol-disulphide interchanges – increase the apparent chain length of the polypeptide rather than acting as an initial network stabilizer among polypeptide chains involved in protein gelation. Disulphide bonds are not essential for gelation of proteins, but their role in gelation is related to their ability to increase the average molecular weight and hence the chain length.

Meat proteins denature at different temperatures (Fig. 13.5.2) and can then form a gel structure. The figure shows that myosin and its subunits denature first (54-58ºC), followed by sarcoplasmic proteins and collagen (65-67ºC), and then actin as actomyosin and as fragments of F and G monomers denature last (71-83ºC; Wright et al., 1977).

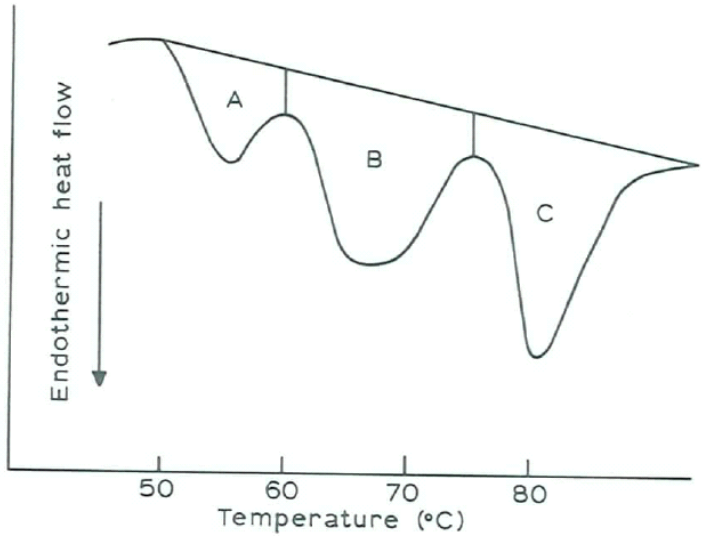


Figure 13.5.2 Typical thermal curve of muscle with three major transition zones. Figure shows a summary of denaturation peaks: (A) myosin subunits; (B) sarcoplasmic proteins and collagen (C) actin. As muscle type and environment change the shape of the curve changes accordingly. Based on data from Barbut and Findlay (1989) and Wright et al. (1977).

Studying the textural changes in a raw meat system during the cooking process and correlating that data with molecular changes is useful in understanding protein gelation. As well, following the rheological changes (i.e., small deformation testing) that take place during gel formation has been useful to studying the sequence of molecular interactions within a food/meat system. The latter studies have become more feasible within the last few years as the market has seen the development of high precision programmable rheometers. Prior to the development of scanning rigidity monitors, samples had to be changed for each temperature point, which resulted in time being a continuous independent variable. An example of information from an early thermal scanning rigidity monitor is shown in Figure 13.5.3. Yasui et al. (1980) studied the effect of using pure myosin, pure actin and their combinations at different ratios on forming a gel matrix. The researchers chose these two proteins because they are the main proteins responsible for meat binding (i.e., myofibrillar salt-soluble proteins). Overall, binding characteristics of meat products prepared from isolated myofibrillar proteins provide a basic understanding of the gelation process. Figure 13.5.3 shows that myosin by itself will start forming a gel at 45ºC. The authors indicated that this gel structure determines the binding quality in meat products and that binding strength bears a

close relationship to the amount of myosin liberated from the myofibrils. The data also show that actin by itself does not form a gel under these conditions.

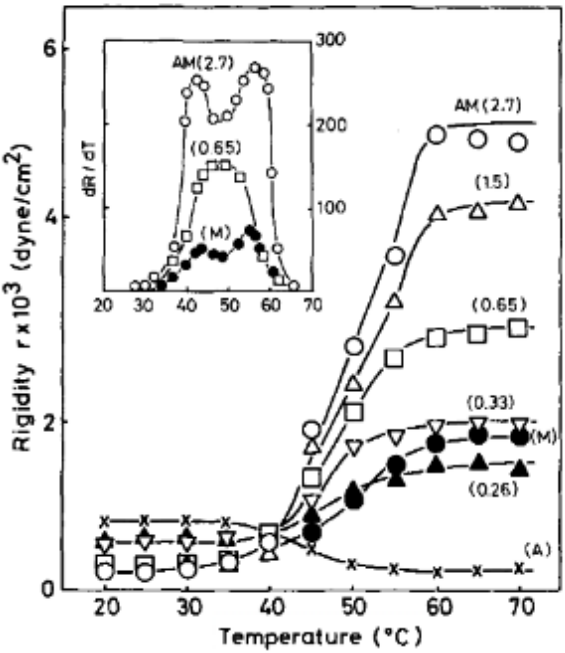


Figure 13.5.3 Heat-induced gel strength of actomyosins reconstitution of different myosin-to-actin ratios. The protein samples (5 mg/ml) were dissolved in a 0.6 M KCl solution containing 20 mM phosphate buffer, pH 6, and incubated for 20 min at temperatures varying from 20 to 70°C. Gel strength was measured at each temperature. M - myosin alone; A - actin alone; AM - actomyosin. The figures in parenthesis indicate the mole ration (corrected) for myosin-to-actin ratio in respective systems. From Yasui et al. (1980).

However, in the presence of myosin, a synergistic effect between actin and myosin is observed. This is because actin, in the presence of other cross-linking proteins, can enhance gel structure. The effect of the relationship between myosin and actin concentration on rigidity is demonstrated in Figure 13.5.3. This can be used to also illustrate the effect of a two protein system that produces a synergistic mixed gel (see also Figure 13.5.1; second row on the right side). Maximum gel rigidity was obtained when the myosin to actin mole ratio was 2.7, (a weight ratio of myosin to actin of about 15:1). Increasing the portion of myosin beyond this point caused

a decrease in gel strength. Yasui et al. (1980) suggested that the synergistic effect is either ionic strength dependent or is determined by the state of myosin per se at different ionic conditions. At <40°C it can also be observed that actin exhibits some resistance to gel, probably due to its thixotropic nature. However, upon heating, the gel collapsed into a compact string or bead-like structure (scanning electron microscopy pictures are not provided here). Isolated myosin fragments were shown to affect gel characteristics differently. Intact myosin monomers produced the strongest gels, followed by myosin rods and the S-1 fragment (see Chapter 3 for myosin structure). The S-1 fragments produced gels with low water-retaining ability. As mentioned above, the differences were also evaluated by electron microscopy. Myosin rods produced an extended three-dimensional network system, while the S-1 fragment formed a bead-like aggregate structure upon heating. Combining the myosin rods and S-1 fragments did not produce high gel strength as was observed for the intact myosin molecules. This indicates that, once cleaved, the fragmented myosin did not have the same capabilities to form a gel matrix.

Table 13.5.1 Effect of sodium chloride (NaCl), tripolyphosphate (TPP) and heating temperature on gel strength and amount of extractable protein. Adapted from Barbut et al. (1996).

	Penetration Force (N)		Extractable Proteins (mg/mL)	
Treatment Temp.	2.5% NaCl	1.5% NaCl[a] + 0.4 TPP	2.5% NaCl	1.5% NaCl[a] + 0.4 TPP
20 ºC	30.8^{f}	25.3^{f}	1.62^{ab}	1.72^{a}
40 ºC	43.3^{ef}	40.1^{ef}	1.58^{b}	1.60^{b}
50 ºC	60.0^{e}	60.5^{e}	1.38^{c}	1.50^{b}
55 ºC	189.0^{d}	194.1^{d}	1.18^{de}	1.21^{d}
60 ºC	356.6^{b}	287.5^{c}	1.07^{e}	1.08^{e}
70 ºC	475.8^{a}	373.3^{b}	0.37^{f}	0.40^{f}

[a]Both the 2.5% NaCl and 1.5% Nacl + TPP were formulated with the same ionic strength (IS=0.42).
Means followed by the same letter, within each test category, are not significantly different at 95% level.

Structure development during heating of a commercial type meat batter can show the direct relationship between the meat protein system (i.e., containing many different proteins) and structure formation. Table 13.5.1 shows gel strength values (measured via penetration force) for a chicken meat batter heated from 20-70ºC and the available protein extracted at each temperature. As temperature increased, more protein-protein interactions occurred and penetration force values increased

from 30 to 475N. At the same time the amount of available proteins decreased because progressively more were bound together to form the gel structure. The microstructure of the gels at the different heating temperatures is shown in Figure 13.5.4. As other researchers have shown, the basic gel structure is formed when the meat batter is prepared (at low temperature) and is solidified during heating through the creation of covalent and disulfide bonds.

In the study, Barbut et al. (1996) followed the gelation of finely comminuted turkey meat (mechanically deboned) prepared with 13% fat and 2.5% NaCl and in reduced sodium (1.5% NaCl plus 0.41% tripolyphosphate) products. From 20-70°C, the process was studied by evaluating gel strength, extracting available proteins, and microscopy. Gel strength, as measured by the penetration test, tripled as temperature increased from 50 to 55°C and then doubled again when temperature was raised to 60°C (Table 13.5.1). The amount of extractable proteins continuously decreased as heating temperature was raised. The decrease in the amount of soluble protein indicates that they were taken up into the gel structure (Asghar et al., 1985). Cryo-scanning electron micrographs (Fig. 13.5.4) revealed that adding phosphate to the low sodium meat batter resulted in a protein matrix with larger pores than the 2.5% NaCl treatment (both treatments were formulated with equal ionic strength). The overall differences in microstructure of the two treatments remained the same during cooking (micrographs taken every 10°C). Development of a rigid gel structure during cooking was characterized by some contraction of protein strands within the matrix. Closer examination of the data revealed that the first major increase in rigidity was observed when the temperature was increased from 20 to 40°C. This corresponded to an initial small reduction in the amount of soluble protein (Table 13.5.1). A further increase was observed from 40 to 50°C and then a major increase was observed when temperature was increased from 50 to 55°C. The latter actually resulted in tripling gel strength values, which could be related to myosin denaturation and its transformation into a rigid structure. A major decrease in the amount of soluble protein at this range has been previously reported by Yasui et al. (1980). They showed that, at this temperature, interactions between actin and myosin were responsible for the rigid structure development (i.e., actin by itself will not gel, but with myosin a synergistic effect can be observed; Fig. 13.5.3). The values for gel strength were further increased when the temperature was increased from 55 to 60°C. Temperature increases in this range have been shown to be critical in the thermal gelation of meat systems. The amount of extractable protein significantly decreased above 50°C in both the 2.5% salt and reduced salt treatments. This corresponded to the large increase in gel strength. Contrast analysis showed that the overall means for extractable protein were significantly different between the 2.5% NaCl and 1.5% NaCl + TPP treatments across all temperatures.

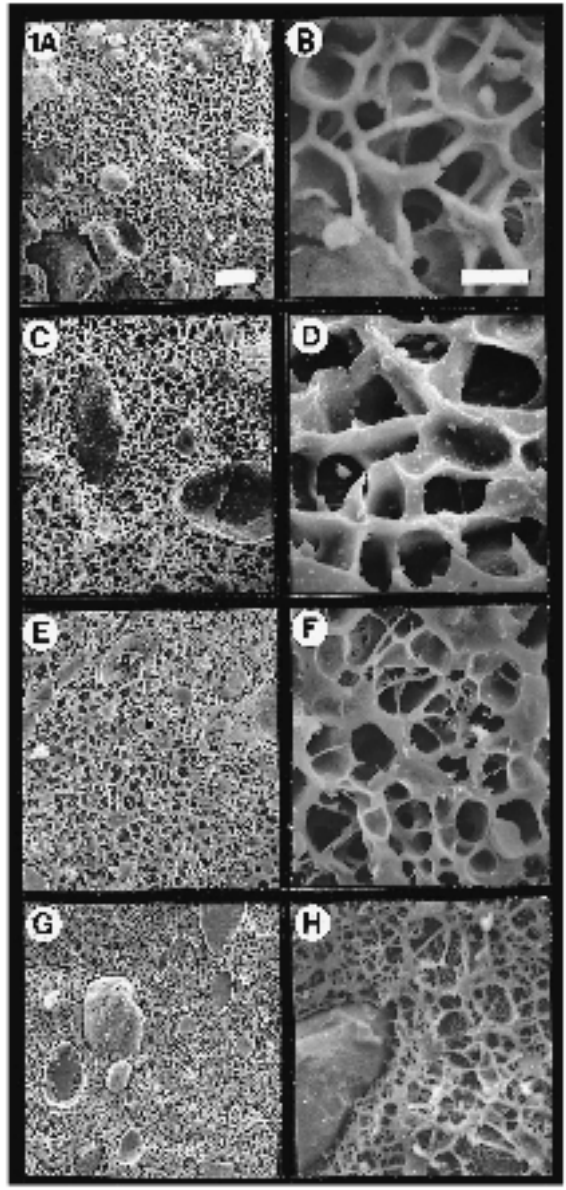


Figure 13.5.4 Cryo scanning electron micrographs of meat batters containing 2.5% NaCl (ionic strength = 0.42), heated to (A,B) 20ºC; (C,D) 40ºC; (E,F) 55ºC; and (G,H) 70ºC. Micrographs on the left are at low magnification (bar = 15 μm), on the right at higher magnification (bar = 3 μm). Part G shows a fat globule entrapped within the protein matrix. From Barbut et al. (1996). With permission.

