CHAPTER 15
Fermented Meat Products

15.1 Introduction

Spoilage of fresh meat by indigenous microorganisms is unavoidable unless the meat is preserved or cured in some manner. In the production of meat products, some manufacturers still depend on naturally occurring microflora to ferment meat, while most use starter cultures consisting of a single species or multiple species of lactic acid bacteria (LAB), staphylococci, and/or micrococci. Understanding the technological, microbiological, and biochemical processes that occur during meat fermentation is essential to ensure safe palatable products. Meat fermentation is a method for improving the keeping qualities of perishable meats. The combination of lactic acid fermentation with salting and drying produces shelf-stable products at ambient temperatures. Meat fermentation is solid substrate-type fermentation with bacteria growing in microcolonies. Some of the fermented meat products are sausage and ham, among others.

15.2 Sausages

The manufacture of sausages began many thousand years ago, and it is still a growing industry. While some of its basic practices are almost as old as human civilization, the industry is constantly adopting new developments in the scientific and technical knowledge. Ancient civilizations made and consumed sausages some thousands of years ago; for example, sausages were used by Egyptians as early as 2000 BC. The Romans made "circelli," "tomacinae," "butuli," and other types of delicious sausage products that were eaten during annual orgiastic festivals and sacrifices. Sausages made of tripes were particularly consumed by the poorer classes of the Roman population. The early Christian Church prohibited the consumption of sausages in Rome for many years.

The modern word "sausage" is derived from the Latin "salsus," meaning salted. The term was probably originally applied to cured or salted meat. In the olden days, people did not had refrigeration to preserve the meat, so making sausages was a way of overcoming this problem. Various types of sausages have been produced through the years in different localities under the climatic and social

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conditions of various geographical areas. Some parts of the world with periods of cold climate, such as northern Europe, were able to keep the fresh sausages without refrigeration during the cold months. Furthermore, sausages are a relatively safe product to consume due to the use of salt, pH, curing, drying, and cooking to preserve the product and eliminate harmful bacteria. Sausages are excellent source of high-quality proteins, containing all the essential amino acids in appropriate amounts necessary for growth, maintenance, and repair of body tissue. Sausage also provides significant amounts of vitamins and minerals.

15.2.1 Some Steps Used in Sausage Production

15.2.1.1 Raw Materials

The use of chilled meat with a low pH (about 5.6) is most suitable. Soft intramuscular fatty tissue should be thoroughly removed. Spices contribute flavor to sausages, but they have an inhibitory and stimulatory activity on certain bacteria. *Lactobacillus plantarum* is stimulated by different spices with respect to growth and acid production.

15.2.1.2 Grinding, Chopping, and Mixing

Methods of grinding and chopping vary widely for the different types of semidry or dry sausages. Grinding and chopping are used for the extraction of proteins while improving the spreading or slicing properties of the finished product, but they increase the possibility of contamination. Beef is normally chopped first and then other ingredients are added. Salt is added at the very end of chopping. The chopped meat mass should be well mixed with other ingredients.

15.2.1.3 Stuffing

The mixture should be immediately stuffed while held at refrigerator temperature to enable the curing process and stabilization of microflora. After remixing the meat mixture again in the mixer, the meat mix is stuffed into precooked salted goat or sheep casings (or artificial casings) as firmly as possible to exclude air pockets. Remaining air inside the casing will produce unsatisfactory results: discolor the meat, reduce the shelf life of the sausage, uneven cooling, non-uniform weight, and curving of the product. The air pockets under the casings are punctured wherever they are excluded by kneading; at the same time, the meat should be covered to eliminate its contact with air. After the sausage has been stuffed, the open end is tied (clipped) and a loop is formed.

15.2.1.4 Treatment

The stuffed sausages are kept in a special place or room to enable the surface moisture to escape at 22 °C and relative humidity (RH) below 80%. The sausages must neither dry too fast nor retain surface moisture and become slimy. Another alternative is to hang the sausages overnight in a chiller at 6–8 °C. If the sausage casings are overdried, smoke will not penetrate.

15.2.1.5 Smoking (Optional)

Smoke is applied from several days to 3 weeks. The smoke density and its distribution in the smokehouse are maintained at the required level with equipment provided for controlling air circulation, temperature, and humidity. Resinous woods impart an unpleasant flavor to product. Soft woods have low resin content and produce a large amount of soot that colors the product. Hardwoods (oak, beech, maple, birch, walnut, cedar, hickory, etc.) are most commonly used to generate smoke. Each smoke compound (acids, aldehydes, and phenols) is active in the hot smoking process. Acids and other smoke components can cause skin formation on the surface of sausages by penetrating the cellulose casing. Smoke penetration may be greater through natural casings. The bacteriostatic and fungistatic effects of smoke depend on the level of the smoke production temperature, which is usually varied between 300 and 400 °C. Smoke gives flavor properties to sausages.

During the hot smoking process, the relative humidity should be maintained at about 80%. A too low humidity causes the formation of a dehydrated protein shell on the sausage surface as well as excessive weight loss and shriveled appearance of the product. High-temperature smoking normally shortens the time of smoking, but processing in a too hot smokehouse induces weight loss and rupture of cellulose casings, while too cold smoking hardens the casings.

Liquid smoke is a water-soluble chemical solution containing smoke flavor that can be sprayed on the sausages while they are in the smokehouse. Liquid smoke is produced by the condensation and fractional distillation of hardwood smoke. Liquid smokes are free of carcinogenic compounds. Liquid smoking cannot give same flavor as wood smoking.

15.2.1.6 Cooking (Optional)

Cooking follows immediately after smoking. There are many methods of cooking: by immersing in the cooking vat, hot showering in a smokehouse, hot showering in separate hot water spray cabinets, cooking by dry heat by raising the smokehouse temperature, cooking in tight boxes through injection of steam, and so on.

If water sprays are used in cooking, the temperature is about 82 °C. The temperature of water in cooking vats may be around 76 °C. An internal sausage temperature of 65 °C is considered as minimum and 68 °C is an optimum endpoint temperature. The cooking provides a sufficient shelf life of the product and desired organoleptic characteristics. The cooking usually requires about 20 min. After cooking in vats, sausages are hot showered to remove any adhering grease.

15.2.1.7 Drying

Drying (or aging) is a key operation in dry sausage production. The drying rate for dry sausages should be as low as possible. The most critical point in drying is to avoid the pronounced surface coagulation of proteins and the formation of sausage surface skin. If the sausages lose moisture too rapidly during the initial stages of the drying period, the surface becomes hardened and a crust or ring develops immediately adjacent to the casing. This hardened ring inhibits further transmission of moisture and the sausage has an excessively moist center. The use of a lower RH at the beginning of the process will permit moisture to migrate from the interior of the sausage to the outer layer. If the drying rate is adequately slow, the sausage casing will enable gradual drying. Thus, the sausage should dry from the inside to outward.

At the start of the drying and smoking process, RH can be as high as 98%. In the following 2–4 days, the RH must be slowly reduced. In that manner, the drying rate at the surface will be kept as low as possible. It is advisable to regulate the RH according to the decrease in water activity (a_w) value of the product. Thus, the air RH should be approximately 4% lower than the a_w value of the product. For instance, when the a_w value of the product is 0.96, the optimum RH of the smokehouse should be about 92%.

Too much humidity in the drying room favors the development of molds and sliming of products. Some producers do not object to a light white surface mold at the very beginning of the drying process. When fully developed, the mold is brushed off or washed. It is believed that mold contributes to the specific flavor of some products. Sausage drying rooms should be equipped with a fan, and with facilities for dehumidification and chilling or warming the air with humidity and temperature control instruments.

