# Fermented Meat Products: Production and Consumption

**By Professor Herbert W. Ockerman and Lopa Basu**
**The Ohio State University, Columbus, OH**

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# Chapter 2. Fermented Meat Products: Production and Consumption

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## I. Introduction

Meat fermentation is a low energy, biological acidulation, preservation method which results in unique and distinctive meat properties such as flavour and palatability, colour, microbiological safety, tenderness, and a host of other desirable attributes of this specialized meat item. Changes from a raw meat to a fermented product are caused by "cultured" or "wild" microorganisms which lower the pH. Since this is a biological system, it is influenced by many environmental pressures that need to be controlled to produce a consistent product. Some of these factors would include a fresh, low-contaminated, consistent raw material, a consistent inoculum, strict sanitation, control of time, temperature, and humidity during production, smoke, and appropriate additives. Lactic acid which accounts for the antimicrobial properties of fermented meats, originates from the natural conversion of glycogen reserves in the carcass tissues and from the added sugar during product fermentation. A desirable fermentation product is the outcome of acidulation caused by lactic acid production and lowering the water activity ($a_W$) caused by the addition of salt (curing) and drying. Both natural and controlled fermentations involve lactic-acid bacteria (LAB). Their growth must be understood to produce a safe and marketable product. Most starter cultures, today, consist of lactic acid bacteria and/or micrococci, selected for their metabolic activity which often improves flavour development. The reduction of pH and the lowering of water activity ($a_W$) are both microbial hurdles that aid in producing a safe product. Fermented sausages often have a long storage life due to added salt, nitrite, and/or nitrate, low pH due to lactic acid production by LAB organisms in the early stages of storage, and later drying which reduces the water activity ($a_W$). A sampling of fermented products produced around the world along with their characteristics can be found in Table 2.1.

**Table 2.1 Selected Fermented Sausages From Various Countries Around the World**

| Country | Processing | Seasoning |
|---|---|---|
| Argentina | | |
| Cervelatwurst | Veal, dry, uncooked, smoked, medium chop, artificial casing | Mild |
| Copenhagen Salami | Beef, semi dry, uncooked, smoked, fine chop, artificial casing | Medium |

| | | |
|---|---|---|
| Csabai Salami | Beef, dry, uncooked, smoked, coarse chop, artificial casing | Heavy |
| Danish Salami | Beef, dry, uncooked, smoked, fine chop, artificial casing | Mild |
| Hungarian Salami | Beef, dry, uncooked, smoked, fine chop, artificial casing | Mild, garlic |
| Mettwurst | Beef, dry, uncooked, smoked, coarse chop, artificial casing | Medium seasoning |
| Milano Salami | Beef, dry, uncooked, unsmoked, coarse chop, artificial casing | Heavy, garlic |
| Pepperoni | Beef, dry, uncooked, unsmoked, medium chop, artificial casing | Heavy |
| Pizza Salami | Beef, dry, smoked, fine chop, artificial casing, | Heavy seasoning, garlic |
| Veneto Salami | Beef, dry, uncooked, unsmoked, medium chop, artificial casing | Heavy, red wine, crushed peppercorn s |
| Austria | | |
| Kantwurst | Beef, pork, dry, uncooked, smoked, coarse chop, artificial casings | Medium, nitrite |
| Landjager | Beef, pork, dry, uncooked, medium chop, pork casing | Medium, nitrite |
| Mailand Salami | Beef, pork, dry, uncooked, unsmoked, coarse chop, artificial casing | Medium, nitrate |
| Plockwurst | Beef, pork, dry, uncooked, smoked, coarse chop, artificial casing | Medium, nitrate |
| Salami | Beef, pork, dry, uncooked, smoked, coarse chop, artificial casing | Medium, nitrate |
| Ungar Salami | Pork, dry, uncooked, smoked, coarse chop, artificial casing | Medium, Nitrate |
| Belgium | | |
| Ardenner | Beef, pork, dry, uncooked, smoked, medium chop, beef casing | Medium |
| Boulogna | Horse, dry, uncooked, unsmoked, medium chop, pork casing | Medium |
| Courant | Beef, pork, dry, uncooked, smoked, medium chop, artificial casing | Medium |
| Edelkost | Beef, pork, dry, uncooked, smoked, medium chop, artificial casing | Medium |
| Fijnkost | Beef, pork, dry, uncooked, or smoked, medium chop, artificial casing | Medium |