Micrographs taken during different stages of cooking (Figure 13.5.4) showed a progressive change in the batters' microstructures. The first micrograph shows an organized gel structure prior to heating. This kind of structure has been previously observed by other groups. On heating to 40°C, the protein strands became thicker while the pore size stayed the same. A further increase to 55°C resulted in an increased number of connections among protein strands. The junction zones between strands also became thicker. In addition, thin protein strands were visible among the thick strands. This also increased the density of the protein matrix. These changes corresponded to the large increases in gel strength at this temperature (Table 13.5.1). Further heating to 70°C resulted in a denser protein matrix, which resulted from the formation of additional protein strands concurrent with a reduction in pore sizes. With the help of a scanning electron microscope, Wang and Smith (1992) reported that a salt-soluble protein solution (30 mg/mL, at pH 6.5) heated to 55ºC produced aggregates composed of globular structures connected by strands. When the temperature was increased to 65ºC the strands became thicker (125 vs. 300 nm). Additional heating to 80ºC caused a reduction in strand size, but the structure remained ordered. Since they only started monitoring the structure at 55ºC, comparison with a structure at a pre-denaturation temperature (20ºC) is not possible.

A meat product's gel formation is strongly affected by use of additives such as salts and pH modifiers. As already shown, salt concentration plays an important role in the amount of proteins extracted and later in binding. This is observed in the reduction of salt from 2.5 to 1.5% in commercial-type poultry meat batters (14% protein and 18% fat), which resulted in a substantially lower final rigidity value (12.2 vs. 4.9 kPa, respectively; Figure 13.5.5) as observed by small deformation testing (using a programmable rheometer). Differences were also observed in the development of the modulus of rigidity (G') after the initial protein coagulation started at around 55°C. In both batters, a small but linear increase was observed up to 55°C, indicating that the protein matrix was continuously developing. When the temperature reached the myosin denaturation zone at around 55°C, a rapid increase in G' was observed. However, when the temperature reached the collagen and sarcoplasmic protein coagulation zone at around 63°C, there was a sharp decline in the 1.5% NaCl treatment's curve, whereas there was a steady G' value in the 2.5% NaCl treatment. The sharp rigidity decline might indicate a structural breakdown in the reduced salt meat batter. The general gelation pattern for the 2.5% NaCl, seen in the figure, is similar to the one reported by Montejano et al. (1984) for hand deboned turkey meat containing 2.5% NaCl. Overall, the rapid steady increase in G' from 56 to 70°C (Fig. 13.5.5) indicates the formation of a stable, elastic, and self-supporting matrix structure typical of heat-induced protein gels. With further increase in temperature, there was no increase in G' value, up to 80°C. When

polyphosphates were added to the reduced salt (1.5% NaCl) meat batters, structure weakening around 63°C was eliminated; however, gelation patterns were different depending on the phosphate. Adding 0.5% sodium acid pyrophosphate (SAPP) resulted in the closest match to the rigidity modulus development pattern seen in the 2.5% NaCl treatment. It is interesting to note that, in another study, a taste panel also rated reduced-salt poultry frankfurters containing SAPP as having the most closely matched texture to frankfurters containing 2.5% NaCl. The curve of the TPP treatment shows that structure formation followed the pattern of the 1.5% NaCl treatment up to 64°C, but unlike the 1.5% NaCl, it did not weaken and stayed at a constant value (G'=8.9) up to 80°C. Addition of SAPP resulted in further increases of the G' values as temperature was raised above 64°C. Evidently, the change from a viscous to an elastic structure in a meat batter happens almost instantaneously; additional heating further increases the rigidity modulus, but only up to a certain point. It is important to note that salt and phosphate addition already affect raw meat batter viscosity during preparation. This can be seen in Figure 13.5.5 as the differences in G' at 20ºC. The authors also investigated the effects of applying higher shear rates to the raw meat batters (Figure 13.5.6) in order to determine viscosity and yield stress values. Both are important when selecting pumps to move large volumes of meat in a processing plant.

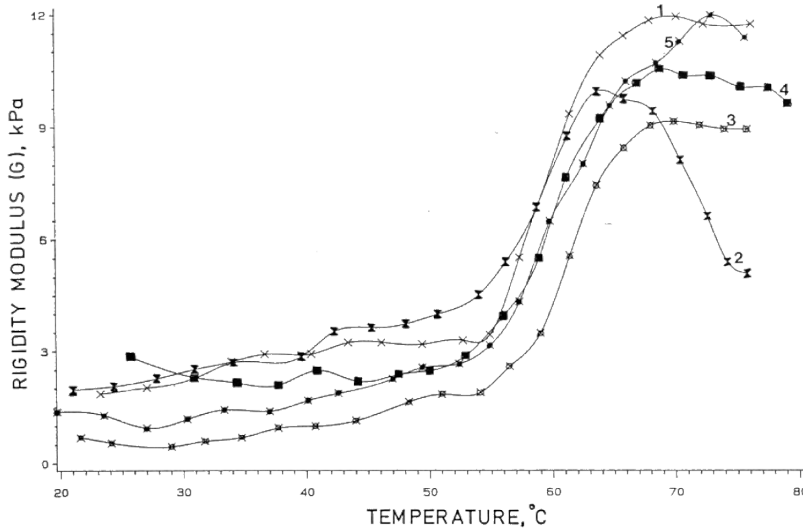


Figure 13.5.5 Shear-rigidity modulus profile of regular and reduced salt meat batters containing various phosphates during heating. (1 = 2.5% NaCl; 2 = 1.5% NaCl; 3 = 1.5% NaCl + 0.5% TPP; 4=1.5% NaCl + HMP; 5 = 1.5% NaCl + 0.5% SAPP). From Barbut and Mittal (1989). With permission.

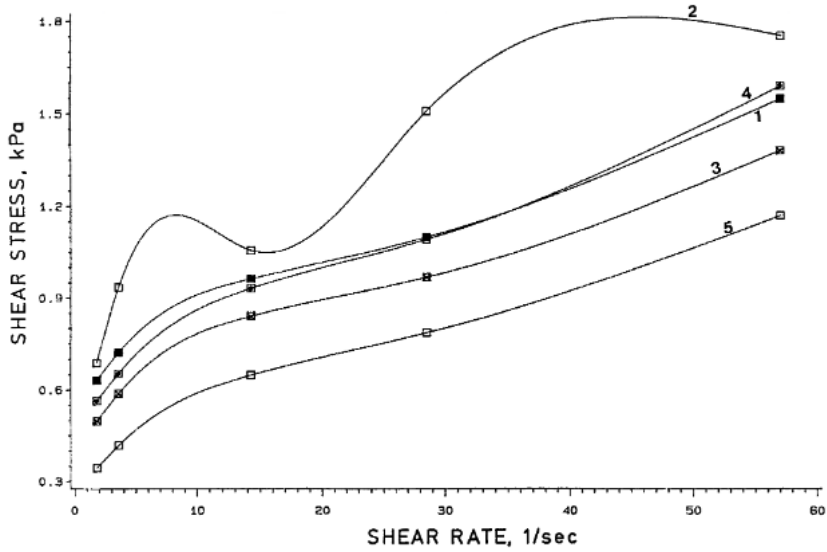


Figure 13.5.6 Relationships between shear stress and shear rate for regular and reduced salt raw meat batters with three phosphates (1 = 2.5% NaCl; 2 = 1.5% NaCl; 3 = 1.5% NaCl + 0.5% TPP; 4=1.5% NaCl + HMP; 5 = 1.5% NaCl + 0.5% SAPP). From Barbut and Mittal (1989). With permission.

The following short discussion is not directly related to meat protein gelation, but is included here to explain flow behavior of raw meat batters and to help the reader understand the forces involved. Figure 13.5.6 shows the relationship between shear rate and shear stress for the same treatments shown in the previous figure. The relationship is nonlinear and displays Bingham pseudo plastic behavior. The shearing rate tends to increase faster than the shearing stress; i.e., also showing a certain yield value. It was suggested that particles (e.g., muscle/connective tissue fibers) in a meat batter are initially randomly oriented and become increasingly more aligned as shear is applied. The contribution of particle interactions to the apparent batter viscosity was reported to decrease when shearing stress increased. All meat batters required the application of a certain shearing force before any noticeable flow took place. On a molecular level, Bingham materials are envisioned as a three-dimensional network at rest. Forces applied to this network can be resisted up to a certain point, but then the network breaks down and the flow becomes essentially pseudo plastic. Both NaCl treatments had the same pH (6.35), TPP slightly increased the pH to 6.45, and SAPP addition decreased the pH to 6.25. These relatively small pH differences are not believed to play a major role in the viscosity differences observed. Rather, the type and concentration of the salt ions involved seem to be most influential. The general power law model

(Herschel-Bulkley) with yield stress was used to fit the data. The 95% confidence interval for yield stress (T_o) was 291 to 580 Pa, for the consistency coefficient (b) was -11 to 191.0 Pa.sn, and for the flow behavior index (n) was 0.50 to 0.82. The T_o for the emulsion containing 1.5 % NaCl + SAPP was significantly lower than those of the other treatments. Thus, SAPP decreased the Bingham behavior of the meat batter. Similarly, the T_o value for the control (2.5% NaC1) was significantly higher than those of the other treatments. Thus, low NaCl (1.5%) reduced the T_o value. The b value of the meat batters with 1.5% NaCl was significantly higher than those of the 2.5% NaCl or 1.5% NaCl + phosphate batters. The n value was between 0 and 1, indicating pseudoplasticity. Similarly, the n value of meat batters containing 1.5% NaCl was significantly lower than those of other treatments. According to previous work, more stable formulations tended to have higher b values, lower n values, and larger values for yield stress. As indicated above, these values and the relationships between them are important for equipment selection in a meat processing plant.

Returning to the effect of pH on meat protein gelation, it is important to note that pH can affect gel characteristics (hard, soft) and certain pH values can actually prevent gel formation. Xiong and Brekke (1991) reported that the optimum pH for gelation of chicken muscle in 0.6 M NaCl (or KCL) was about 6.0 for breast myofibrils and 5.5 for leg meat myofibrils. Wang et al. (1990) studied the effect of pH on the gelation (30 to 80ºC) of 3% salt soluble proteins (SSPs) extracted from chicken breast. Table 13.5.2 shows the storage modulus (G', the elastic element) and the loss modulus (G", the viscous element). Salt soluble proteins at all conditions exhibited higher G' than G" throughout the heating process which indicated the elastic nature of SSPs during the sol-to-gel transformation. The pH 5.5 and 6.5 treatments show the highest final G' values, indicating the strong effect of pH on gel formation. At the end point, the G' of SSPs at pH 4.5 was not significantly different from that at pH 7.5. Salt soluble proteins at pH 5.5 and 6.5 tended to have a higher G' at the end point, which indicated the formation of a more elastic gel matrix and more cross-linking between the protein molecules. Protein gels at pH 5.5 exhibited the highest G" at the end point, which indicated the formation of a more viscous matrix.