15.2.1.8 Storage

If raw sausages are stored in a warm hanging room, they shrink excessively and become firm; if left in too humid or too cool a room, they soon lose their color. Most producers favor handling raw sausages, especially in warm weather, at temperatures around 20 °C. This is done to avoid condensation on sausages with transfer from a cold to a warm place (condensation favors growth of molds).

15.2.2 Types of Sausages

Sausages are usually defined as seasoned meats stuffed into casings; they may be smoked, cured, fermented, and heated. The production of a wide variety of sausages is possible using different variables, such as meat formulation, processing temperature, spices, casing, and other ingredients. In spite of their multiple varieties, sausages can be divided into two general groups: raw sausages and heat-processed sausages. According to the methods applied in their processing, raw sausages may further be subdivided into two categories: fresh sausages and fermented sausages. Similarly, heat-processed sausages are classified into three categories: smoked precooked sausages, emulsion-type sausages, and cooked sausages.

15.2.2.1 Fresh Sausages

Fresh sausages are not heat treated and made from seasonings and meats that have not been previously cured. These sausages are refrigerated and thoroughly cooked before eating. Fresh sausages are stuffed into casings and twisted at regular intervals. Fresh sausages are dried at room temperature for a short time and chilled rapidly. The most common seasonings used in fresh sausage production are salt, dextrose, red pepper, sage, chili, garlic, ginger, lemon bark, cinnamon, onion, cumin, monosodium glutamate, salt, and so on. The binders, which provide satisfactory control of shrinkage in cooking, are wheat or soy flour, rusk, isolated soy protein, and nonfat milk solids. Examples of fresh sausages are Boerewors, Italian pork sausage, fresh beef sausage, and British banger sausage.

Shelf Life of Fresh Sausages

Fresh sausages are more perishable than other types of sausages and should be handled with special care. They deteriorate relatively rapidly due to both microbial spoilage and oxidative rancidity. They must be kept at a temperature close to 0–4 °C. Their storage life at refrigerator temperatures is usually 2–4 days. Freezing protects the product against bacterial spoilage but not against oxidative rancidity. Air circulation in a sausage storage room must be kept reasonably dry. A humidity of 75–80% seems high enough with a temperature of 6–8 °C to prevent excessive loss of moisture or low enough to keep the product and to avoid the growth of molds. In fact, one of the main spoilage in sausage storage is molding. Mold growth can be controlled by extreme sanitation and washing with water containing sodium hypochlorite.

The oxidation can be controlled, to a limited extent, by extremely low air circulation in the storage room, by avoiding processing of long stored frozen meats and fats, by proper selection of spices, and by avoiding excessive dehydration of the product. Antioxidants, both the fat-soluble type (butylated hydroxyanisole and butylated hydroxytoluene) and the water-soluble type (ascorbic acid and citric acid), are effective in retarding rancidity. The use of pre-rigor meat is also a method of reducing excessive dehydration and oxidative rancidity.

Fresh Sausage Production

Different techniques and formulas are used in manufacturing fresh sausages in various countries.

Fresh sausages for grilling

These sausages are most widely manufactured as restaurant or grill sausages in some Arab countries. They are often sold in small butcher shops where they are also produced on request in desired qualities.

Formulation *Basic ingredients for 100 kg*: 90 kg lean beef, 10 kg fat, and seasonings. *Seasonings per 1 kg*: 0.2 g rusk (or other binders), 20.0 g salt, 1.0 g red pepper, 0.02 g chili, 0.5 g cardamom, 0.2 g ginger, 0.4 g fenugreek, and 0.5 g sugar.

Processing The meat and fat are grinded separately: meat through an 8 mm plate and fat through a 6 mm plate. They are then mixed for a few minutes while the above-mentioned seasonings are added. The mixture obtained can be regrinded through a 5 mm plate and finally stuffed into casings. The stuffed casings are twisted for short links. The finished sausage should be either immediately used in the kitchen or stored at 0–4 °C for a maximum of 2 days.

Sausage burger (hamburger)

Technologically, hamburgers are typical fresh beef sausages that are not stuffed into casings. Stuffing hamburgers into appropriate casings may be used by small-scale manufacturers. Hamburgers are made from meats that are removed as soon as possible from the carcass. Mixing with salt gives a product of high water-binding capacity. Sometimes soy protein is added to the formula.

Formulation *Basic ingredients for 100 kg*: 85 kg beef flank, 15 kg beef or mutton tail fat, and seasonings. *Seasonings per 1 kg*: 17.8 g salt, 2.7 g curry powder, 0.4 g sugar, 0.3 g cinnamon, and 2.2 g red pepper.

Processing Meat and fat are ground twice: once through a coarse plate (10–12 mm) followed by addition of the binder and seasoning, and after mixing, the second grinding is performed through a finer plate having holes of 4 mm in diameter. The meat is mixed until the desired degree of binding is obtained. The mass is immediately stuffed into cellulose casings of about 6 mm in diameter or rolled. They are then chilled or frozen as soon as possible. After freezing, the sausage is cut by machine (hamburgers) with a desired thickness.

If hamburgers are immediately used, a binder (about 0.2 g) may be added (such as egg, protein, and starch), so the product may be more easily sliced and marketed. The keeping quality of frozen sausage burgers is limited to 1–2 weeks in refrigerator.

15.2.2.2 Fermented Sausages

Fermented sausages originated in the Mediterranean region, but they probably developed independently in several locations (Europe, North America, China, and Southeast Asia). In the United States, lactobacilli or pediococci are the predominant culture bacteria, whereas in Europe (as well as in Turkey) these genera are most often used in combination with micrococci and staphylococci. The stuffed sausages are processed by smoking, drying, and aging. They are divided into two categories: semidry (such as summer sausages) and dry fermented sausages (such as air-dried fermented sausage, sucuk and salami). In Turkey, dry fermented sausage is named as "sucuk" and sucuk represents the largest category of fermented meat products.

Semidry Fermented Sausages

Semidry (quickly fermented) sausages differ greatly from dry (slowly fermented) sausages in terms of their fermentation time. The pH of semidry sausages ranges from 4.8 to 5.4 (with water content of 35% or more). Semidry fermented sausages are regularly smoked and only exceptionally slightly cooked by the heat applied in the smokehouse at various temperatures, mostly not exceeding 45 °C. After smoking, the sausages are air dried for a relatively short time. The higher shelf life of semidry sausages is due to low water activity. A high level of hygiene in the manufacturing process is essential for the good keeping quality of sausages. This category of sausages is popular in many European countries and North America. The main sausages of this group are summer and bologna sausages (in the United States).

Summer Sausages

Summer (semidry) sausages are ground-fermented products and produced under conditions that promote microorganism growth, which gives flavor and the desired keeping quality. Starter cultures may be used to obtain high-quality products.

Formulation

Basic ingredients for 100 kg: 80 kg beef meat, 20 kg fat, and seasonings. *Seasonings per 1 kg*: 29 g nitrite salt for curing, 0.5 g sodium nitrate, 3.2 g ground black pepper, 1.2 g coriander, 2.1 g mustard seed, 0.5 g fresh garlic, 0.5 g allspice, 5.2 g dextrose, and 2.3 g sucrose.

Processing

The meat and fat are ground separately through a grinder plate having 5 mm holes. The meat and ingredients are mixed and passed through a grinder. The sausage mixture is stuffed into casings. The sausages are tied into the desired length. They are fermented at about 38 °C and 95% RH from 1 to 3 days. Fermented sausages may also be manufactured using a commercial lactic acid starter culture with or without 0.6% glucono-delta-lactone (GDL). The drying process is conducted until the desired degree of quality is achieved.