| | | |
|---|---|---|
| Ole | Dry, uncooked, unsmoked, artificial casing | Medium |
| Pur Porc | Pork, dry, unsmoked, smoked, medium chop. Pork casing | Heavy |
| Salami Extra | Beef, pork, dry, uncooked, smoked, medium chop, artificial or pork casing | Medium |
| Westfalie | Beef, pork, dry, uncooked, smoked, medium grind, pork casing | Medium |
| Brazil | | |
| Salame Tipo Italiano | Pork, dry, uncooked, unsmoked, fine chop, artificial casing | Medium |
| Salame Tipo Milano | Pork, dry, uncooked, unsmoked, fine chop, artificial casing | Medium |
| France | | |
| Arles | Beef, pork, goat, horse, donkey, dry, uncooked, unsmoked, medium chop, beef or pork or artificial casing | Mild or medium |
| Cervelas, a l'Ail | Pork, moist, cooked, unsmoked, medium chop, beef or artificial casing | Medium |
| Cervelas de Lyon | Pork, moist, uncooked, unsmoked, medium and coarse chop, beef casing | Mild, truffles under casing |
| Chasseur | Beef, pork, goat, horse, donkey, dry, uncooked, unsmoked, coarse chop, pork or artificial casing | Medium |
| Chipolata | Pork, moist, uncooked, unsmoked, medium chop, sheep casing | Mild |
| Chorizo | Beef, pork, goat, dry or semi-dry, uncooked, smoked or unsmoked, medium or coarse chop, beef or pork or artificial casing | Heavy |
| Figatelli | Pork, moist or semi-dry, uncooked, to be fried, smoked or unsmoked, medium or coarse chop, pork casing | Medium, liver |
| Gendarme | Beef, pork, semi-dry, uncooked, smoked, coarse chop, pork casing with square sections | Medium |
| Jesus | Pork, dry, uncooked, unsmoked, coarse chop, pork casing | Mild |
| Longanissa | Beef, pork, semi-dry, uncooked, unsmoked, medium chop, pork or sheep casing | Heavy |

| | | |
|---|---|---|
| Menange | Pork, dry, uncookerd, unsmoked, medium or coarse chop, pork casing | Mild |
| Merghez | Beef, pork, moist or semi-dry, uncooked, unsmoked, medium chop, sheep casing | Heavy |
| Merguez Veritables | Moist or semi-dry, uncooked, to be fried, unsmoked, medium chop, sheep casing | Heavy |
| Mettwurst | Beef, pork, semi-dry, uncooked, smoked, medium chop, beef or pork casing, spreadable | Mild |
| Montagne | Pork, dry, uncooked, unsmoked, coarse chop, pork casing | Mild |
| Mortadelles | Pork, moist or semi-dry, cooked, unsmoked, beef casing | Mild, may be fermented |
| Sabodet Coudenat | Pork, moist, uncooked, to be cooked, unsmoked, coarse chop, beef or pork casings | Mild |
| Salami Danoix | Pork, dry, uncooked, smoked, medium chop, pork casing | Medium |
| Salami de Milan | Beef, pork, dry, uncooked, unsmoked, medium chop, beef casing | Mild |
| Salami Hongrois | Pork, dry, uncooked, smoked, medium chop, beef casing | Medium |
| Salami Strasbourg | Beef, pork, dry, uncooked, smoked, medium chop, beef casing | Medium |
| Saucisse de Counfnne | Pork, moist, uncooked, to be cooked, unsmoked, medium or coarse chop, beef or pork casings | Mild |
| Saucisse de Foie | Pork, moist or semi dry, uncooked, to be fried, unsmoked, medium or coarse chop, pork casing | Medium, contains liver |
| Saucisse D'auvergne | Pork, dry, uncooked, unsmoked, medium or coarse, pork casing | Mild |
| Sucisse de Francfort | Pork, moist, uncooked, smoked, fine chop, sheep casing | Mild |
| Saucisse de Lyon | Pork, dry, uncooked, unsmoked, fine + medium chop, pork casing | Mild |
| Saucisse de Morteau | Pork, semi-dry, uncooked, smoked, coarse chop, pork casing | Mild or medium |
| Saucisse de Toulouse | Pork, moist, uncooked, unsmoked, coarse chop, pork casing | Mild |
| Saucisse ou carvelas a Cuire | Beef, pork, semi-dry, uncooked, unsmoked, coarse chop, beef, or pork or sheep casing | Mild |