The increase in G" was thought to be due to the partial unfolding of protein structure, which caused an initial increase in the viscous characteristics of the SSPs. The subsequent increase in G', which indicated an increase in the elastic or solid nature of the material, indicated that the SSPs were cross-linking to form an elastic gel. An examination of the tangent delta (G"/G') showed the relative viscous:elastic properties of the material (i.e., in an elastic solid the tangent delta is zero and for a viscous fluid it is infinite). For all pH levels, there were no significant differences in

the tangent delta values for the SSP preparations at the initial point prior to heating. No second peak was observed in SSPs at pH 4.5, which corresponded to the lack of transitions in both G' and G". Similarly, no significant differences in tangent delta were observed at the first and second peaks in SSPs at 5.5, 6.5, and 7.5. At the end point, protein gels at pH 4.5 showed higher viscous properties than at pH 6.5 and 7.5. This indicated that gels at pH 6.5 and 7.5 formed a more elastic network.

Table 13.5.2 Effect of pH on the storage modulus (G'), loss moduli (G"), and loss tangent (tangent delta) of 3% chicken breast salt-soluble proteins heated from 30 to 80ºC at 1ºC/min and with 0.6 M NaCl. Adapted from Wang et al. (1990).

Parameters	pH			
	4.5	5.5	6.5	7.5
Storage modulus (Pa)				
Initial point	34.2^{b}	141.6^{ab}	196.0^{a}	187.0^{a}
Peak maximum	…	1,000.3^{a}	1,190.7^{a}	614.7^{a}
End point	216.3^{b}	1,725.7^{a}	1,286.0^{a}	575.9^{b}
Loss modulus (Pa)				
Initial point	6.8^{b}	32.8^{ab}	38.8^{a}	31.4^{ab}
Peak maximum	…	116.6^{a}	128.6^{a}	82.8^{a}
End point	24.4^{b}	123.1^{a}	30.6^{b}	24.9^{b}
Loss tangent (temp;C)				
Initial point				
Temperature, C	30	30	30	30
Tangent delta	0.22^{a}	0.23^{a}	0.20^{a}	0.17^{a}
First peak				
Temperature, C	37^{b}	34^{c}	47^{a}	49^{a}
Tangent delta	0.24^{a}	0.20^{a}	0.19^{a}	0.17^{a}
Second Peak				
Temperature, C	…	53^{b}	57a	58^{a}
Tangent delta	…	0.15^{a}	0.12^{a}	0.15^{a}
End point				
Temperature, C	80	80	80	80
Tangent delta	0.12^{a}	0.07^{ab}	0.02^{b}	0.04^{b}

^{a,b}Means within the same row with no common superscripts are significantly different ($P < 0.05$), n=3.

The authors also reported the complex modulus (G*, the amount of force required to deform a sample). There were no major transitions at pH 4.5 when SSP solutions were heated. This was because the proteins coagulated at this low pH and did not from a gel network. This is typical of protein systems at pH levels close to their isoelectric point (i.e., where the net charge on the proteins is close to zero). The isoelectric point of actomyosin is around 5.0 and at this point an electrostatic attraction between the molecules can be seen. Electrostatic attraction minimizes protein unfolding during heating and prevents gel formation. At pH 5.5, 6.5 and 7.5, G* increased after the first transition at 35-47°C. Afterwards, it peaked, then decreased on further heating to the third transition around 54-60°C, and then increased again until 80°C. The first transition, which led to the development of gel elasticity, was attributed to unfolding in the tail portion of the myosin molecule. The G* values at the end of cooking were significantly higher at pH 5.5 and 6.5 than at pH 4.5 and 7.5 ($P < 0.05$). The authors mentioned that the thermal transitions, graphed as differential plots of the complex modulus against temperature (dG*/dT versus T; not shown here), were pH-dependent throughout the heating process. The differential plot illustrated the rate of G* change during heating and provided additional information on how pH affects protein conformational changes during sol-to-gel transition. No rate changes were observed for the SSPs kept at pH 4.5 during the heating process. The first transition of the pH 6.5 and 7.5 treatments occurred at temperatures above 45°C. At pH 5.5 even the third transition had occurred before any changes were observed in the higher pH treatments. However, further transitions at pH 5.5 were similar to those of the higher pH treatments; temperature differences between the first and sixth transition were 18°C, 14°C, and 12°C for pH 5.5, 6.5, and 7.5, respectively. The pH 6.5 and 7.5 treatments showed almost identical transition temperatures and rheological transitions, which suggested similar changes in protein conformation during the gelation process. These results also demonstrate that pH influences the unfolding and aggregation of native protein molecules during heating and results in different gel properties.

Overall, the data presented above indicate that pH should be monitored and adjusted (if needed) to obtain consistent meat product quality. The texture and water binding capacity of meat products can be manipulated by adjusting the pH and by adding various salts and binders to optimize meat formulations.

13.6 Fat Binding and Emulsification

Meat products that are finely comminuted, sometimes referred to as meat emulsions (e.g., bologna and frankfurters), are basically composed of protein, fat, water, and salt. Products in this category are produced from different meat and non-meat ingredients (e.g., salt, soy proteins, starch) all around the world. In North America their estimated market share is over 35%. Producing high quality comminuted products is an ongoing challenge to processors who deal with a large selection of raw materials whose prices fluctuate daily (see Section 13.3 on Least Cost Formulation). The basic structure of a comminuted product is shown in Figure 13.5.4 where fat globules are dispersed in a protein gel matrix. The matrix has a structure that can be described as a sponge where there are lots of small spaces that confine water. The products shown in the figure have about 60% water, 20% fat, and 14% protein. The protein matrix represents the main structure that forms the product/holds the water and fat components. It consists of the salt soluble proteins and small pieces of intact muscle and collagen fibers. All ingredients are comminuted either in a bowl chopper or an emulsion-mill (see Chapter 10) in order to reduce the lean meat particles, open their structure, and extract the salt soluble proteins. This process also reduces fat particle sizes to increase their stability (see later discussion) and obtain a homogeneous mass. However, as the fat particle/globule size can be above 20μm, these products cannot be classified as true emulsions and the forces that govern a true emulsion cannot explain their entire stability. In any case, the challenge to the meat processor is to produce a stable meat product that can withstand the cooking process without fat and water separation (Acton et al., 1983; Barbut et al., 1996).

A good understanding of the mechanism(s) responsible for stabilizing/binding the fat within the product is essential to the meat processor because most comminuted products contain 15-40% fat that is held by a smaller amount of protein. As the proteins are also needed to retain water, they should be of high quality. Studying the mechanisms affecting meat batter stability is important because an "emulsion breakdown" can be very costly especially in high volume processing plants. In addition, understanding the relationship between meat batter stability and processing equipment can help the processor select the right equipment (i.e., different machines are available) and utilize the best ingredients for a specific product. It should be noted that this is not an easy task as there are many binders available on the market. Understanding meat batter stability also helps the processor effectively use least-cost-formulation programs and respond to consumer demands (e.g., reduced fat/salt meat products which cannot actually be prepared by a straight fat/salt reduction).

From a practical standpoint, one of the major reasons for studying meat batter stabilization is that during chopping the processor cannot see/detect any warning signs indicative of a later "emulsion breakdown" (a term referring to fat separation during cooking). This point is illustrated in Figure 13.6.1, which shows the effect of chopping time on meat batter stability. As chopping time increases, more proteins are extracted, fat particle size is reduced, and less liquid and fat is separated from the product. This is known to most meat processors; however, just looking at the raw meat batter usually does not provide any hint to the amount of liquid/fat losses that can be expected during cooking. This is a constant challenge because meat block formulations can change daily depending on the availability of raw materials, cost, etc. Therefore, meat processors usually use pretty high safety margins (e.g., more proteins and longer chopping time; both of which increase processing costs) to protect themselves against emulsion breakdown incidents. The data in Figure 13.6.1 are used to illustrate the point that understanding the process should benefit the processor. This material was also used in the development of an automated fiber-optic system to monitor the emulsification process.

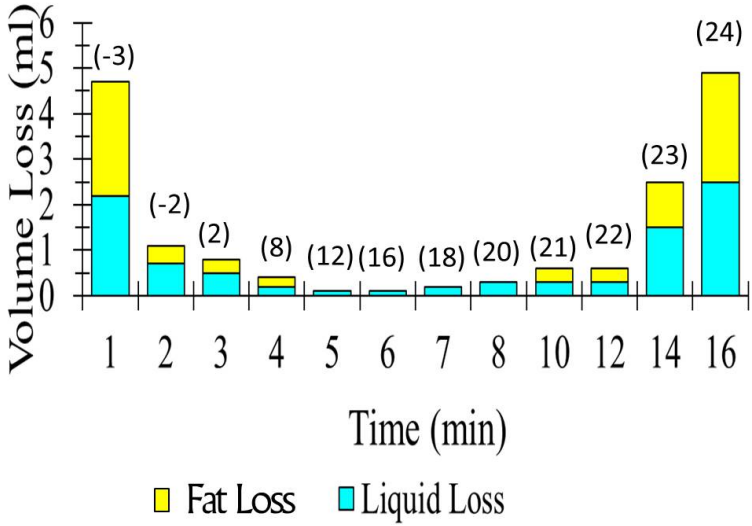


Figure 13.6.1 Effect of chopping time on cooking loss (ml) from comminuted beef meat batter. Temperature values (ºC) at each time are listed above bars. From Barbut (1998).

There is still debate in the scientific community as to the correct definition of finely comminuted meat products: meat emulsion or meat batter? The controversy arises from the interpretation of the mechanisms responsible for holding the fat within the

product. Figure 13.5.4 shows the microstructure of finely comminuted products where the small fat globules are dispersed within a water soluble protein matrix. Borchert et al. (1967) were among the first to show the presence of an interfacial protein film (IPF) surrounding the fat globules (Fig. 13.6.2) and suggested that the film is responsible for stabilizing the fat.

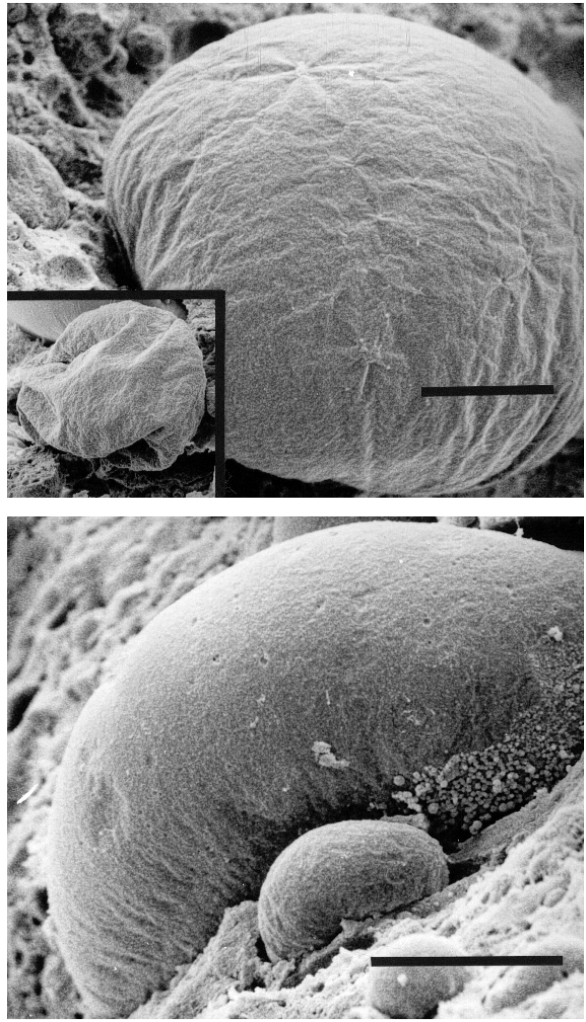


Figure 13.6.2 Scanning electron micrographs of fat globules with surrounding interfacial protein film in a cooked, low salt poultry meat batter formulated with 1.5% NaCl (top), and with an adequate salt level of 2.5% NaCl (bottom). Bars = 10 μm. From Barbut (1988). With permission.