Dry fermented sausages

The organoleptic and other properties of dry (slow-fermented) sausages depend on not only the bacterial fermentation, but also biochemical and physical changes occurring during the long drying or aging process. The length of production, either with or without smoking, and drying periods depends on a number of factors, such as diameter and physical properties of casings, sausage formulation, methods of preparing meat, and conditions of drying, among others. The final pH of dry sausages is usually somewhat higher (5.0–5.5) than that in semidry sausages and it increases during the long aging process. Some of dry sausages are subjected to cold smoking (at 14–18 °C). In some countries, they are heavily spiced with red pepper or garlic or sometimes heavily smoked and strongly salted. The formulation, degree of grinding, level of fermentation, smoking intensity, temperature of aging, and type and size of casing as well as other factors determine the properties of the final product. In the preparation of dry sausages, natural casings are preferred because they adhere closely to the sausages as sausages shrink. Dry sausages are usually sold as new dry sausages (about 20% weight loss from original weight), moderately dry sausages (about 30% weight loss), and dry sausages (about 40% weight loss).

Air-Dried Sausages

Air-dried (dry fermented) sausages are distinguished by high-quality characteristics, such as attractive appearance, aroma, and keeping quality with a low pH and low a_w. The use of GDL (from 0.3 to 0.5%) can improve the texture and color of the product and accelerate acid production.

Formulation

Basic ingredients for 100 kg: 25–35 kg beef meat (well-trimmed, prefrozen at −10 °C), 30–40 kg sheep meat (prefrozen at −5 °C), 20–30 kg back fat (well-trimmed fat, prefrozen at −5 °C), and seasonings. *Seasonings per 1 kg*: 30 g nitrite salt for curing, 0.3 g potassium nitrate, 3.8 g dry starch syrup (or dextrose), 2.8 g ground white pepper, 1.2 g white whole pepper, 0.5 g coriander, 2.0 g mustard seed, 0.5 g fresh garlic, and 2.0 g dextrose.

Processing

The beef is chopped in the cutter to approximately 3 mm size and all seasoning ingredients except salt are added and homogenized. Finally, salt is added, mixed, and filled into casings. The stuffed and tied casings are kept at 23 °C with 93% RH for 24 h. During the next 24 h, the RH is reduced to 90%. In the following 3–4 days, the temperature is gradually decreased to approximately 15 °C as is the RH to 80%. The rest of the aging process is carried out at 14 °C and 77% RH.

Salamis (Dry Fermented Sausage)

There are several varieties of beef salamis depending on the length of the curing sausage mixture, degree of fermentation, diameter of casings, and so on. The acceleration of beef salami fermentation may be achieved by adding GDL or 0.5% of a starter culture into the mixture before stuffing.

Formulation

Basic ingredients for 100 kg: 75 kg beef meat, 25 kg beef brisket fat, and seasonings. *Seasonings per 1 kg*: 20 g nitrite salt for curing, 0.5 g potassium nitrate, 0.4 g fresh garlic, 2.6 g ground white pepper, 2.1 g dextrose, 1.2 g red pepper, and 0.2 g binder.

Processing

The meat is run through a 4 mm grinder and brisket fat is diced. After mixing with other ingredients, the mixture is placed in 15 cm deep pans for curing at 4 °C for 18–48 h. The dough is then remixed and stuffed into casings. Stuffing and tying must be very firm. If a fully fermented product is preferred, the salamis should be hung for 3–5 days at 17–22 °C. The smoking is performed by gradually increasing temperatures to 60 °C for 2–4 days in the smokehouse. Salamis are dried according to demand. To avoid the growth of molds, the smoked salamis can be rinsed in hot water saturated with salt and chilled.

Sucuk (Turkish Dry Fermented Sausage)

In traditional Near East meat processing, several groups of sausages are produced but sucuks are doubtlessly more typical and frequent. Sucuks are popular Turkish national products, but they are manufactured throughout the Near East. This type of product substantially differs from its European counterparts. Sucuks are exclusively beef products and, more rarely, mutton meat is used. They are often annular shaped. There are several types of sucuks that can be classified according to amount of fat, diameter of casing used, and degree of drying. The composition of meat skeletal muscle (lean) used in the production of sucuks is given in Table 15.1. The actual composition of lean will vary with the breed, age, diet of the animal, and type of animal.

The quality standards of sucuks are given in Table 15.2. The sucuk has pinkish color, cherry rotten and marble appearance, is not soft or hard with finger pressure, and leaves no pieces on the cutter knife. Manufacturing procedures

Table 15.1 Approximate composition of sucuk meat.

Component	Composition (wt%)
Water	65–80
Proteins	16–22
Lipids	3.0
Nonprotein nitrogenous substances	1.5
Free amino acids	0.3
Carbohydrates	1.0
Inorganic compounds	1.0
pH	5.5–5.9

Table 15.2 Quality standards of fermented sucuk.

	Limits
Chemical criteria	
Meat protein	At least 16% (14% for heated)
Collagen in meat protein	Maximum 20% (25% for heated)
Moisture ratio to total meat protein	Less than 2.5 (3.6 for heated)
Fat ratio to total meat protein	Less than 2.5 (2.5 for heated)
Salt	2.2–3.3%
Coloring matter	None
pH	Maximum 5.4 (5.6 for heated)
Microbiological criteria (cfu g^{-1})	
Aerobic plate count (APC)	10^{-5} to 10^{-6} cfu g^{-1}
Escherichia coli/25 g	$n = 5$, $c = 1$, $m = 10$, $M = 100$ ($c = 0$ for heated sausage)
Staphylococcus aureus/25 g	$n = 5$, $c = 1$, $m = 500$, $M = 5000$
Salmonella, *E. coli* 0157H, or *L. monocytogenes*/25 g	$c = 0$
Clostridium perfringens	$n = 5$, $c = 2$, $m = 10$, $M = 100$
Coliforms	Maximum 10
Molds and yeasts	$n = 5$, $c = 2$, $m = 10$, $M = 100$
Organoleptic criteria	
Flavor	Must be in its original flavor
Taste	Not rancid, not sour, not bitter
Appearance	Must be in appropriate color and texture

of sucuks involve the following basic steps: (i) reducing the particle size of raw meat, (ii) incorporation of ingredients and a desired LAB, (iii) uniformly blending all ingredients and further reducing the particle size, (iv) vacuum stuffing into a semipermeable casing, (v) ripening of sucuk until a specific pH endpoint, (vi) heating (optional) the product to inactivate the inoculums and ensure pathogen destruction, and (vii) drying (aging) the product to the required moisture.

Formulation

Basic ingredients for 100 kg: 90 kg fresh beef meat (with 18% fat) (or 60 kg beef lean and 30 kg mutton or lamb meat), 10 kg tail fat, and seasonings. *Seasonings per 1 kg*: 5.5 g cumin, 1.1 g cinnamon, 11.4 g allspice, 0.5 g cloves, 5.5 g red pepper, 11 g black pepper, 20.7 g garlic, 0.4 g ginger, 3.5 g sugar, 18 g NaCl, 0.3 g $NaNO_3$, 0.15 g $NaNO_2$, and 2.1 g olive oil.