| | | |
|---|---|---|
| Saucisses Poitau Charente | Pork, moist, uncooked, to be cooked, unsmoked, beef or pork casing | Mild |
| Saucisson Brioche | Pork, moist, cooked, unsmoked, medium chop, no casing | Mild, 60% sausage in 40% brioche |
| Saucisson de Paris | Pork, moist, cooked, smoked or unsmoked, medium chop, beef casing | Mild |
| Soubressade | Beef, pork, semi-dry, uncooked, unsmoked, medium chop, beef or pork casing | Heavy |
| Germany | | |
| Bauernsalami | Beef, pork, dry, uncooked, smoked, medium chop, beef or artificial casing | Medium |
| Karpatensalami | Beef, lamb, dry, uncooked smoked, medium chop, beef or artificial casing | Medium |
| Katenwurst | Beef, pork, semi dry, uncooked, heavy smoked, medium chopped, beef or pork casing | Heavy |
| Mettwutst | Moist, finely chopped, spreadable, | Medium |
| Rindfleischsal ami | Beef, dry, uncooked, medium chop, beef or artificial casing | Heavy |
| Salami | Beef, pork, dry, uncooked, smoked, medium or coarse chop, artificial casing, 40-65 mm | Medium |
| Schinkenpol-nische | Beef, pork, semi-dry, uncooked, smoked, coarse chop, pork casing | Medium |
| Schlackwurst | Beef, pork, semi-dry, uncooked, smoked, medium chop, pork casing | Mild |
| Schwartenmagen | Pork, with ground skins, moist,cooked, smoked, coarse chop, pork casings | Medium |
| Teewurst | Moist, finely chopped, spreadable, | Medium |
| Westfalische Wettwurst | Beef, pork, dry, uncooked, unsmoked, coarse chop, pork casing | Medium |
| Zervelatwurst | Beef, pork, semi-dry, uncooked, smoked, medium, beef or artificial casing | Medium |
| Greece | | |
| Hungarian Salami | Beef, pork, dry, uncooked, smoked or unsmoked, medium chop, artificial casing | Medium |
| Karamanlidika | Lamb, semi-dry or dry, cooked in | Heavy |

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|---|---|---|
| | sheep fat, unsmoked, coarse chop, sheep casing | |
| Levkas Salami | Pork, dry, uncooked, unsmoked, coarse chop, pork or artificial casing | Medium, pork fat |
| Milan Salami | Beef, pork, dry, uncooked, unsmoked, fine chop. Pork or artificial casing | Medium |
| Salami Aeros | Beef, pork, dry, uncooked, smoked or unsmoked, coarse chop, sheep or artificial casing | Medium, garlic, black pepper, pork fat |
| Sebrian Salami | Beef, pork, semi-dry, cooked, unsmoked, fine chop, sheep casing | Medium seasoning |
| Soutjoukia | Lamb, semi-dry or dry, cooked, unsmoked, coarse chopped, sheep casing | Heavy |
| Hungary | | |
| Salami | Pork, dry, uncooked, smoked, medium chop, artificial casing, 40-65mm | Heavy |
| Iceland | | |
| Lamb-Aspaeipylsa | Beef, lamb, pork, dry, uncooked, smoked, medium chop, artificial casing | Heavy |
| Spaeipylsa | Beef, pork, dry, uncooked, smoked, medium chop, artificial casing | Heavy, pork fat added |
| Ireland | | |
| Cervelat | Beef, pork, dry, uncooked, smoked, medium or coarse chop, artificial casing | Medium |
| Farmhouse Salami | Beef, pork, dry, uncooked, smoked, coarse chop, artificial casing | Medium |
| Irish Whisky Salami | Beef, pork, dry, uncooked, smoked, coarse chop, artificial casing | Medium |
| Kabanossi | Pork, dry, uncooked, smoked, coarse chop, artificial casing | Heavy |
| Krainer | Pork, dry, uncooked, smoked, coarse chop, artificial casing | Heavy |
| Mettwurst | Pork, semi-dry, uncooked, smoked, fine chop, artificial casing | Medium |
| Italy | | |
| Cacciatori | Beef, pork, dry, uncooked, unsmoked, medium chop, beef casing | Medium |