The myofibrillar proteins, which have hydrophilic and hydrophobic sites, arrange themselves in such a way that they reduce surface tension and forces responsible for fat globule coalescence and prevent separation. The same phenomenon is observed in homogenizing milk, where small fat globules are covered with the milk protein caseinate (to help reduce fat separation/creaming). If finely comminuted meat products hold fat using this mechanism, they would be considered true emulsions. However, other researchers have suggested that the protein matrix is the main factor responsible for physically entrapping the fat globules (Lee, 1985). According to the physical entrapment theory, the viscous protein matrix restricts fat globule movement, hence coalescence. This mechanism would suggest that finely comminuted products are behaving as meat batters. In any case, the whole issue of which mechanism is more important is not so simple, since numerous changes take place during the production of products such as frankfurters/bologna. During the initial stage of chopping, a flowable product, with a toothpaste-like texture, is formed and the meat batter can be easily pumped (note: care should be taken to limit shear forces, which can cause fat globules to coalesce and destabilize the meat batter). The structure formed in the raw stage is shown in Figure 13.5.4.A. Later, during the initial heating process (20-40ºC), the fat starts to melt and is present in a liquid form. Myofibrillar protein denaturation and gelation starts at a higher temperature (around 50ºC; see Fig. 13.5.4.E). At that point, the melted fat starts to expand, collagen starts to be transformed into gelatin (i.e., liquid form), and the salt soluble proteins form a gel. The texture of the product at the end of the cooking process (70°C) is semi-rigid and does not flow anymore because the salt soluble proteins have been denatured. As indicated above, there is continuing debate about which mechanism is more important but today there is support for the notion that fat stabilization is a combination of the ability of proteins to form an interfacial film, as well as the formation of a gel matrix which physically restricts the movement of fat globules prior to cooking (Youssef and Barbut, 2011).

The thickness of the interfacial protein film, its elasticity, complete or partial coverage of the fat globules, and weak spots along the film have been discussed by various researchers (Borchert et al., 1967; Jones and Mandigo, 1982; Barbut, 1999; Ramirez-Suarez and Xiong, 2003). The authors discussed the formation of a relatively thin, flexible protein film around fat globules, and emphasized the importance of pore formation as a "pressure release mechanism" during the cooking stage (i.e., when fat is heated and expands). Some have experimentally modified the thickness of the protein film by varying chopping procedures. Overall, it appears that the formation of a relatively thin and flexible protein film provides the best stability, whereas a thick inflexible film results in large ruptured holes during cooking. Figure 13.6.3 illustrates the microstructure of stable and unstable finely comminuted meat products. In the stable product, fat globules are confined within a distinct globular structure. In the unstable product (in this figure caused

by Tween 80 addition) they are distorted in shape and start to form fat channels. Destabilization can also be caused by decreasing the salt level (e.g., 2.5 to 1.5%), which is associated with lower protein extractability and subsequently higher fat and moisture losses during cooking (Acton et al., 1983). The combined loss of fat and moisture from finely comminuted meat products has been mentioned by Schmidt (1984), who observed that fat exudation usually follows moisture loss. Schmidt postulated that the formation of channels through the meat batter was important to allow some moisture and fat losses. Figure 13.6.2 shows a fat globule that has lost some of its fat, during cooking, due to salt reduction in the raw meat formulation (2.5 to 1.5%). The scanning electron micrograph reveals a protein envelope around the fat globule. When too much fat is exuded from the globule, the protein envelope shrinks and indentations plus small exudative holes are seen on the surface. When salt is increased, little or no fat is lost and round globules can be seen. Whiting (1987) has also reported that 1.5% salt is a threshold in frankfurters, as determined by the amount of fat and water released during cooking. It should be mentioned that the amount of salt required to produce a stable batter also depends on factors such as the amount of fat and protein and their quality.

The connection between the texture of the meat protein matrix and the size of the fat globules can be seen in Table 13.6.1. Youssef et al. (2011) indicated that increasing the meat protein level (9–15%) increased the hardness of finely comminuted meat batters prepared with beef and animal fat or canola oil (CO). Overall, a higher protein level formed a denser protein network (microstructure not shown here), which had increased resistance to compression. The meat emulsions prepared with animal fat showed lower fracturability and hardness values compared to the CO emulsions. This is most probably due to the higher number of small CO globules present in a given volume (similar results were also shown for milk protein gels). In a previous experiment the authors showed that fat globule size was reduced from 6627 to 121 μm^2 when beef fat was substituted with CO at 8% protein. The same idea can also be seen here in Figure 13.6.3. Overall, the presence of smaller fat globules and higher protein increase resistance to compression. This is in line with the composite gels discussed at the beginning of the section.

The treatments with Tween 80 + animal fat resulted in higher fat and moisture losses than the CO-Tween 80 or animal fat treatments (Table 13.6.1). This resulted in an increased protein concentration and higher hardness values in the cooked products; i.e. they formed denser protein matrixes.

Table 13.6.1 Effects of meat protein level and fat type on texture profile analysis parameters of cooked finely comminuted meat batters Meat batters were produced with 9, 12 or 15% protein, with either beef fat (BF), or canola oil (CO; all treatments contain 25% fat or oil). An emulsifier (Tween 80 indicated as T-80) was added to one set of products, and sodium caseinate (SC) was used to replace 2% of the meat proteins in another set. M=meat protein; P*=indicates total protein when 2% SC was used. Data adapted from Youssef et al. (2011).

Treatment	Treatment Identification	Fracturability (N)	Hardness (N)	Springiness (cm)	Cohesiveness (ratio)	Chewiness (n cm)	Gumminess (N)
1	9M + BF	16.57 ± 0.24^{h}	17.13^{j}	0.68	0.22	2.56 ± 0.10^{hi}	3.76 ± 0.14^{j}
2	12M + BF	26.98 ± 0.38^{e}	33.99^{g}	0.77	0.26	6.80 ± 0.19^{f}	8.83 ± 0.17^{g}
3	15M + BF	29.99 ± 0.39^{abc}	61.50^{e}	0.79	0.28	13.60 ± 0.36^{c}	17.22 ± 0.28^{d}
4	9M + CO	29.53 ± 0.28^{bcd}	31.33^{g}	0.81	0.34	8.62 ± 0.25^{e}	10.65 ± 0.28^{f}
5	12M + CO	31.54 ± 0.48^{a}	66.35^{d}	0.81	0.46	24.72 ± 0.55^{a}	30.52 ± 0.60^{a}
6	15M + CO	29.27 ± 0.35^{bcd}	69.78^{c}	0.85	0.43	25.50 ± 0.67^{a}	30.00 ± 0.75^{a}
7	9M + BF-T80	19.38 ± 0.68^{g}	20.42^{i}	0.71	0.25	3.62 ± 0.20^{h}	5.10 ± 0.26^{i}
8	12M + BF-T80	29.01 ± 0.82^{cd}	46.27^{f}	0.76	0.31	10.90 ± 0.70^{d}	14.34 ± 0.90^{e}
9	15M + BF-T80	31.30 ± 0.44^{a}	73.69^{b}	0.78	0.37	21.26 ± 0.69^{b}	27.26 ± 0.45^{b}
10	9M + CO-T80	10.31 ± 0.44^{i}	13.78^{k}	0.57	0.23	1.80 ± 0.11^{i}	3.31 ± 0.12^{j}
11	12M + CO-T80	25.29 ± 0.66^{f}	27.71^{h}	0.71	0.26	5.11 ± 0.21^{g}	7.20 ± 0.21^{h}
12	15M + CO-T80	29.06 ± 0.50^{cd}	63.59^{e}	0.84	0.40	21.36 ± 0.33^{b}	26.45 ± 0.41^{c}
13	9P* + BF-SC	10.54 ± 0.33^{i}	12.48^{k}	0.60	0.21	1.57 ± 0.06^{i}	3.04 ± 0.07j
14	12P* + BF-SC	30.75 ± 0.68^{abc}	32.60^{g}	0.74	0.24	5.78 ± 0.21^{fg}	10.48 ± 0.21^{gh}
15	15P* + BF-SC	30.84 ± 0.55^{ab}	80.16^{a}	0.78	0.33	20.63 ± 0.85^{b}	29.48 ± 0.79^{c}
16	9P* + CO-SC	7.87 ± 0.47^{j}	11.73^{k}	0.59	0.26	1.79 ± 0.18^{i}	3.15 ± 0.19^{j}
17	12P* + CO-SC	27.98 ± 1.02^{de}	33.81^{g}	0.80	0.31	8.38 ± 0.53^{e}	10.73 ± 0.62^{f}
18	15P* + CO-SC	31.64 ± 0.61^{a}	71.91^{bc}	0.83	0.41	24.47 ± 0.66^{a}	31.23 ± 0.59^{a}

[a-p]Means within a column no common superscript are significantly different ($P < 0.05$).

The CO-T80 batters had lower hardness values than batters prepared with CO, possibly related to the formation of an incoherent protein matrix (Fig. 13.6.3). When Tween 80 surrounds fat globules it can interfere with the interaction of the interfacial protein film with the actual protein matrix. Theno and Schmidt (1978) observed that fat particles coated with proteinaceous material could cross link with the protein matrix and therefore stabilize frankfurters. It was suggested that the physical binding of fat might be the result of protein–protein interactions between the interfacial protein film and the matrix proteins.

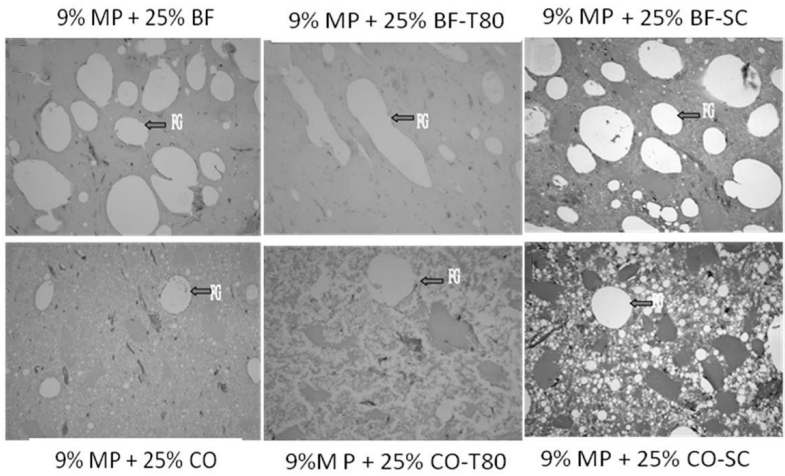


Figure 13.6.3 Light micrographs of meat batters with pre-emulsified fat/oil with T-80. Fat globule (FG); meat protein (MP); made with canola oil (CO), or beef fat (BF); pre-emulsified with Tween 80 (T80) or with the addition of sodium caseinate (SC). Bar = 200µm.
From Youssef et al. (2011). With permission.

The use of sodium caseinate (SC), which is used by the meat industry to stabilize fat, lowered fracture and hardness values at the 9% protein level (hardness of 12.48 vs. 17.13 N with and without SC, respectively) when 2% of meat proteins were replaced with SC. This was because SC cannot form a heat induced gel (at 72°C) and the amount of meat protein (7%) was insufficient to produce a hard texture. However, when 12% protein and 2% SC was used, the texture was comparable to the 12% meat protein. At 15% protein (13% meat protein and 2% SC), hardness surpassed the control (15% meat proteins). CO-SC batters showed reduction in hardness values at the 9% and 12% protein levels compared to the comparable CO treatments. This change in hardness indicates that incorporation of pre-emulsified fat/oil with SC can significantly modify the textural properties of meat batters.

Replacing beef fat with CO also increased springiness and cohesiveness; this is possibly related to the size and distribution of the fat globules (Table 13.6.1), which agrees with previously published data.

Overall, the control beef fat treatment revealed a typical meat batter in which fat globules are embedded within a homogenous protein matrix (Fig. 13.6.3). Microstructure was affected by the type of fat/oil and protein content. In all treatments, increasing protein resulted in the formation of a denser protein matrix structure, caused by the higher amount of extracted salt soluble proteins forming more protein–protein interactions. Replacing beef fat with CO showed a larger number of small, closely packed, fat globules compared to the beef fat treatment. This is because of the liquid nature of CO relative to the more solid nature of beef fat, which plays an important role during chopping. As meat protein level was raised in the CO emulsions, irregularly shape fat globules began to appear as fat globules coalesced into larger globules that later led to the formation of fat channels. The discontinuity of the protein matrix allowed fat and liquid to leach out of the matrix.