Traditional sucuks

Processing The general outline for processing of sucuks is given in Figure 15.1. The meat is ground through a 4 mm grinder at low temperatures (4 °C). The meat

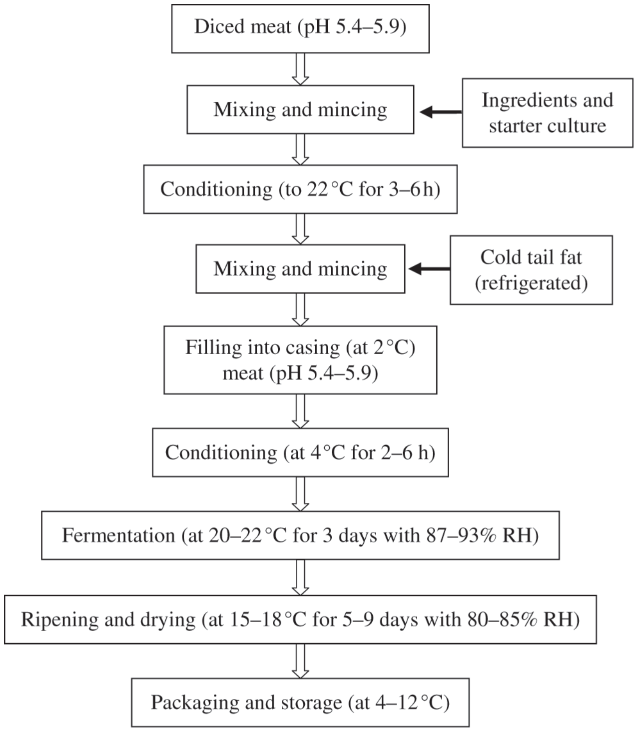

Figure 15.1 Flowchart of sucuk processing.

and ingredients (except salt) are mixed and passed through a 1–2.5 mm grinder. Then, salt is added and mixed. Sucuk dough is stored at 4 °C overnight (conditioning). The sucuk dough water activity is about 0.95–0.96 at this point. The tail fat is ground through a 4 mm grinder and thoroughly mixed with meat mixture. Then, they are packed into animal casings (mostly beef or sheep) with 25 mm or more diameter at 2 °C using filling apparatus of a 3 mm grinder. Annular sucuk stuffing in casings must be free of any remaining adhering fat and air bubbles. Traditional collagen from intestinal tract, fibrous cellulose, and collagen from animal hides are more commonly used as casings.

Fermentation The filled casings are allowed to remain for 2–6 h at 22 °C (conditioning) with >90% RH. Sucuk fermentation is performed with a stepwise reduction of temperature and RH. Sucuks are fermented at 22 °C for the first day with 93% RH and for the second day with 90% RH, and for the third day at 20 °C with 87% RH. The water vapor pressure differences between sucuk and air conditioner should be about 4% to prevent formation of a dried ring.

Ripening (aging and drying) After fermentation, sucuks are dried (also dried) with stepwise RH and temperature reduction: Sucuks are ripened at 18 °C for 2 days with 85% RH, at 16 °C for 3 days with 82% RH, and at 15 °C for 2 days with 80% RH (ripening conditions change according to the final product characteristics). Dried and ripened sucuks are packaged and stored at 4–12 °C.

Heated sucuks

The preparation of heated sucuk dough is done in the same manner as traditional sucuk processing. A starter culture is added into sucuk dough with 10^6–10^7 colony forming unit (cfu) g^{-1}. Sucuk dough is stuffed into artificial casings. It is allowed to remain for 6 h and heated first for 15 min at 40 °C and finally for 20 min at 60 °C. Heated sucuks are washed and stored at 4 °C.

15.2.2.3 Smoked Precooked Sausages

Smoked precooked sausages (such as Chinese sausages) are smoked and/or air heated, often cured, but not fermented. Smoking is normally performed immediately after stuffing. Sausages are precooked in a smokehouse in two phases: (i) steaming for 3–5 min or more to an internal temperature between 50 and 60 °C and (ii) dry heating to an internal temperature of 65 °C. Following heating, they are quickly chilled. The chilling contributes texture, appearance, and overall consumer acceptability of product. The shelf life of sausages depends on raw materials and methods of processing. Subsequent smoking and precooking may inhibit or kill most of the bacteria coming from raw materials.

Formulation

Basic ingredients for 100 kg: 55 kg beef, 25 kg mutton fat, 20 kg beef flank, and seasonings. *Seasonings per 1 kg*: 21.0 g nitrite salt for curing, 2.0 g red pepper, 0.3 g garlic, 0.3 g cardamom, 4.0 g sage, 1.6 g celery, 0.4 g rosemary, 11.0 g ground dehydrated mustard seed, 4.0 g corn syrup, and 9.0 g soy protein concentrate.

Processing

The chilled meats are ground through a plate, having holes of 5–8 mm in diameter. The salt and spices are mixed with ground meat. The mixture is stuffed into sheep or cellulose casings (16–22 mm). The sausages are further processed by smoking and air heating. The smoking schedule is as follows: 2 h at 38 °C, then 1 h at 50 °C, and finally at 78 °C. If they are sufficiently smoked and dried, the sausages have a good keeping quality.

15.2.2.4 Emulsion-Type Sausages

Emulsion-type sausages are ready-to-eat products made from cured meats, fatty tissue, water, and seasonings, usually smoked and slightly cooked. Nonfat milk powder, cereals, starch, and other nonmeat ingredients may also be used. In Europe, these sausages are known as “scalded” because they are only scalded (pasteurized) and not fully cooked. The term "meat emulsion" has been used as a general term to describe frankfurter-type sausages. Emulsion-type sausages originated in Europe. Small diameter sausages are usually eaten after immersion in hot water for several minutes; only rarely, they are grilled prior to consumption. They may be subdivided into small diameter (frankfurters) and large diameter sausages (bologna).

Frankfurters

They can be produced from beef meat. The frankfurter formulations contain different filler meats such as hearts, giblets, tripes, tongues, snouts, and lips. However, filler meats should not exceed 20% of the meat formulation. Nonmeat binders are also added in low-cost formulations. In preparing frankfurters, the beef components are usually ground or chopped first with the dissolved curing ingredients, seasonings, and water.

Formulation

Basic ingredients for 100 kg: 50 kg beef, 30 kg beef fat, 5 kg beef head meats, 15 kg ice, and seasonings. *Binders* (if permitted by regulations): 1.1% of soy or milk protein, 0.4% phosphate, 2.9% wheat flour, 3.2% potato starch, and so on. Soybean proteins especially are used as economical substitutes for meat because their amino acid patterns are similar to beef except for slightly higher phenylalanine and lower methionine. *Seasonings per 1 kg*: 22.0 g nitrite salt for curing, 0.2 g sodium glutamate, 2.2 g white pepper, 0.7 g red pepper, 0.4 g dextrose, 0.6 g mace, 0.4 g cardamom, 0.3 g ginger, 0.4 g allspice, and 0.1 g ascorbic acid.

Processing

In preparing frankfurter emulsions, the beef components are ground first with the dissolved curing ingredients, seasonings, and water. This is followed by fat addition and mixing. Ascorbate or erythorbate (if used) is added in solution approximately 1 min before the end of the chopping process. The finished emulsion is often passed through an emulsion mill to improve fineness. The emulsion is then placed in shallow pans for 1–2 days for curing. After curing, the emulsion is remixed and filled into narrow sheep casings (22 mm in diameter).

The sausage is smoked. The starting smoking temperature is generally about 43 °C for 1 h, then it may be increased to 55 °C, and finally it is raised to 80 °C and maintained to reach the final internal temperature of 71 °C. An alternative frankfurter thermal processing schedule may consist of 1 h period at 58 °C and then a period of 45 min at 70 °C, followed by a smoking period at 83 °C until the internal temperature of the product reaches the desired level (71 °C). Immediately after cooking, the sausages are cooled with cold water. The frankfurters are stored in a chill room or held at −18 °C until used.

Bologna

Like frankfurters, bologna is also an emulsion-type sausage that is stuffed in a large casing.