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|---|---|---|
| Salame Felino | Beef, pork, dry, uncooked, unsmoked, coarse chop, pork casing | Medium |
| Salame felino | Pork, dry, uncooked, unsmoked, medium chop, pork casing | Medium |
| Salame Gonovese | Beef, pork, dry, uncooked, unsmoked, coarse chop, beef or pork casing | Medium |
| Salome Milano | Beef, pork, dry, uncooked, unsmoked, fine chop, pork casing | Heavy |
| Salame Napoletano | Beef, pork, dry, uncooked, smoked, coarse chop, pork casing | Medium |
| Salame Varzi | Pork, dry, uncooked, unsmoked, coarse chop, beef or pork seasoning | Medium to heavy |
| Salame Veronese | Beef, pork, dry, uncooked, unsmoked, medium chop, pork casing | Medium |
| Mexico | | |
| Chorizo Pamplona | Beef, pork, paprika, dry, uncooked, unsmoked, coarse chop, artificial casing | Heavy |
| Salami Hungaro | Beef, pork, dry, uncooked, smoked, fine chop, artificial casing | Medium |
| Salami Milano | Beef, pork, dry,uncooked, unsmoked, medium chop, artificial casing | Medium |
| Salami Varzi | Beef, pork, dry, uncooked, unsmoked, coarse chop, artificial casing | Medium |
| Netherlands | | |
| Bieworst (Dauerwurst) | Beef, pork, semi-dry, uncooked, smoked, medium chop, artificial casing | Medium |
| Boeren (Metworst) | Pork, dry, uncooked, smoked or unsmoked, coarse chop, pork casing | Mild |
| Cervelaat-worst | Beef, pork, semi-dry, uncooked, smoked, medium chop, pork or artificial casing | Medium |
| Gelderse Rookworst Onverpakt | Beef, pork, moist, uncooked, smoked, fine or medium chop, pork or artificial casing | Medium |
| Gelderse Rookworst Verpakt | Beef, pork, moist, uncooked, smoked, fine or medium chop, pork or artificial casing | Medium |
| Plokworst | Beef, pork, dry, uncooked, smoked, coarse chop, collagen casing | Medium |
| Salami | Beef, pork, dry, uncooked, smoked, | Medium or |

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| | medium or coarse chop, beef or artificial casing | heavy |
| Snijworst | Beef, pork, semi-dry, uncooked, smoked, medium chop, beef or collagen casing | Medium |
| Theeworst | Pork, moist, uncooked, smoked, fine chop, artificial casing | Medium |
| Norway | | |
| Faremorr | Beef, lamb, pork, horse, plucks, blood, dry, uncooked, smoked, medium chop, beef casing | Medium |
| Farepolse | Beef, lamb, goat, horse, dry, uncooked, heavy smoke, medium chop, artificial casing | Mild |
| Faresnabb (Chub) | Beef, lamb, pork, horse, plucks, uncooked, smoked, medium chop, artificial casing | Medium |
| Fenarull | Beef, lamb, dry, uncooked, smoked, coarse chop, artificial casing | Medium |
| Fjuellbit | Beef, lamb, plucks, blood, dry, uncooked, smoked, medium, chop, artificial casing | Medium |
| Fjellmorr Gilde | Beef, lamb, pork, plucks, blood, dry, uncooked, smoked, medium chop, beef casing | Heavy |
| Gullstjerna Salami | Beef, pork, dry, uncooked, smoked, medium chop, no casing | Heavy |
| Haugpolse | Beef, lamb, horse, blood, plucks, dry, uncooked, smoked, fine chop, no casing | Heavy |
| Haugtussa Farepolse | Beef, lamb, goat, horse, dry, uncooked, heavy smoked, medium chop, artificial casing | Mild |
| Lux | Beef, pork, dry, uncooked, smoked, medium chop, artificial casing | Medium |
| Luxussalami | Beef, pork, dry, uncooked, smoked, medium chop, artificial casing | Heavy |
| Metwurst | Beef, pork, dry, uncooked, smoked, medium chop, artificial casing | Heavy |
| Rallarsnabb Gilde (Chub) | Beef, pork, reindeer, plucks, dry, uncooked, smoked, medium chop, artificial casing | Medium |
| Reinrose Reinsdyr-polse | Beef, pork, goat, reindeer, dry, uncooked, smoked, medium chop, artificial casing | Medium |
| Sae Terpolse | Beef, lamb, pluck, dry, uncooked, | Medium |