The beef fat -Tween 80 (BF - T80) showed more protein matrix aggregation than the beef fat treatment, suggesting that fat mobility overcame the ability of the protein matrix to contain the fat. This resulted in large irregularly shaped and elongated fat pools; this also caused meat batter instability (Fig. 13.6.3). The CO-Tween 80 treatment, at 9% protein, showed an incoherent matrix with very few fat globules with visible IPF. In the past, non-protein emulsifiers, particularly Tween 80, were shown to be preferentially absorbed by fat globules than meat proteins because of their higher hydrophilic–lipophilic balance values. This can reduce protein–lipid interactions by interfering with the adsorption of protein molecules to the fat globule surfaces and can result in decreased binding of fat globules to the protein matrix.

Pre-emulsification of fat/oil with sodium caseinate produced a finer dispersion of fat globules compared with the control (Fig. 13.6.3); this was probably because caseinate has a higher emulsifying capacity than lean beef meat. The protein matrixes were also less dense than in the all other meat matrixes. This is believed to be due to the dilution effect of replacing 2% meat protein with SC (which does not gel at 72°C).

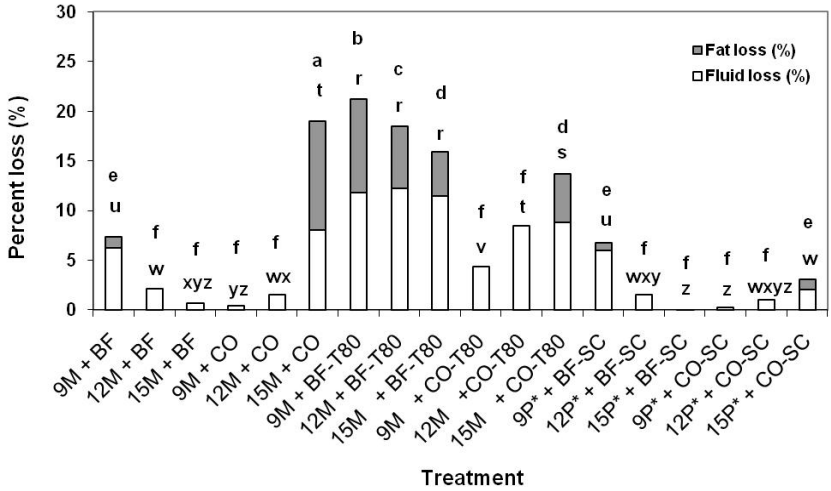


Figure 13.6.4 Means of fat and fluid losses of meat batters prepared with 25% beef fat (BF) or canola oil (CO) and pre-emulsified fat/oil with T-80 or sodium caseinate (SC) at different protein levels. All treatments contain 25% fat or oil; 2% of the meat protein was substituted with SC; M, meat protein; BF-T80, beef fat pre-emulsified with T-80; CO-T80, CO pre-emulsified with T-80; P, protein; BF-SC, beef fat pre-emulsified with SC; CO-SC, CO pre-emulsified with SC. Means related to fluid loss (r-z), and fat loss (a-f), with no common superscript are significantly different ($P < 0.05$). Last six treatments; 2% of the meat proteins (M) were substituted with SC and then denoted as P* to show total protein in the whole treatment.
From Youssef et al. (2011). With permission.

13.7 Casings

Meat and sausages have been stuffed into natural casings for thousands of years. Today this continues in the industry but with increased automation, a larger variety of pre-formed casings (Fig. 13.7.1), and the option for co-extrusion. The latter has been one of the most significant developments in sausage casings over the past century. This process allows continuous, direct deposit of an initially semi-liquid material (e.g., collagen paste) onto the product as it is extruded from the stuffer. This has allowed the industry to move from a batch type operation to a continuous operation (see also Chapter 1 discussing automation). The continuous operation is a key concept in reducing labour cost, increasing efficiency, and introducing more mechanization into the process. However, it should be pointed out that the process does not fit all products (e.g., large diameter sausages) and the initial capital cost can be high.

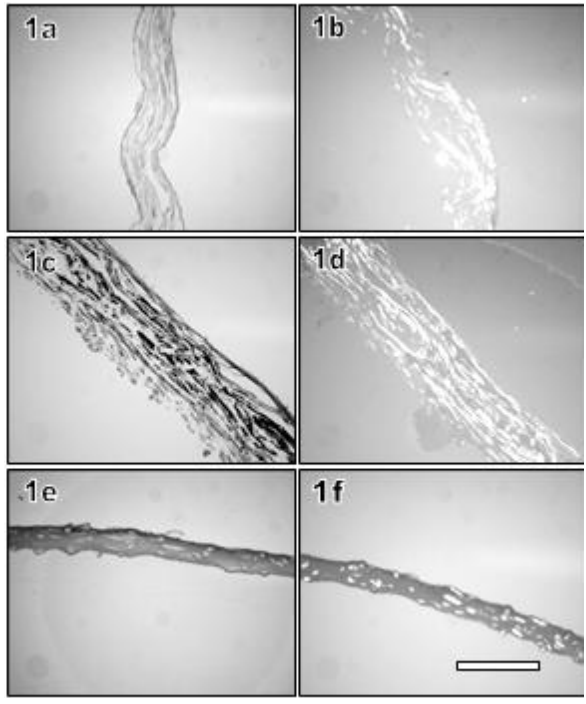
Figure 13.7.1 Different types of casings used for various meat products. Products made at the University of Guelph. Photo by S. Barbut.

When producing a sausage, the raw meat batter consists of ground/chopped meat which is a fairly viscous material that can be pumped and stuffed into different sized casings. During cooking, the meat proteins are denatured and form a heat stable gel (see Section 13.5). At that point, the cooked firm product can be removed from the casings (e.g., cellulose casings stripped off hot dogs at the meat plant), or by the consumer prior to slicing/consumption (e.g., salami casings removed at home by the consumer). In the case of edible casings (natural or manufactured collagen) the casing is left on the product (see recipe for European Style Chicken Weiners at the end of the chapter).

As mentioned above, humans have been using natural casings, such as those derived from the gastrointestinal tracts of sheep, cattle, etc., for thousands of years. These casings are still popular in certain products and to some represent the golden standard. Over the past century, there has been a rapid development of new packaging materials, including casings (Savić and Savić, 2002), and currently there are hundreds of different casings on the market. Overall, they can be divided into a few groups based on their origin.

a. Natural collagen casings are derived from the digestive tracts of sheep and hogs. Because of the bovine spongiform encephalopathy (BSE) problem, cattle

casings are not so popular today. Preparation of casings involves thorough cleaning, removal of the mucosa layer, and washing the casings several times. This is done in dedicated plants and requires a lot of manual labour. The cleaned and inspected casings are then stored in a saturated salt solution and have a shelf life of a few months. The microstructure of such casings can be seen in Figure 13.7.2, which shows the collagen fibers in the casing. These fibers provide elasticity during stuffing of the raw product and a bite/snap in the cooked product. The casings are permeable to water and smoke, and can shrink with the product since they adhere to the surface. This is a desired feature, especially in sausages that shrink during the smoke house operation and/or later on. An example for the latter is dry sausage manufacturing, where the product loses a substantial amount of water during the drying process (can be 30 – 50%), and loose casings will make the product unsalable. Most natural casings are edible and digestible, and do not need to be peeled off prior to consumption. However, if a very thick casing is used consumers will peel it off. Overall, natural casings are relatively expensive because of the labour involved in their cleaning and application. Today they are used for selected products to provide an "old fashioned" look and a certain "snap".



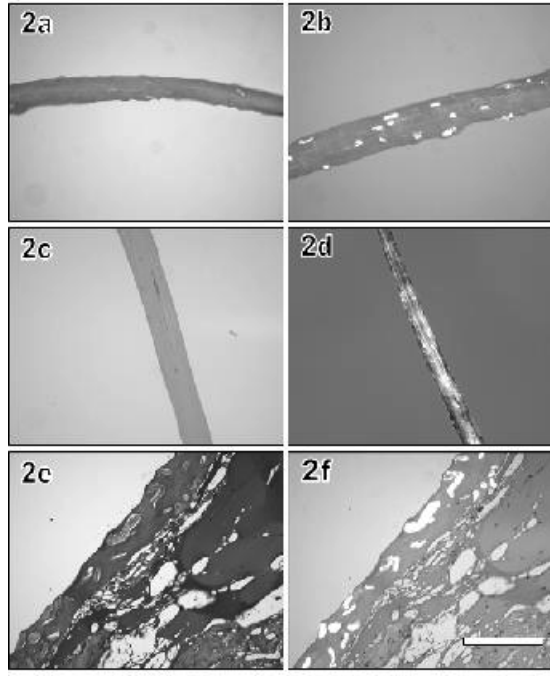


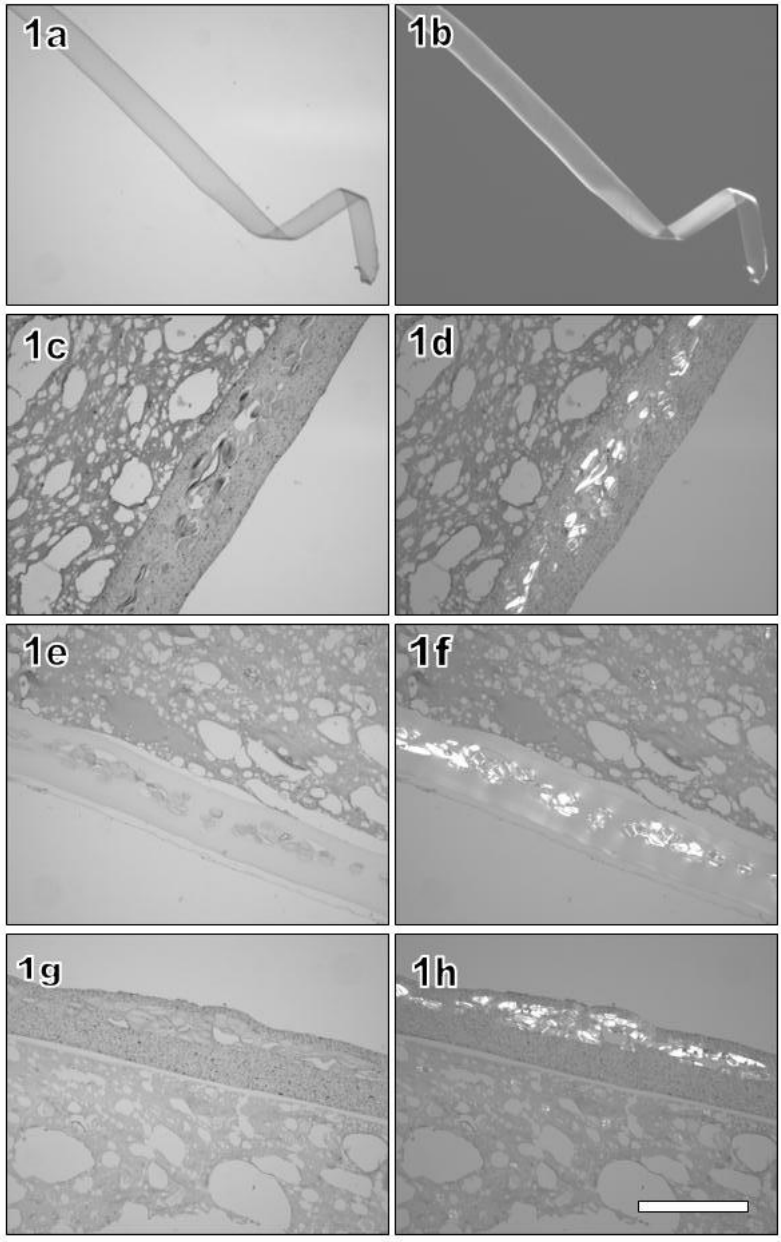
Figure 13.7.2 Light micrographs of raw collagen casings. First frame showing: (1a) and (1b) natural sheep; (1c) and (1d) natural hog; (1e) and (1f) manufactured collagen for fresh sausage. Polarized light was used in (1b), (1d) and (1f) to reveal connective tissue fibers. Second frame showing: (2a) and (2b) manufactured for smoked sausage; (2c) and (2d) manufactured for large diameter ring sausage; 2(e) and (2f) co-extruded; the lower right part shows the meat batter. Polarized light was used in (2b), (2d) and (2f) to reveal connective tissue fibers. Bar = 200 μm. From Barbut (2010). With permission.