Formulation

Basic ingredients for 100 kg: 30 kg beef, 40 kg beef trimming, 12 kg beef fat, 15 kg ice, 2.2 kg soy (or milk) protein (or 4.8 kg wheat flour), and seasonings. *Seasonings per 1 kg*: 20.0 g nitrite salt for curing, 2.0 g sugar, 0.1 g sodium ascorbate (or 0.4 g sodium glutamate), 0.6 g mace, 0.4 g caraway seed, 0.6 g red pepper, 2.1 g white pepper, 0.4 g marjoram, 0.4 g ginger, and 0.4 g coriander.

Processing

The emulsion is prepared in the cutter as described for emulsion-type sausages. Emulsion is stuffed into natural (beef) or artificial casings with sizes of about 4.7 cm in diameter. The stuffed mixture is placed in the smokehouse at a temperature of 55 °C for about 30 min, which is slowly increased to 80 °C or until the internal temperature reaches 71 °C for 6–8 h. The product should be immediately chilled with a cold water spray in 45 min and kept under refrigeration.

15.2.2.5 Cooked Sausages

Cooked sausages are ready-to-serve products, made with fresh meats and then fully cooked. They are either eaten immediately after cooking or refrigerated and are usually reheated before eating. Examples include Braunschweiger, veal sausage, and liver sausage. Cooked sausages can be prepared from a variety of raw materials, such as edible portions of heads, mutton, pork or beef trimmings, blood, hearts, tripes, livers, lungs, pork stomachs, tongues, and various fat materials. Cooked sausages are distinguished from variety of materials used in their formulations and partial cooking of most of raw materials prior to grinding or chopping. Raw materials rich in connective tissue, such as heads, are cooked until the meat separates from the bones. Protein emulsifying agents (sodium casein or soy protein preparations) are increasingly used in some cooked sausage products. The addition of an emulsifier stabilizes the emulsion and helps in binding the components more firmly together. This can provide homogeneous consistency, contribute more attractive color, and ensure typical spreading properties to the product.

Liver Sausages

Liver sausages include many varieties due to different formulations. Liver sausages are produced from ground meats, liver (pork or beef), fat, and ingredients (such as spices, milk powder, phosphates, etc.). Raw materials used in liver sausage preparations are cooked before being chopped, mixed, and filled into casings. Livers are used either previously cooked or raw. All types of fats can be incorporated in liver sausage emulsions but generally carcass fats are preferred. Fat material, particularly internal fats, must be washed in cold water. Special care should be paid to eliminate factors enhancing oxidative changes.

Formulation

Basic ingredients for 100 kg: 25–30 kg pork liver, 30–40 kg meat, 20–40 kg fat, and seasonings. *Seasonings per 1 kg*: 24 g nitrite salt for curing, 12–18 g salt, 0.07 g ascorbic acid, 3.4 g white pepper, 1.3 g coriander, 1.2 g mace, 0.3 g cloves, 0.6 g marjoram, 0.2 g thyme, 45.0 g peeled onions, and 0.1 g monosodium glutamate.

Processing

Warm precooked meat should be minced with a 3–5 mm grinder plate. Liver is ground cold. As it contains a lot of water and blood, the ground liver is easily emulsified. Grinding of meats, especially liver, with a small plate increases the surface area and improves spreadability. Basically, there are two main processing methods in the manufacturing of liver sausages: (a) hot processing of precooked materials and (b) cold processing of precooked materials. The first method gives a finer, more spreadable product. The second method results in a firmer product characterized by a richer liver taste and aroma.

Hot processing of precooked materials The meats are placed with the peeled onions and about one-third of salt into the cooker, and cooked at a temperature not exceeding 80 °C for 45–90 min to melt the fat and denature proteins. The meats are normally cooked until they are so tender that the bones can be easily removed. The broth is left to settle for a while after the meats and fatty tissues have been removed and the grease is skimmed from the top. The broth is then concentrated by boiling, clarified by passing through cheesecloth, and used when still hot (60 °C). The salt is added until the mass is finely homogenized. If soy or milk proteins are used, the addition of one-half of the amount should be done at the very beginning and the second half at the end of the operation.

Raw livers with one-half of salt are comminuted in the cutter until a dark semiliquid mass is obtained. As soon as air bubbles appear, the machine is stopped and the liquid liver is removed from the cutter and kept until used.

The hot broth of liver is added gradually during the operation in such a way that the temperature of the whole mixture is maintained constantly at 60 °C. Raw livers should be added when the temperature of the meat–fat mixture falls below 60 °C to avoid liver protein denaturation, but the temperature of the emulsion must not be below 45 °C to ensure melting of fat. The mixture is thoroughly homogenized. The raw liver sausage emulsion is ready.

Homogenized raw liver sausage mass may be passed through an emulsifying mill and filled into casings. If raw livers are being used, the casings must not be stuffed too tightly because the raw livers expand when cooked.

The filled products in casings are cooked at about 80 °C for about 60–90 min up to the jelly pockets product. Some products are cold smoked for 1 h or more. Immediately after cooking, the sausages are cooled and transported to the cold storage room at 3 °C.

Cold processing of precooked meats and fats Alternatively, especially if a firmer higher value final product is desired, liver, the cooked meat, and scalded fat after chilling (below 25 °C) are placed in the cutter together with other ingredients and thoroughly chopped until a fine emulsion is produced. All other operations are identical to those mentioned under hot processing of liver sausage after filling into casings.

15.2.3 Chemical Changes in Sausages During Processing and Storage

15.2.3.1 Acid Formation

In fermented products, acids are effective on the taste and microorganisms in sucuks. This product contains little aromatic substances that are formed by microbial activity. Microbial acidity has a great impact on the quality of final product from the microbiological safety point. The acid formation rate depends on the processing conditions, and activity and ability of LAB to ferment sugars.

15.2.3.2 Lipid Oxidation

Two most important lipid reactions are the oxidation and hydrolysis of fat. In fat oxidation, the carboxylic acid group of fatty acid chain is oxidized, making the fat rancid. This reaction is slower in the presence of antioxidants (such as vitamin E and ascorbic acid) and faster at higher temperatures with more unsaturated fats (fats with more double bonds) and with trace metals. Hydrolysis is the reverse of the reaction for fat oxidation. In hydrolysis, fat reacts with water to give glycerol and fatty acids. The rate of this reaction increases with temperature up to 70 °C and is catalyzed by the enzyme lipase. One of the most important deterioration in sucuks is the lipid oxidation that affects fatty acids and polyunsaturated fatty acids. Lipid oxidation and hydrolysis in sucuks may have significant effects on the quality, such as color, flavor, texture, and nutritional value. The malondialdehyde forms as a result of oxidation and causes bitterness. It is important for human health because it causes cancer and mutation.