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|---|---|---|
| | smoked, medium chop, artificial chop | |
| Salami | Beef, pork, dry, uncooked, smoked, medium chop, artificial casing | Heavy |
| Salamisnabb (Chub) | Beef, pork, dry, uncooked, smoked, medium chop, artificial casing | Heavy |
| Spgnekorv Gilde | Beef, lamb, pork, horse, pluck, dry, uncooked, smoked, medium chop, artificial casing | Medium |
| Sognemorr Gilde | Beef, lamb, pork, horse, pluck, dry, uncooked, smoked, medium chop, beef casing | Medium |
| Solvfaks Stabbur | Beef, horse, blood, dry, uncooked, smoked, medium chop, artificial casing | Medium |
| Stabbhur | Beef, horse, blood, dry, uncooked, smoked, medium chop, artificial casing | Medium |
| Stabbursnabb (Chub) | Beef, lamb, pluck, blood, dry, uncooked, smoked, medium chop, artificial casing | Medium |
| Tiriltunga | Beef, lamb, goat, horse, dry, uncooked, heavy smoked, medium chop, artificial casing | Mild |
| Toppen | Beef, pork, horse, pluck, dry, uncooked, smoked, medium chop, artificial casing | Heavy |
| Trondermoor | Beef, lamb, pork, horse, dry, uncooked, smoked, medium chop, beef casing | Heavy |
| Poland | | |
| Salami | Beef, pork, dry, uncooked, smoked, fine chop, beef casing | Medium |
| Sweden | | |
| Hashallsmed-vurst | Beef, pork, potatoes, semi-dry, uncooked, smoked, medium chop, artificial casing | Medium |
| Isterband | Beef, pork, barley, semi-dry, uncooked, smoked, coarse chop, pork casing | Medium |
| Roktmed-vurst | Beef, pork, semi-dry or dry, uncooked, smoked, medium chop, sheep casing | Medium |
| Salami | Beef, pork, semi-dry or dry, uncooked, smoked, medium chop, artificial casing | Medium |

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|---|---|---|
| Spickekorv | Beef, pork, dry, uncooked, unsmoked, heavy salt, coarse chop, beef casing | Heavy |
| Switzerland | | |
| Alpenklubler | Beef, pork, dry, uncooked, medium or coarse chop, artificial casing | Heavy |
| Bauernsalami | Beef, pork, dry, uncooked, smoked, medium or coarse chop, beef or pork or artificial casing | Heavy |
| Bauernschub-lig | Beef, pork, dry, uncooked, smoked or unsmoked, medium or coarse chop, beef, pork or artificial casing | Heavy |
| Landjager | Beef, pork, dry, uncooked, smoked or unsmoked, medium or coarse chop, beef or pork or artificial or no casing | Heavy |
| Pantli | Beef, pork, dry, uncooked, smoked, medium or coarse chop, beef or pork or artificial casing | Heavy |
| Rauchsalami | Beef, pork, dry, uncooked, smoked, fine or medium or coarse chop, beef or artificial or no casing | Heavy |
| Salametti | Beef, pork, dry, uncooked, unsmoked, medium or coarse chop, pork or artificial casing | Heavy |
| Salami | Beef, pork, dry, uncooked, unsmoked, medium chop, beef or pork or artificial casing | Heavy |
| Salami Nostramo | Dry, uncooked, unsmoked, coarse chop, beef or pork or artificial casing | Heavy |
| Salsiz | Beef, pork, dry, no garlic, uncooked, unsmoked, fine or medium or coarse chop, beef or artificial casing | Heavy |
| Thailand | | |
| Nham | Pork, garlic, starter often used, semi-dry, wrapped in a banana leaf or cellulose casing, fermented for 3 to 4 days at ~30°C (86°F), consume in 1 to 2 days often without cooking | Medium |
| United States | | |
| Apennino Salami | Beef, pork, garlic, uncooked, unsmoked, coarse chop, pork casing | Mild |
| Calabrese | Pork, dry, uncooked, unsmoked, | Heavy |