b. Manufactured collagen casings are made from regenerated collagen extracted from the skins and hides of various red meat animals (Savić and Savić, 2002). The microstructure of such casings can be seen in Figure 13.7.2. The casings are usually edible (depending on the thickness) and therefore do not have to be removed prior to consumption. They are very uniform and do not have size variations or weak spots like the natural casings. Because of this, manufactured casings are easier to work with than natural casings. They are also very uniform, which is important for portion control, and they are less expensive to buy and require less labour (i.e., they arrive at the plant as a roll that can be put directly onto the stuffing horn). Since they can be made by extruding the regenerated collagen, they can be made with

different thicknesses and degrees of cross linking. They are made at special plants and cross linking agents such as ammonia or gluteraldehyde can be used as well as special colouring agents. Their microbial counts are much lower than natural casings since they are manufactured from collagen that was extracted at high pH. Like natural casings they are permeable to water and smoke and can also adhere to the product and shrink with it.

c. Co-extruded casings are made from pretty much the same material as the manufactured casings described above and are often made by the same companies. The collagen gel is usually sold to the industry as a 3.5 – 5.5% protein dough. It is used by the meat processor with a special counter rotating head (see Chapter 10 for description of the equipment) that dispenses the gel on top of the product while it is coming out of the stuffer. Later on, the casing is dewatered to some extent in a salt bath, dried in an oven, and the collagen molecules are cross-linked with liquid smoke (i.e., using the aldehyde components; see discussion on liquid smoke in this chapter). This is usually followed by a full cook cycle inside or outside a cook-in-bag. Note that there is also a process where alginate is used for co-extrusion but the sensory characteristics are different compared to collagen casings. New hybrid gels of collagen and alginate have also started to appear on the market (Harper et al., 2013).

d. Manufactured cellulose casings are very popular for the manufacturing of high volume products such as hot dogs, bologna, and salami. They are made from cotton liners and can be produced at various sizes (e.g., 1.5 to 15 cm in diameter). The microstructure of such casings can be seen in Figure 13.7.3. The casings are very strong and lend themselves to highly automated equipment. Because they are so uniform and manufacturers control the degree of stretching, portion control is easy. They are non-edible and have to be peeled off prior to consumption. In the case of many small diameter products such as hot dogs they are peeled at the plant by an automated high speed peeler. In the case of products such as large diameter salami, they are sometimes left on the product and peeled off by the consumer. Where some shrinkage of the product is expected, the inside of the casing is coated with protein to improve adherence to the product. Cellulose casings are water and smoke permeable unless they are coated with plastic (see below – combination casings). The casing can be dyed with different colours and information can be printed on them. They also have low microbial counts due to the way they are made. In order to keep them that way, they should be kept in a dry environment; otherwise mold can grow on them.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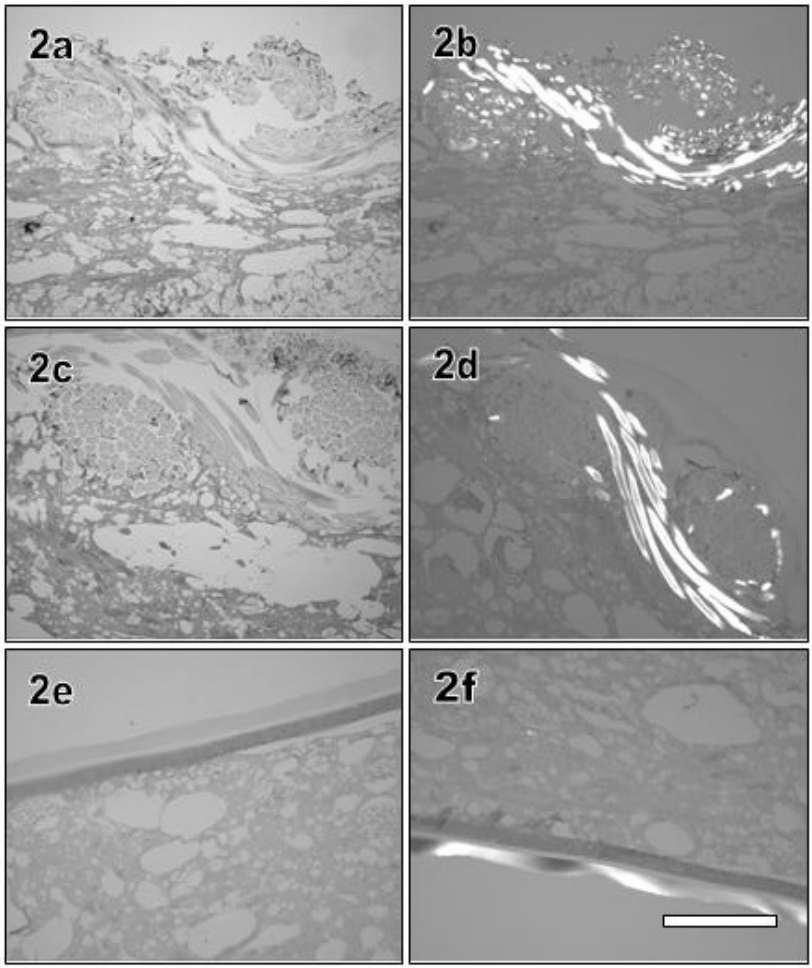
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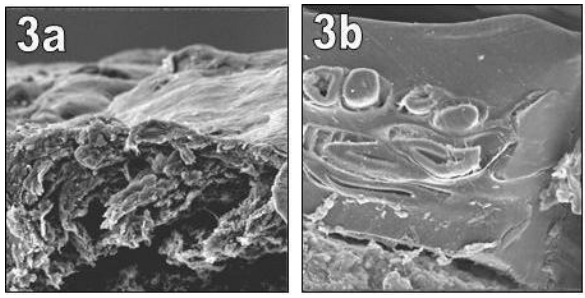
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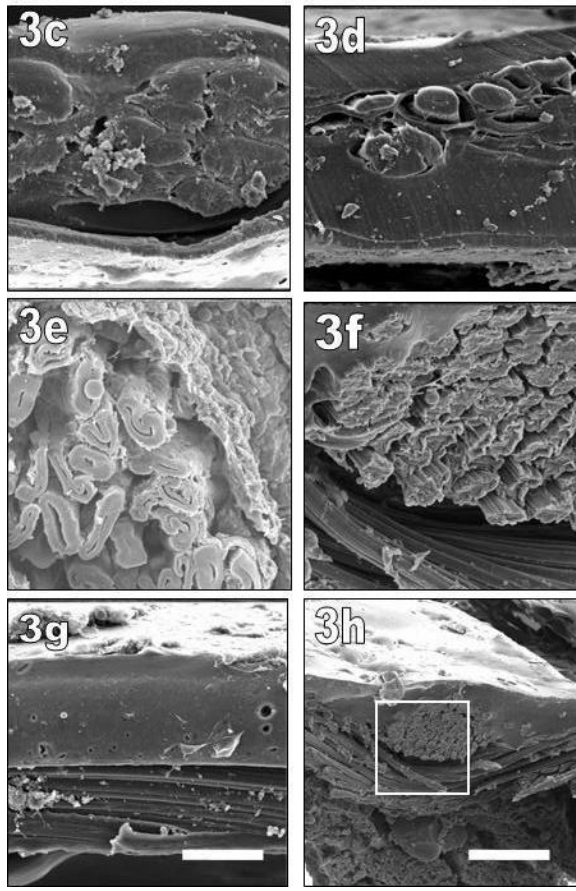

Figure 13.7.3 Light micrographs of cellulose and plastic casings. First frame shows: (1a) and (1b) thin cellulose type "Fast-peel"; (1c) and (1d) large diameter regular casings covering the actual meat batter; (1e) and (1f) outside polyvinylidene dichloride (PVDC) coated cellulose casings; (1g) and (1h) inside PVDC coated cellulose. Polarized light was used in (1b), (1d), (1f), and (1h) to reveal cellulose fibers. Bar = 200 μm. Second frame shows: (2a) and (2b) fibrous/cotton casing covering a meat batter; (2c) and (2d) outside coated fibrous/cotton; (2e) and (2f) extruded plastic casing. Polarized light was used in (2b), (2d) and (2f) to reveal cellulose fibers/special plastic. Bar = 200 μm. Third frame shows scanning electron micrographs of casings: (3a) thin cellulose type "Fast-peel"; (3b) large diameter cellulose sausage; (3c) outside PVDC coated cellulose; (3d) inside PVDCcoated cellulose; (3e) regular fibrous/cotton; (3f) outside coated fibrous/cotton; 3(g) extruded plastic; and (3h) lower magnification of micrograph "f" - see box. Bars = 25 μm for all, except (3h) which is 120 μm. From Barbut (2011). With permission.

e. Plastic polymer casings are very popular for water/steam cooked sausages because they are impermeable to water (this is advantageous as water is a more efficient medium to transfer heat than dry, hot air). A simple way to demonstrate this is by imagining putting your hand into an oven set at 100ºC compared to a boiling pot of water. Where smoking and drying of the sausage surface is not required, plastic casings represent a viable option. The microstructure of a plastic casing can be seen in Figure 13.7.3 and a product in this casing is shown in Figure 13.7.4. The micrograph shows the lamination of the layers and is basically a dense barrier. Extruded plastic casings are strong and uniform, and can therefore be used for very large diameter products. They also offer protection against oxidation since they are usually impermeable to oxygen. This also means that they are impermeable to smoke. Thus, if smoke flavourings are desired they should be added to the meat mix. There are also some new developments where liquid smoke can be applied to the inside of the casings prior to stuffing. Materials such as polyethylene, nylon and polypropylene are used as a single layer or as a combination of different layers in the manufacture of plastic polymer casings (Savić and Savić, 2002). These casings are extruded so usually there is no seam/weak point in the casing. The casings can be coloured and material printed on them can be used to describe the product (e.g., nutritional label). Casings can also be extruded with a UV-barrier so colour fading is not a problem (see Chapter 16).

Figure 13.7.4 Plastic casings used for a jelly meat loaf. Product made at the University of Guelph. Photo by Barbut.

f. Metal casings/molds are commonly used for canned meats (e.g., meat loaf processed at high temperature, 121ºC, in hermetically sealed cans) or for producing large sausages/hams/loaves at lower temperature (70 - 80ºC). The mold provides the product with a certain defined shape. This is important for large meat masses and it also helps in precise portion control when using high speed automated systems. In some cases, a cellulose or plastic casing is used to stuff the product before it is placed in a metal press to facilitate removal of the cooked product (no sticking and/or peeling surfaces) and cleaning of the molds. When plastic casings are used, prior to placing the meat in the mold, they are often left on the product after cooking and act as the packaging material that also provides a barrier against cross/re-contamination of the product. This technology can be seen in the preparation of oven roasted turkey breast, 4 × 4 hams, etc.

g. Retortable pouches are flexible pouches usually made from several layers of synthetic polymers, of which aluminum foil is one. They provide good moisture and oxygen barrier properties. It is interesting to note that although the pouch thickness appears small, it can contain a dozen different layers. The pouches can be used for meat products that are sterilized at high temperatures. Slices of meat loaf-type products and chicken soup/stew are commonly packaged in such a way and then retorted at a temperature of about 121ºC. The advantage of these thin pouches is that they can reach the desired cooking temperature much faster than a traditional round can. As with cans, the product is shelf stable after the heat treatment and no refrigeration is needed.

h. Combination casings are manufactured casings made from two or more materials such as collagen reinforced with a cotton mesh, or cotton fibers coated with plastic. Figure 13.7.3 shows an example of this where two components (cellulose and plastic) are included. By combining two or more layers, the processor can take advantage of both materials (e.g., strength of the plastic mesh with the smoke permeability of cellulose, or peeling ease of cellulose casings with the strength of large cotton fibers).

13.8 Formulations

In this section you will find various recipes of further processed meat products popular around the world. The recipes are courtesy of Hermann Laue Spice Company, Canada. These formulations are used by the industry but here they only serve as general guidelines and should be used as such. Also, local government regulations vary among countries (e.g., use of additives such as nitrite, phosphate) and therefore careful examination of local legislation is required. The section

contains formulations related to whole muscle products, restructured products, boneless, bone in, ground and emulsified products.