15.2.3.3 Color Formation

Sodium nitrate and sodium nitrite used in sausage production have antimicrobial and curing effects in meats. Curing is a process in which the addition of nitrate/nitrite salt causes characteristic flavor and color formation in products. In early curing processes, bacteria (such as *Micrococcus* and *Staphylococcus* spp.) produce nitrate reductase and nitrite reductase enzymes and these enzymes reduce nitrate to nitrite and nitrite to nitric oxide (NO, a gas), respectively. Nitrite is inhibitory to a range of bacteria (such as *Clostridium botulinum*, *Escherichia*, *Flavobacterium*, *Micrococcus*, *Pseudomonas*, and others), while *Salmonella* and *Lactobacillus* species are more resistant. Inhibitory action of nitrite appears on bacteria when initial levels of nitrite are greater than $100\,mg\,kg^{-1}$. Bacterial inhibition increases with decreasing pH due to the formation of nitrous acid (HNO_2, pK_a 3.4). NO can react with myoglobin or some bacteria can produce ammonia (NH_2) from NO. Low pH, ascorbate, and other reducing conditions accelerate the formation of NO. Nitrite can also be decomposed to corresponding products in water and NO is produced in acidic solution. Reactions for the formation of NO from nitrate and nitrite are outlined below:

- Reduction of nitrite in water:

$$NaNO_2 + H_2O \rightarrow HNO_2 + NaOH$$
$$\text{or } NO_2 + H_2O \rightarrow HNO_2 + OH^-$$
$$\text{in acidic solution:} \quad 3HNO_2 \rightarrow HNO_3 + 2NO + H_2O$$

- Reduction of nitrate and nitrite by bacterial enzymes:

$$NO_3 \rightarrow NO_2 \rightarrow HNO_3 + 2NO + H_2O$$
$$NO \rightarrow NH_3 + N_2O$$

Adding more nitrite may lead to the formation of effective carcinogenic nitrosamines, while in the case of lower quantity, there appears a color problem in the product or nitrite cannot show antimicrobial effect.

The principal pigment in meat muscle is myoglobin. Myoglobin consists of a single polypeptide chain of about 150 amino acid units and a heme group. The heme group contains an iron atom, whose various oxidation states and ability to form a complex with other components result in different colors. It is important to distinguish between oxidation–reduction reactions and oxygenation reactions. Oxidation and reduction reactions involve a loss (oxidized) and gain (reduced) of electron, respectively, from one substrate to other, such as between nitrosomyoglobin and metmyoglobin. Oxygenation reactions involve the addition of molecular oxygen to hemoglobin without electron transfer.

Myoglobin is responsible for the purplish red muscle color of fresh meat. Myoglobin (purple red color, fresh meat color) can be exhibit different colors depending on oxidizing and reducing agents, temperature, and pH. (i) On exposure of meat to air, an oxygen molecule is added directly to the iron portion of the myoglobin, and myoglobin is oxygenated to oxymyoglobin (bright red, typical fresh meat color). In the presence of nitrite, oxymyoglobin can be oxidized to metmyoglobin (brown color). Oxidizing agents, dehydration, and high temperature accelerate this reaction. Myoglobin can also be directly oxidized to metmyoglobin. Under conditions of low oxygen partial pressure, the formation of metmyoglobin is favored. The formation of unattractive brown metmyoglobin is maximized at an oxygen partial pressure of about 10 mmHg, which has implications for vacuum. (ii) Cured red color of sausages depends on the reaction of NO with meat myoglobin to produce nitrosomyoglobin, which is a pinkish red pigment (cured color of sausages). In the presence of NO, metmyoglobin can also be reduced to nitrosomyoglobin or nitrosomyoglobin may also oxidize to metmyoglobin in the presence of oxidizing agent, such as oxygen. (iii) Sometimes, after curing, heat is applied to the product. At this time, nitrosomyoglobin is converted to nitrosohemochrome (light pink color) and metmyoglobin is denatured (gray-brown cooked fresh meat color). When a reducing agent (such as NO) is present, denatured myoglobin is also reduced to nitrosohemochrome. (iv) Bacteria, oxygen, light, and chemicals further oxidize nitrosohemochrome and denature metmyoglobin to oxidize porphyrins (green, yellow, colorless).

The packaging or wrapping of meat in oxygen-impermeable packaging material prevents oxidation and oxygenation of myoglobin and oxidation of cured products. The packaging of sausages is important in retaining the pigments of sausages. Vacuum-packed sausages must have very low oxygen pressure (such as below 10 mmHg). Vacuum-packaged conditions prevent oxidation and inhibit bacterial growth.

15.2.4 Quality of Sausages

There are four basic quality criteria for sucuks: physical, chemical, microbiologic, and organoleptic (Table 15.2). Organoleptic criteria are color, appearance, structure, texture, cooking, and eating properties of sucuks.

15.2.4.1 Processing Factors Affecting Quality of Sausages

Different factors affect the product quality (color, texture, flavor, and appearance) of sausages during the fermentation and drying. Some factors affecting the quality of sausages are given in Table 15.3. Factors affecting quality of sausages can be divided into two major groups: external factors (relative humidity, temperature, and air condition) and internal factors (raw materials, pH, water, oxygen, salt, sugar, starter culture, antimicrobial preservatives, etc.).

Starter Culture

In fresh meat, LAB is a minor component of the microflora, but when meat is packaged and stored under vacuum, the resulting microenvironment facilitates the growth of LAB. For selection of starter cultures, starter should produce adequate quantity of lactic acid, be able to grow at a salt concentration of at least 6%, be homofermentative, be capable of rapidly converting glucose to lactic acid anaerobically, grow in the presence of sodium or potassium nitrate (0.3 mg kg^{-1} nitrate) or nitrite (0.15 mg kg^{-1} nitrite), grow between 21 and 43 °C, be nonproteolytic, be nonlipolytic, be inactivated at 63 °C, resistant to phage infection

Table 15.3 Factors affecting the quality of sausage.

Parameter	Factors	Guidelines
Raw meat	Animal species	pH ≤5.8; good microbial quality.
	Age at slaughter	Do not use old animal meat and no antibiotics in meat.
Additives	Sodium chloride	Initially, a_w of meat mixture is about 0.96.
	Nitrate/nitrite	Maximum 300/150 mg kg^{-1} meat.
	Sugar	0.2–0.5% of fermentable sugar.
	LAB	pH reduction to ≤5.4.
	Spices	Good microbial and sensory quality.
Comminution	Grinding/cutting	Low temperatures (at 4 °C) to avoid melting of fat.
Filling	Filling equipment	No air inclusions.
	Casing	Permeability high for vapor and smoke, and low for oxygen; shrinkable; and peelable.
Fermentation	Temperature	≤25 °C.
	Time	Until pH ≤5.4.
	Humidity	No vapor condensation.
Ripening	Temperature	≤18 °C until $a_w < 0.85$.
	Humidity	RH in storage area should be 10–15 units below product RH.
	Air movement	Provides uniform drying.

and mutation, be able to outgrow and suppress pathogens, be catalase positive, be able to enhance flavor in the processed sucuk, and not produce biogenic amines and slimes.

Traditional fermentation of dry sucuks can be performed by the inherent lactic acid-producing microorganisms or by back inoculating a portion of recently fermented meat into the freshly prepared batch.

Some starters include yeasts, such as *Debaryomyces hansenii* and *Candida famata*. Some others also include molds, usually *Penicillium* spp., to produce extracellular enzymes and hydrolyze fats and proteins. In natural fermentation, the dominant LAB are psychrotrophic and heterofermentative *Lactobacillus*. Most of these are *Lb. sake* and *Lb. curvatus*.