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|---|---|---|
| Salami | coarse chop, pork casing | |
| Chorizos | Beef, pork, paprika, vinegar, garlic, chili powder, lightly smoked, pork or sheep casing | Heavy |
| D'Arles or Arles or DeArles Salami | Beef, pork, dry, uncooked, unsmoked, coarse chop, beef or pork or artificial casing with criss-cross cording | Mild |
| Dry or Hard Salami | Beef, pork, extenders or binders, dry, uncooked or cooked to speed drying, unsmoked, medium chop, pork or artificial casing, moisture protein ratio 1.9:1, moisture loss 30%, moisture level 32-38% | Mild |
| Farmers Sausage | Beef, pork, sugar, semi-dry or dry, uncooked, smoked, coarse chop, beef middles or collagen or fibrous or pork or artificial casing | Mild |
| Farmers Summer Sausage | Mostly beef, pork, dry, garlic, cooked, heavy smoked, medium chop, beef or artificial or fibrous casing ~ 2 inches in diameter | Mild |
| Genoa Salami | Beef, pork, light garlic, moisten with grape juice or wine, dry, uncooked, unsmoked, coarse chop, pork casing, end to end cord wrapping, pH 4.9, lactic acid 0.79%, moisture protein ratio 2.3:1, moisture loss 28%, moisture content 28% | Mild |
| German Salami | Beef, pork, garlic, dry, uncooked, smoked, medium chop, pH 4.7-4.8, pork or artificial casing, scalloped cording, moisture protein ratio 1.6:1, 1% moisture loss, 34-35% moisture | Mild |
| Goteborg or Goetborg | Beef, pork, thyme, high salt, dry, uncooked, smoked, coarse chop, beef or artificial casing | Mild |
| Gothaer | Pork, dry, pepper, uncooked, unsmoked, medium chop, pork or artificial casing | Mild |
| Holsteiner | Beef, semi-dry, uncooked, smoked, coarse chop, beef or artificial wide casing, ring shape | Mild |

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| Landjaegar | Beef, pork, semi-dry, uncooked, smoked, wrinkled, black, flat, medium chop, pork or artificial casing | Mild |
| Lebanon Bologna | Beef, no extenders, moist to semi-dry, uncooked, smoked, with heavy smoky flavour, coarse chop, artificial casing, pH 4.7, moisture protein ratio 2.5:1, moisture loss 10-15%, moisture level 56-62% | Medium |
| Lola 2-1/2 oz links or Lolita 14 oz links | Pork, garlic, dry, uncooked, unsmoked, coarse chop, pork or artificial casing | Mild |
| Lyons | Pork, cured meat, garlic, dry, uncooked, unsmoked, medium chop, pork or artificial casing | Mild |
| Pepperoni | Beef, pork, lamb, pepper, dry, uncooked, smoked or unsmoked, medium chop, pork or artificial casing, 15-40mm, mold growth, topping for pizza, pH 4.5-4.8, lactic acid 0.8-1.2 %, moisture protein ratio 1.6:1, moisture loss 35%, moisture level 25-32% | Heavy |
| San Francisco Italian Style Salami | Beef, pork, nonfat dry milk, dry, uncooked, unsmoked, medium chop, pork seasoning | Mild |
| Salami,German | Beef, pork, garlic, sugar, dried, slightly smoked, coarse chop, 2-1/2 inch diameter casing, twind looped every 2 inches | Mild |
| Sicilian Salami | Beef, pork, no garlic, dry, uncooked, unsmoked, coarse chop, pork casing | Mild |
| Snack | Beef, pork, starter culture, dry, cooked, smoked, medium chop, sheep or artificial casing, 10 mm or less diameter | Mild or medium or heavy |
| Sopressata or Soppresate Salami or Frizzles | Beef, pork, light garlic, heavy hot paprika, red or black pepper, dry, uncooked, smoked, medium chop, pork casing | Heavy |
| Thuringer Cervelat or Soft Summer | Beef, pork, variety meats, by products, peppercorns, semi-dry, cooked or uncooked, smoked, medium | Mild |