13.8.1 Smoked Chicken Roast – Naturally Cured

Ingredients

Meat:

- 72.0 kg boneless skinless chicken breast
- 8.0 kg white chicken trim

Brine:

- 20.0 kg

The brine is made by mixing:

- 12.0 kg cold water
- 3.4 kg ice flakes
- 1.7 kg sea salt
- 1.2 kg vinegar (serves as a bacteriostat)
- 1.0 kg evaporated cane sugar
- 0.6 kg fermented celery extract
- 0.058 kg onion powder
- 0.040 kg ground white pepper
- 0.002 kg rosemary extract

Processing

- Grind the chicken breast through a 25 mm plate.
- Grind the white chicken trim through a 5 mm plate.
- Mix the brine and add to the ground chicken meat inside a vacuum tumbler.
- Vacuum tumble for 1.5-2.0 hr at 10-12 rpm.
- Rest overnight.
- Firmly stuff the product into a 105 mm caliber, cellulose casings.
- Process in a preheated smokehouse.
- Heat at 55ºC and 30% RH for 30 min.
- Dry at 65ºC for 20 min.

- Hot smoke at 65ºC for 45 min or to the desired colour
- Steam cook at 85ºC to an internal temperature of 74ºC (Fig. 13.8.1.1).
- Chill down rapidly and store under refrigeration prior to shipping.

Figure 13.8.1.1 Oven roasted chicken. Photo by Barbut and Jinde.

13.8.2 Traditional Chicken/Turkey Roast (30% pump; optional 50% pump)

Ingredients

Meat:

- 100.0 kg boneless skinless chicken/turkey breast

Brine:

- 30.0 kg

The brine is made by mixing:

- 22.0 kg cold water
- 3.6 kg ice flakes
- 4.0 kg brine and cure unit (salt, sugar, phosphate, erythorbate, nitrite)

- 0.4 kg roast seasonings (natural roast flavour, spices)
- Spice rub: 6 g roast flavoured rub mixed with 18 ml of water, per 1 kg of tumbled roast.

Processing

- Inject the turkey breast meat with 30% brine.
- Vacuum tumble for 4 hr at 12-15 rpm; start immediately after injecting. Rest overnight and tumble for 1½ hr at 12-15 rpm.
- Combine 2 turkey breasts together (thick end over thin end) and wrap with a collagen film before stuffing it into a net #22-3 (i.e., a net with 22 squares around the circumference made up of 3 stitches between squares). Clip both ends of the net.
- Mix 5 parts of roast flavoured rub together with 3 parts of water until a thick paste has been formed and rub the roasts evenly.
- Place roasts on smoke screens, place in an oven and cook.
- Dry at 90°C for 1 hr or until the surface is completely dry.
- Steam cook at 78°C to an internal temperature of 71°C (Fig. 13.8.2.1).
- Shower with cold water to cool down quickly.
- Note: a 50% pump roast can also be made by adding 50 kg brine to 100 kg of boneless skinless turkey/chicken breast meat. The brine consists of 35 kg cold water, 9 kg of ice flakes, 5 kg of turkey/chicken roast brine unit (salt, sugar, phosphate) and 1.3 kg spice unit (soy protein isolate, sugar, spice extracts).

Figure 13.8.2.1 Oven roasted chicken prepared in netting.
Photo by Barbut and Jinde.

13.8.3 Smoked Turkey Roast

Ingredients

Similar to previously described Traditional Chicken/Turkey Roast.

Processing

Similar to injection and stuffing of Traditional Chicken/Turkey Roast.

- Dry at 65°C for 45-60 min.
- Hot smoke at 65°C for 1.5 hr or to the desired colour.
- Steam-cook at 78°C to an internal temperature of 71°C (Fig. 13.8.3.1).
- Shower with cold water to cool down quickly.

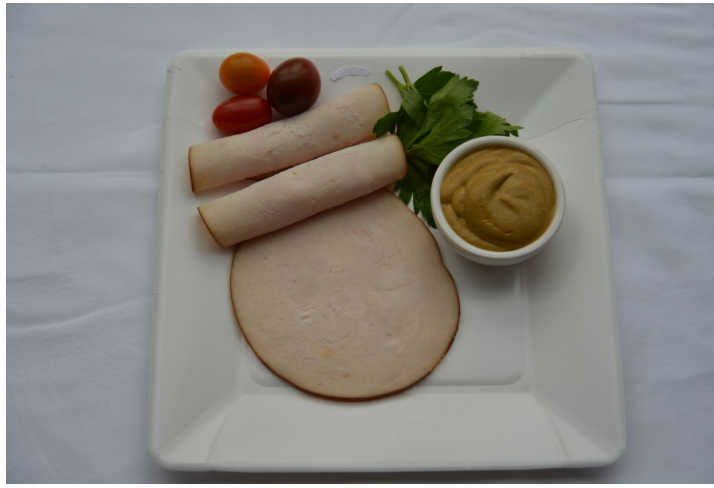

Figure 13.8.3.1 Oven roasted turkey. Photo by Barbut and Jinde.

13.8.4 Turkey Roast Slicing Log – Salt Free

Ingredients

Meat:

- 100.0 kg skinless turkey breast

Brine:

- 15.0 kg

The brine is made by mixing:

- 7.2 kg cold water
- 2.8 kg potassium lactate/diacetate
- 4.28 kg salt free turkey roast pumping unit
- 0.72 kg transglutaminase powder

Processing

- Grind the turkey breast meat through a kidney plate.
- Mix the transglutaminase with cold water.
- Mix the ground turkey meat with the dry ingredients for 8 min.
- Add the transglutaminase slurry and mix for 8 min.
- Add the potassium lactate/diacetate and mix for 4 min.
- Firmly stuff into moisture proof casings of desired caliber.
- Store under refrigeration for at least 2-3 hr prior to cooking (time for enzyme to work).
- Steam cook at 80ºC to an internal temperature of 72ºC.
- Cool down quickly with a cold water shower.

13.8.5 Smoked Chicken Ham – Naturally Cured

Ingredients

Meat:

- 72.0 kg chicken thigh meat (defatted)
- 8.0 kg chicken drum meat

Brine:

- 20.0 kg

The brine is made by mixing:

- 12.0 kg cold water
- 3.3 kg ice flakes
- 1.8 kg sea salt

- 1.25 kg vinegar (serves as a bacteriostat)
- 0.90 kg evaporated cane sugar
- 0.600 kg fermented celery extract
- 0.058 kg onion powder
- 0.050 kg sweet cherry powder
- 0.040 kg garlic powder
- 0.002 kg rosemary extract

Processing

- Grind the chicken thigh meat through a 25 mm plate.
- Grind the drum meat chicken trim through a 3 mm plate.
- Mix the brine and add to the ground chicken meat in a vacuum tumbler.
- Vacuum tumble for 2.5 hr at 10-12 rpm.
- Rest overnight and vacuum tumble for 20 min.
- Firmly stuff the product into a 105 mm caliber, cellulose casings.
- Process in a preheated smokehouse.
- Heat at 55ºC and 30% RH for 30 min.
- Dry at 65ºC for 20 min.
- Hot smoke at 65ºC for 45 min or to the desired colour
- Steam cook at 85ºC to an internal temperature of 74ºC.
- Chill down rapidly and store under refrigeration prior to shipping.

13.8.6 Turkey Ham (4 × 6)

Ingredients

Meat:

- 100 kg boneless lean turkey thigh meat

Brine:

- 40 kg

The brine is made by mixing:

- 28 kg cold water
- 6.5 kg ice
- 5.5 kg brine and cure unit
- (salt, soy/whey proteins, phosphate, spices, erythorbate, nitrite)

Processing

- Lacerate the turkey thigh meat (especially from the skin side) to increase the surface area.
- Tumble the meat with the brine in a well-chilled vacuum tumbler for 6 hr at 12-15 rpm.
- Rest overnight and tumble for 1.5 hr the next day.
- Stuff the meat into cook-in-bags (also referred to as "cook & ship bags").
- Place hams into 4 × 6 inches ham molds and press firmly.
- Cook in a smoke house by using steam at a temperature of 78°C, until reaching an internal temperature of 71°C (Fig. 13.8.6.1).
- Shower with cold water to chill quickly prior to transferring to a refrigerator.

Figure 13.8.6.1 Turkey ham. Photo by Barbut and Jinde.

13.8.7 Turkey Pastrami

Ingredients

Meat:

- 100 kg skinless turkey breast

Brine:

- 50 kg

The brine is made by mixing:

- 14.0 kg cold water
- 12.3 kg ice flakes
- 8.7 kg sodium lactate/diacetate
- 1.85 kg brown sugar
- 0.35 kg pastrami liquid seasoning
- 13.5 kg brine and cure unit
- (salt, soy/whey proteins, phosphate, spices, erythorbate, nitrite)
- Rub per 1.0 kg of tumbled turkey breast: 10g fine/coarse pastrami rub.

Processing

- Completely dissolve all of the dry ingredients in the cold water.
- Add ice and the sodium lactate/diacetate and mix until all of the ice has melted.
- Pump the turkey breast 50% and immediately start the tumbling process.
- Vacuum tumble for 3-4 hrs at 10-12 rpm.
- Rest under refrigeration overnight and tumble again for 30 min under vacuum.
- Add the spices and rub ingredients into the tumbler and tumble at slow speed until an even coating is created.
- Place the turkey breast onto smoke screens and process in the smokehouse:
- Dry at 75°C for 1 hr or until the surface feels dry.
- Hot smoke at 65°C for 30 min.
- Steam cook at 78°C to an internal temperature of 71°C.
- Shower for 5 min, then quick chill with air.
- Store under refrigeration overnight prior to shipping.

13.8.8 Regular Smoked Turkey Sausage

Ingredients

Emulsion part (60 kg):

- 42.0 kg turkey thigh meat (first ground 3 mm)
- 8.0 kg turkey skin (frozen, first ground 3 mm)
- 10.0 kg ice

Coarse insert (40 kg):

- 34.0 kg turkey thighs (ground 5 mm)
- 6.0 kg cold water

Spice and ingredients:

- 3.0 kg seasoned binder (salt, potato starch, dextrose, spices, erythorbate)
- 1.0 kg brown sugar
- 0.3 kg curing salt
- 0.3 kg phosphate
- 0.2 kg garlic powder
- 0.1 kg black pepper (fine grind)

Processing

- Mix the coarse ground meat, one day prior to processing, together with water and 40% of the spice and ingredient mix, until a good bind develops. Store the meat under refrigeration overnight.
- Chop the ground meat and skin, intended for the emulsion part, while adding the rest of the spice and ingredient mix. Chop for a few revolutions at the slow speed before adding about half of the ice. Continue cutting at high speed to a temperature of 12°C, add the rest of the ice and proceed cutting to a final temperature of 8°C.
- Add the pre-seasoned coarse insert and mix well before cutting at slow speed to the desired size.
- Stuff the meat into collagen casings (caliber 29/32) or any other smoked sausage casing.
- Dry in a smoke house at 55°C for 15 min.
- Hot smoke at 60°C, 25-30% relative humidity for 30 min or desired colour is reached.

- Steam cook at 78°C to an internal temperature of 71°C.
- Shower with cold water for fast cooling.

13.8.9 Smoked Maple Flavour Turkey Sausage

Ingredients

Emulsion part (60 kg):

- 50.0 kg skin on turkey thigh meat (first ground 3 mm)
- 10.0 kg ice

Coarse insert (40 kg):

- 25.0 kg turkey drum meat (ground 5 mm)
- 5.0 kg turkey skin and fat
- 10.0 kg cold water

Spice and ingredients:

- 3.0 kg seasoned binder
- 1.0 kg maple flavour
- 1.5 kg brown sugar
- 1.0 kg specialty starch
- 0.3 kg curing salts (erythorbate, nitrite)
- 0.3 kg phosphate
- 0.1 kg black pepper (32 mesh)

Processing

- Follow procedure of previous product (Turkey Sausage) up to the stuffing stage.
- Stuff into collagen casings, caliber 32/35 and link to 110g.
- Warm up in a smokehouse set at 55ºC and 40% RH for 20 min.
- Dry at 65ºC for 20 min.
- Hot smoke at 65ºC for 40 min or to the desired colour.
- Steam cook at 80ºC to a core temperature of 71ºC.
- Cool down with shower and store under refrigeration overnight prior to packaging.