The predominant genera of bacteria used in the production of dry fermented sausages either singly or as mixed cultures are *Pediococcus*, *Lactobacillus*, *Streptococcus*, *Micrococcus*, and *Staphylococcus*. The reason for applying these bacteria in the production of sausages is their ability to produce consistent and controlled acids and bacteriocins to inhibit growth of undesirable microorganisms, and to provide an aid in obtaining the desired structure and color of the final product. Culture type can also be selected based on fermentation temperature. *Lb. plantarum*, *Ped. acidilactici*, and *Ped. pentosaceus* are used for rapid and nearly complete conversion (>90%) of glucose to lactic acid (pH 4.8–5.1). Highly active starter cultures are able to decrease pH from about 5.6 to 4.8 within 24 h of fermentation. *Ped. acidilactici* is used in high-temperature fermentation (35–46 °C) for rapid pH decline. For low-temperature fermentation (21–34 °C) and rapid pH decline, *Ped. pentosaceus* is preferred, while for low-temperature fermentation and slow pH decline (slow fermentation), *Lb. plantarum* strains are preferred. *Micrococcus* spp. are added for color and flavor development. Less fermentative (pH 5.2–5.6) microorganisms, *Staphylococcus xylosus*, *Staphylococcus carnosus*, *Staphylococcus simulans*, and *Staphylococcus saprophyticus*, can be used. *Staphylococcus* and *Micrococcus* spp. are preferred for flavor development, reduction of nitrate/nitrite to nitric oxide with reductase enzymes, and red color enhancement. They are catalase-positive bacteria. The cultures used in the sucuk production are *Ped. acidilactici*, *Lb. plantarum*, and *S. carnosus*.

Some *Lactobacillus* spp. (*Lb. lactic*, *Lb. sake*, *Lb. forciminis*, *Lb. brevis*, *Lb. buchneri*, and *Lb. suebicus*) reduce nitrite to nitric oxide. Red color development in meat products can also be provided by bacterial consumption of oxygen. Bacteria initially consume oxygen and reduce the level of oxygen; this allows metmyoglobin reduction to purple red myoglobin. *Lb. curvatus*, *Lb. sake*, *Lb. plantarum*, *Ped. pentosaceus*, and *Ped. acidilactici* produce bacteriocins. The most commonly isolated LAB from dry fermented sucuks and used for sucuk fermentation are *Lb. sake, Lb. curvatus, Lb. plantarum, Ped. Pentosaceus*, *Ped. acidilactici*, and *S. carnosus*. *Debaryomyces hansenii* and *Penicillium nalgiovense* are used for reduction of oxygen and lipolytic activity. *P. nalgiovense* can also hydrolyze peroxidise and proteins. Therefore, they can be used as aroma producers.

Raw Meat

Fresh or frozen raw meats (after rigor mortis) to be used for sucuk production should be chilled (<4 °C). Meat should be free from physical and chemical defects. The meat should always be of high quality. Dark, firm, and dry (DFD) meats are not suitable for dry sausage production because of their excessive water-binding capacity and potential for microbial spoilage. DFD meat is characterized by a dry surface, dark red color, and high pH (>6.0). Fat tissues from beef or lamb have a high proportion of saturated fatty acids and yield products having a more desirable texture than poultry fats (which contain polyunsaturated fatty acids). Polyunsaturated fatty acids are more susceptible to oxidation and rancidity, which can lead to the development of unwanted flavors.

Ingredients

Incorporation of sodium chloride (NaCl), sodium nitrate ($NaNO_3$), sodium nitrite ($NaNO_2$) or potassium nitrate/nitrite, glucose, and spices in sausage formulas dramatically alters the ecology of the culture environment and chemical characteristics of finished products. Fermentation of sausages at the optimum temperature using starter cultures under a reduced oxygen environment causes a reduction in pH by the rapid conversion of glucose to lactic acid and subsequent suppression of unwanted microflora. *Pseudomonas* and Enterobacteriaceae spp. are sensitive to low pH, salt, nitrite, and reduced oxygen tension.

Nitrite has several functions when added into sausages:

1 Nitrite leads to the formation of a purple red color with the appropriate pH.
2 It helps the curing of the sucuk to gain flavor and aroma.
3 Antioxidant feature of nitrite prevents oxidation of lipids.
4 It prevents the growth of spoilage and pathogenic microorganisms, such as *Clostridium botulinum*.

Spices (ground pepper, paprika, garlic, mace, pimento, cardamom, and mustard) used in sausage production should be sterilized to avoid microbial contamination. Red pepper and mustard stimulate lactic acid fermentation, since the available manganese in these spices enhances the glycolytic enzyme fructose-1,6-diphosphate aldolase. Garlic, rosemary, and sage contain antioxidant and antimicrobial compounds, and may assist in preserving flavor, color, and microbial shelf life of sausage.

A sufficient level of acidification can also be obtained by the addition of GDL. At GDL levels of 0.5%, the curing agent should be nitrate, but at GDL levels higher than 0.5%, nitrite is preferred since too high acidification does not permit the process of denitrification performed by microorganisms. GDL is hydrolyzed to gluconic acid, which is then converted to lactic acid and acetic acid by lactobacilli. It may be used at a concentration from 0.25 to 1%. At high concentrations, GDL can inhibit growth of lactobacilli and produce undesirable aroma and a sweet flavor from the unfermented sugar.

Casings

The sausage dough is filled into casings. Generally, casings are divided into two major groups: natural and artificial casings. Natural casings are produced from various parts of the alimentary tract of cattle or sheep. Casings are normally packed in salt. Before use, they should be thoroughly soaked and washed in warm water at about 30 °C. Salted casings are washed free from salt before use. Air-dried beef casings must be free of any adhering fat. Artificial casings are also utilized. After washing, the casings should be kept wet at all times until they are filled.

The advantages of artificial casings over natural casings lie in their uniformity of size, the absence of risk of contamination from improper preparation, and the ability in most cases to be used without preliminary washing, soaking, and so on. They are of several types, such as cellulose, polyvinylidene chloride (PVDC), PVDC/fibrous, and collagen casings.

15.2.4.2 Factors Affecting Keeping Quality of Sausages

The microflora of sausages is essentially different from that of carcass meat. In general, three basic requirements must be met for a hygienically satisfactory product: (i) During sausage production, toxigenic microorganisms and their toxins should not be present in raw materials and in the product during or after processing. (ii) The final sausage product should not contain pathogenic microorganisms (spore-forming anaerobes, enteric organisms of typhoid, paratyphoid, and dysentery groups, and streptococci). (iii) The total bacterial count of the sausage product should be reasonably low. The first and second requirements mean in general that the meat raw materials should be free from toxigenic and pathogenic microorganisms. The third requirement demands the selection and processing of good quality meats and other raw materials and maintaining reasonable standards of hygiene during all stages of the process. If the sausages are to be held in warm and humid conditions, they promote microbial growth. Microbial spoilage is affected by processing temperature, available water, oxygen, pH value, salt and nitrite contents, and types of spices.

The state of water in sausages has a direct effect on microbial, chemical, and enzymatic reactions. Water activity is expressed as the "free" water in the sausage. In sausage processing, a_w is reduced either by drying or by addition of curing salts and nonionic solutes, such as sugar, spices, and different additives. Fat, water, and salt contents directly influence the a_w value. The addition of 1% fat reduces a_w by 0.00045. In the same manner, the addition of 1% NaCl reduces a_w by about 0.0060, while 1% sugar and 1% soy or milk protein reduce a_w by about 0.0023 and 0.0012, respectively. Sausage dough containing 30% fat, 3% salt, 2% sugar, and 2% soy protein has an initial a_w of 0.9521. The final a_w of the product depends on the degree of processing (heating, drying, etc.). To inhibit the growth of the yeast and most bacteria, the water content of sausages must be reduced to a value below 30% or a_w below 0.88. Most molds cannot grow at a_w below 0.80. Xerophilic molds and osmophilic yeasts cannot grow at a_w below 0.71 and 0.60, respectively. *S. aureus* can grow at a_w as low as 0.86 but cannot produce enterotoxin below 0.93. *C. botulinum* cannot grow and produce toxins below 0.94. *C. perfringens* spore germination requires a_w of over 0.95. Gram-negative bacteria cannot grow at a_w below 0.91. Halophilic microorganisms cannot grow at a_w below 0.75.