13.8.10 Tikka Masala Fresh Chicken Sausage

Ingredients

Meat:

- 30.0 kg chicken breast (ground 8 mm)
- 55.0 kg chicken thigh (ground 8 mm)
- 15.0 kg cold water

Spices and ingredients:

- 16.0 kg salt
- 5.0 kg Tikka Masala seasoning unit
- 1.0 kg potato starch
- 0.2 kg phosphate

Processing

- Mix the ground chicken meat with all the ingredients until a good bind has developed.
- Add the water in 2-3 steps while mixing.
- Stuff the meat batter into collagen casings of desired caliber, link to the desired weight and pack. Product to be kept refrigerated or frozen prior to shipping.

13.8.11 Turkey Kielbasa

Ingredients

Coarse meat insert (70 kg):

- 59.0 kg lean turkey thighs (ground 25 mm)
- 11.0 kg cold water

Fine meat part (30 kg):

- 25.0 kg turkey thighs (ground 3 mm)
- 5.0 kg cold water

Spice ingredients:

- 1.9 kg salt
- 0.9 kg kielbasa seasoning
- 0.8 kg brown sugar
- 0.6 kg curing salt (includes erythorbate and nitrite)
- 0.3 kg phosphate

Processing

- One day prior to processing, put the coarse meat in a vacuum-tumbler for 1.5 hr together with water and 70% of the dry ingredients.
- Cover and store the tumbled coarse insert under refrigeration overnight.
- Immediately before processing, tumble/mix again for 10 min.
- Mix the fine ground turkey thigh meat together with the rest of the dry ingredients and water, until a good bind has developed.
- Add the tumbled coarse material to the fine ground meat and mix together to an even distribution and a good bind.
- Stuff the batter into collagen ring casings cal. 52 mm.
- Process the product in a smokehouse:
- Warm at 50ºC and 40% humidity for 30 min.
- Dry at 60ºC for 15 min.
- Hot smoke at 60ºC for 45 min or to the desired colour.
- Steam-cook at 78ºC to a core temperature of 71ºC (Fig. 13.8.11.1).
- Product to be cooled down with shower.
- Store under refrigeration overnight prior to shipping.

Figure 13.8.11.1 Turkey kielbasa. Photo by Barbut and Jinde.

13.8.12 European Style Chicken Wieners

Ingredients

Meat:

- 40.0 kg chicken thigh meat
- 26.0 kg chicken drum meat
- 7.0 kg fine textured chicken meat (frozen)
- 5.0 kg chicken skin and fat

Ice:

- 28.0 kg

Spices and additives:

- 1.7 kg salt
- 1.4 kg dextrose
- 1.0 kg modified starch
- 0.8 kg Wiener seasoning
- 0.6 kg curing salt (with erythorbate and nitrite)
- 0.2 kg phosphate
- 0.1 kg paprika
- 0.1 kg onion powder

Processing

- Grind all meats and skin through a 3 mm plate.
- Use a bowl cutter to cut the meat for a few revolutions at slow speed before adding all of the spices and ingredients plus 1/3 of the ice.
- Cut at high speed to 8 - 10ºC.
- Add the remaining ice in 2 steps while cutting at high speed to 6ºC.
- Cut at slow speed to 8ºC.
- Stuff into sheep casings and link to the desired size.
- Smoke and cook:
- Pre heat in a smokehouse at 55ºC and 40% RH for 20 min.
- Dry at 65ºC for 15 min.
- Hot smoke at 65ºC for 30 min.
- Steam-cook at 78ºC to a core temperature of 71ºC (Fig. 13.8.12.1).
- Cool down with a cold water shower.
- Store under refrigeration overnight prior to packaging.

Figure 13.8.12.1 Chicken wieners. Photo by Barbut and Jinde.

13.8.13 Chicken/Turkey Hot Dogs/Bologna

Ingredients

Meat:

- 86.0 kg mechanically deboned chicken/turkey meat

Ice:

- 14.0 kg

Spices and additives:

- Binder unit – 8.70 kg (salt, soy/whey proteins, spices, erythorbate)
- Curing salt – 0.3 kg (includes nitrite)
- Phosphate – 0.3 kg

Processing

- Slowly cut the slightly frozen meat with about 5 kg of flaked ice in a bowl chopper for a few revolutions.
- Add the binder unit, salt and phosphate and chop at the high speed setting while adding the rest of the ice until temperature reaches 8-10°C.

- Remove the emulsion from the chopper.
- Stuff into easy-peel hot dog casings and link to desired size.
- Place the product on a smoke house tree.

Smoke and cook:

- Dry the surfaces in a smoke house at 55ºC for 5 min or as required.
- Hot smoke at 55°C and 25% RH for 20-30 min.
- Steam cook at 75°C to an internal temperature of 71°C (Fig. 13.8.13.1).
- Shower with cold water for 10 min.
- Refrigerate overnight prior to peeling the casings.
- Note: for bologna – use the same formulation and procedure, and then stuff into large diameter cellulose or fibrous casings. Heat process should be lengthened to achieve a 71°C internal temperature.

Figure 13.8.13.1 Chicken bologna. Photo by Barbut and Jinde.

13.8.14 Turkey Pepperoni Sticks

Ingredients

Meat:

- 60.0 kg turkey thigh meat
- 22.0 kg turkey drum meat

Water:

- 18.0 kg cold water

Spices and additives:

- 1.7 kg salt
- 1.5 kg mild pepperoni seasoning
- 1.5 kg potato starch
- 1.2 kg liquid vinegar
- 1.0 kg corn syrup solids
- 0.6 kg curing salt (including erythorbate and nitrite)
- 0.3 kg phosphate

Processing

- Grind the turkey thigh meat through the 5 mm plate.
- Grind the turkey drum meat through the 3 mm plate.
- Mix for 2 – 3 min all the meat and dry ingredients before adding 6 kg of the cold water.
- Add the remaining water in 2 steps while mixing to a good bind.
- Stuff into collagen casings (19 – 21 mm caliber) and link to 60 – 65 g.
- Smoke and cook:
- Use a smoke house to dry the surfaces at 65ºC for 20 min.
- Hot smoke at 65ºC for 20 min or to the desired colour.
- Cook at 70ºC and 60% RH for 20 min.
- Cook at 78ºC and 60% RH to a core temperature of 71ºC (Fig. 13.8.14.1).
- Cool down with shower and store under refrigeration overnight prior to packaging.

Figure 13.8.14.1 Turkey pepperoni sticks. Photo by Barbut and Jinde.

13.8.15 Hot Habanero Turkey Sticks

Ingredients

Meat:

- 40.0 kg turkey drum meat, ground 3 mm
- 10.0 kg turkey fat, frozen, ground 5 mm
- 50.0 kg turkey thigh, ground 5 mm

Spices and cure:

- 5.55 kg seasoning and cure mix (salt, dextrose, paprika, spices, erythorbate, nitrite)

Processing

- Mix all of the ground meat and fat together with the spices and cure until a good bind has developed.
- Stuff the batter into natural casings or collagen casings (calibre 15-20 mm).
- Process the product in a smokehouse:
- Dry heat at 55°C for 2 hr.
- Dry heat at 60°C for 1 hr.
- Dry heat at 65°C for 1 hr.
- Dry heat at 72°C for 1 hr or until the desired dryness is reached.
- If desired, hot smoke can be applied during the second drying cycle.
- Product to be air cooled only.

13.8.16 Honey Garlic Marinated Chicken Wings

Ingredients

Meat:

- 90.0 kg chicken wings

Water:

- 10.0 kg (cold)

Spice:

- 5.5 kg honey garlic marinade (sugar, salt, garlic, natural honey flavour, vinegar, spices)

Processing

- Dissolve the spice unit in the cold water.
- Vacuum tumble the well-chilled chicken wings together with the liquid marinade; use slow speed for 30-45 min.
- Remove the marinated chicken wings from the tumbler and pack in vacuum bags or immediately freeze (IQF).
- Keep product refrigerated or frozen prior to shipping.
- Cook at home/restaurant to 72 C internal (Fig. 13.8.16.1).

Figure 13.8.16.1 Chicken wings. Photo by Barbut and Jinde.

13.8.17 Mesquite Chicken Wings

Ingredients

Meat:

- 95.0 kg chicken split wings

Water:

- 5.0 kg (cold)

Spice:

- 5.0 kg Mesquite marinade

Processing

- Put the fresh chicken wings into a vacuum tumbler.
- Mix the BBQ marinade together with the cold water and add to tumbler.
- Vacuum tumble for 15-20 min.
- Remove the seasoned chicken wings from the tumbler, tray pack and overwrap.

13.8.18 Ginger Lemon Chicken Drum Sticks

Ingredients

Meat:

- 85.0 kg chicken drum sticks

Water:

- 15.0 kg (cold)

Spice:

- 6.5 kg ginger lemon marinade
- (salt, sugar, lemon juice, spices)

Processing

- Mix the spices together with the cold water.
- Vacuum tumble the well-chilled chicken drum sticks together with the liquid marinade; use slow speed for 30-45 min.
- Remove the marinated chicken drum sticks from the tumbler and pack in plastic bags or immediately freeze.

- Note: other variations, such as Hot Buffalo Chicken Wings can also be made the same way, but with a different spice mix.
- Keep product refrigerated or frozen prior to shipping.

13.8.19 Caribbean Jerk Chicken Drum Sticks

Ingredients

Meat:

- 95.0 kg chicken drum sticks

Water:

- 5.0 kg (cold)

Spice:

- 1.2 kg salt, fine
- 1.5 kg Caribbean Jerk seasoning
- 0.2 kg phosphate

Processing

- Place the well chilled fresh chicken drum sticks into a vacuum tumbler.
- Dissolve the dry ingredients in the cold water and vacuum tumble for 15 – 20 min.
- Remove the seasoned chicken drum sticks from the tumbler, tray pack and overwrap.

13.8.20 Fajita – Chicken/turkey/duck/goose

Ingredients

Meat:

- 82.0 kg chicken/turkey/duck/goose breast filets or breast strips
- 14.8 kg cold water

Spice:

- 3.2 kg chicken Fajita seasoning (salt, dextrose, soy sauce powder, phosphate, garlic powder, spices)

Processing

- Completely dissolve the Fajita seasoning in the cold water.
- Vacuum tumble the chicken meat and seasoning solution for 40-50 min at 8-10 rpm.
- The marinated chicken strips can then be individually quick frozen (IQF) and packed or put onto a skewer and frozen.
- Prior to serving, pan fry together with red, yellow and green bell pepper strips and fresh or frozen diced onions.
- Serve on pita bread or in taco shells; a sauce can be added if desired.

13.8.21 Jellied Chicken/Turkey/Duck Roll

Ingredients

Meat:

- 45 kg white turkey/chicken roast (see second recipe)

Vegetables:

- 15 kg canned mushrooms and/or broccoli heads

Gelatin:

- 40 kg gelatin solution (7 kg seasoned gelatin powder plus water)

Processing

- Dice the chicken/turkey roast into approximately 1 × 1 × 1 cm cubes.
- Rinse the mushrooms (and/or broccoli) with hot water and mix with the diced meat.
- Completely dissolve the dry gelatin powder in hot water (> 80°C). You can add a little bit of oil to the hot water to avoid foaming.
- Fill clear plastic casings (e.g., 12 cm diameter) with the diced meat and vegetable mix.

- Add the proper amount of gelatin solution into the casings and remove all air bubbles prior to clipping.
- Cool down in a cold water bath (see Fig 13.7.4).

13.8.22 Chicken/Turkey/Duck Chili Con Carne

Ingredients

Meat:

- 31.25 kg chicken/turkey/duck thigh meat

Vegetables:

- 25.00 kg red kidney beans (canned)
- 28.15 kg ground tomatoes (canned)
- 7.80 kg diced onions (frozen)
- 7.80 kg hot water

Spice:

- 2.62 kg chili seasoning mix
- (sugar, salt, paprika, garlic powder, spice)

Processing

- Grind chicken/turkey thigh meat through a 3 mm plate.
- Mix ground meat together with the chili seasoning mix and hot water. Cook in a steam kettle over medium/high heat until meat is well done.
- Add all of the canned and frozen vegetables, bring to a boil and simmer over medium heat for 10-15 min.
- Cool down completely prior to packing.

13.8.23 Chicken Nuggets

See Chapter 14

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