15.2.4.3 Biogenic Amines and Nitrosamines in Sausages

Biogenic amines are natural antinutrition basic nitrogenous compounds that are formed mainly by the decarboxylation of amino acids or by amination and transamination of aldehydes and ketones. Biogenic amines are formed by the enzyme amino acid decarboxylase of the raw material or microorganisms. Biogenic amines can be aliphatic (such as putrescine, cadaverine, spermine, and agmatine), aromatic (such as tyramine and phenylethylamine), and heterocyclic (such as histamine and tryptamine). They are the causative agents of food poisoning, hypertensive crisis, weight loss, and mortality, and are able to initiate various pharmacological reactions in living organisms. Biogenic amines may also be considered as carcinogens because of their ability to react with nitrites to form potentially carcinogenic nitrosamines. They are designated as biogenic because they are formed by the action of living microorganisms.

Biogenic amines are formed in sausages due to the decarboxylase activity of microorganisms during the manufacturing and storage periods. The formation of biogenic amines in sausages depends on decarboxylase-positive microorganisms, ripening and storage conditions (temperature, pH, gas composition, etc.) of products, free amino acids, amount of salt, and hygienic conditions of the processing environment. Optimum pH and temperature for decarboxylation are 4.0–5.5 and 30 °C, respectively, but microorganisms are able to decarboxylate amino acids from 10 to 20 °C. Biogenic amine formation can be prevented with salt concentration greater than 5%. Amino acids are released from proteins with proteolysis of proteins. Bacteria able to decarboxylate amino acids with the production of decarboxylase enzyme are *Acinetobacter*, *Aeromonas*, *Bacillus*, *Citrobacter*, *Clostridium*, *Enterobacter*, *Escherichia*, *Hafnia*, *Klebsiella*, *Lactobacillus*, *Micrococcus*, *Morganella*, *Pediococcus*, *Photobacterium*, *Plesiomonas*, *Proteus*, *Pseudomonas*, *Salmonella*, *Shigella*, *Staphylococcus*, *Streptococcus*, and *Vibrio*. Several functional groups of amino acids are susceptible to reduction, such as nitro, diazo, carboxyls, disulfides, sulfoxides, and alkenes. Most important biogenic amines in fermented sucuks are putrescine, cadaverine, spermine, spermidine, histamine, and tyramine.

Anaerobic conditions reduce biogenic amine formation while aerobic conditions favor it. Refrigeration and acidification due to fermentation reduce formation of biogenic amines by preventing microbial growth. Strict hygienic conditions during production of sausages prevent microbial growth, enzyme production, and decarboxylation activity. Some biogenic amines can be easily inactivated at pasteurization temperature, while others retain activity. The presence of biogenic amines in sausages can indicate production during processing, but they can also be formed before processing. Oxidative rancidity in sausages prevents biogenic amine formation and microbial growth. Biogenic amines may be used as possible indicators of poor hygienic quality of raw materials, poor process conditions, freshness, and spoilage of sausages.

Other toxic amines formed in sausages are nitrosamines (chemical structure: $R_1NR_2{-}N{=}O$). Nitrosamines are cancer-causing chemicals. Nitrosamines are formed by the reaction of secondary and tertiary amines or amino groups (such as dialkylamines, alkylarylamines, piperidine, and pyrrolidine) with nitrite. Their formation can occur only under certain conditions, including strong acidic conditions (such as that of the human stomach) and high temperatures (as in frying). Under acidic conditions, the nitrite forms nitrous acid (HNO_2), which is protonated ($H_2NO_2^+$) and splits into the nitrosonium cation ($N{\equiv}O^+$) and water. In another way, nitrous acid decomposes to nitrous anhydride and water. The nitrous anhydride and nitrosonium cation then react with amine (R_nNH) to produce nitrosamine ($R_2NN{=}O$). The formation of nitrosamine from nitrite takes place through various steps:

$$2NO_2 + 2H^+ \Leftrightarrow HNO_2 \Leftrightarrow N_2O_3 + 2H_2O$$
$$N_2O_3 + R_2NH \rightarrow R_2NN{=}O + HNO_2$$
$$\text{or } N_2NO_2 + H_2O \rightarrow HNO_2 + NaOH$$
$$H_2NO_2{}^+ \rightarrow H_2O + NO^+$$
$$R_nNH + NO^+ \rightarrow R_nNN{=}O$$

Ascorbic acid is a powerful reduction agent, releasing NO from NO_2. With the larger supply of NO, a larger quantity of myoglobin is converted into nitrosomyoglobin ("cured red"). Examples of nitrosamines are nitrosodiphenylamine, dimethylnitrosamine, nitrosodiethanolamine, nitrosoazetidine, methylnitrosourea, and nitrosomethylethylamine. U.S. Department of Agriculture allows 0–3 ppb of nitrosamines in sausages.

15.2.4.4 Safety of Sausages

Hazards to be controlled during production of sausages are *Salmonella*, pathogenic *E. coli* (such as enterohemorrhagic *E. coli*: EHEC), *Listeria monocytogenes*, *S. aureus*, *Yersinia enterocolitica*, bacteria forming biogenic amines, and molds producing mycotoxins.

Protein degradation by tissue enzymes during prolonged storage of raw meat, in conjunction with growth of psychrotrophic LAB, can decarboxylate histidine (certain strains of *Carnobacterium* spp. and *Lb. curvatus*) and this appears to be the main risk factor for the formation of biogenic amines. Mold growth on fermented sausages may be inhibited by appropriate control of temperature and RH during ripening, storage, and distribution, by excluding oxygen from the packages and/or by surface treatment with permitted antifungal agents.

Viruses can contaminate meat at the time of slaughter and viruses are only slowly inactivated during sausage ripening. Meats should not be exported from areas where viral diseases of meat animals prevail. Viruses pathogenic for humans retain their infectivity during sausage fermentation. In all cases where food is handled, contamination of the food by human feces must be avoided by proper personal hygiene.

Parasites (protozoa, nematodes, and tapeworms) in meats at the slaughterhouse are inactivated by low a_w values of 0.90 or below and low pH. Meat must be inspected for the absence of parasites (such as *Trichinella*).

15.2.4.5 Sanitation in Sausage Processing

A well-designed sausage plant cannot be attained through buildings alone. Sanitation is essential in a sausage-producing plant. The hygienic maintenance of equipment and the plant as a whole is a cardinal factor for production efficiency and keeping quality of finished products. Tiled walls, hard-surfaced brick or concrete floors carefully sloped to drains, stainless steel tabletops, galvanized metal trucks, barrels, and pans are an integral part of a good sanitation program. Briefly, strict sanitary methods and conditions must be employed throughout the entire process.

Provisions should be made for elimination or removal of any vapor that could condense on walls. A sausage-producing plant must be provided with suitable facilities for collection and disposal of bones, removal of wastes, and so on.

Cabinets must be provided for efficient cleaning and sterilization of trucks and other movable equipment. Equipment should be placed in the cabinets and then sprayed with cleansing solutions, and finally rinsed with clean hot water. Cleaned equipment should be disinfected and dried. Every possible precaution should be taken to keep the plant free of flies, rats, and mice. Screens for outer openings that do not allow entry of files are necessary. Adequate arrangements should exist for effluent disposal.

For daily routine cleaning in any sausage plant, the scrupulous brushing and flushing with water under pressure should be the most widely used method of cleaning. The cutting and trimming section requires exceptionally careful attention. Steam or hot water is required to remove grease adhering to the surfaces of tables and machines. Detergents contribute considerably in cleaning because they emulsify fat and dissolve proteins. Disinfection of the sausage plant is done in connection with general and thorough cleaning. The regular repair of walls, floors, and equipment is also an important part of plant sanitation.