| | | |
|---|---|---|
| Sausage, or Farmer Cervelat | chop, pork or sewed bung or small diameter artificial casing, <5.0, lactic acid, 1%, moisture protein ratio 3.1-3.7:1, moisture loss 10-15%, moisture level 41-52% | |
| Uruguay | | |
| Longaniza | Beef, pork, dry or semi-dry, uncooked, smoked, coarse chop, beef or artificial casing | Heavy |
| Salame Chacarero | Beef, pork, small pieces, dry or semi-dry, uncooked, smoked, coarse chop, beef or artificial casing | Medium |
| Salame Milan | Beef, pork, dry or semi-dry, uncooked, smoked, medium chop, beef or artificial casing | Medium |
| Yugoslavia | | |
| Kulen | Pork, dry, uncooked smoked, coarse chop, pork or artificial casing | Heavy |
| Sremska Kobasica | Pork, dry, uncooked, smoked, coarse chop, pork casing | Heavy |
| Zimska Salamaq | Pork, dry, uncooked, smoked, medium chop, beef or artificial casing | Mild |

Source: Modified form: Kinsman, 1980; Rust, 1976; Komarik, *et al.*,1974; Campbell-Platt and Cook, 1995; Doyle, *et al.*, 1997; Ad Hoc Panel of the Board on Science and Technology for International Development, 1992; Farnworth. 2003.

# II. Current fermentation and drying procedures

## A. Definitions

Fermented meat in South East Asia (called sour meat) seems to be growing in popularity as consumers search for more varieties in their food choices. The characteristics and types of fermented products can be found in Tables 2.2 and 2.3.

Guidelines proposed in the U.S. (American Meat Institute, 1982, Hui, *et al.,* 2004) for making fermented dry or semi-dry sausages include a definition of dry sausage as chopped or ground meat products, that due to bacterial action, reaches a pH of 5.3 or less. The drying removes 20 to 50% of the moisture resulting in a moisture-to-protein ratio (MP) of no greater than 2.3 to 1.0. In Germany, cured meat can be safely stored at 10°C. According to USDA/FSIS, dry salami must have a MP ratio of 1.9 to 1, pepperoni- 1.6 to 1, and jerky 0.75 to 1, to be labeled as such.

Semi-dry sausages are similar except that they have a 15 to 20% loss of moisture during processing. Semi-dry sausages also have a softer texture and a different flavour profile than dry sausages. Because of the higher moisture content, semi-dry sausages are more susceptible to spoilage and are usually fermented to a lower pH to produce a very tangy flavour. Some sausages are heavily smoked and some have a high sugar level giving them a sweet flavour. Semi-dry products are generally sold after fermentation (pH of 5.3 or less). These are heated, and do not go through a drying process ($a_W$) is usually 0.86 or higher). They are also usually smoked during the fermentation cycle and have a maximum pH of 5.3 in less than 12 hours. If the semi-dry sausage has a pH of 5.0 or less and a moisture protein ratio of 3.1 to 1 or less, it is considered to be shelf stable (USDA/FSIS Food Labeling Policy Manual) but most semi-dry products require refrigeration (2°C; 37°F). In Europe, fermented meat with a pH of 5.2 and a water activity ($a_W$) of 0.95 or less is considered shelf stable. To decrease the pH (below 5.0) with limited drying, the U.S semi-dry products are often fermented rapidly (12 hours or less) at a relatively high temperature (32-46°C; 90-115°F). In Europe, fermentation is slower (24 hours or more) at a lower temperature and results in a higher pH. These differences in speed of fermentation and final pH, result in products having different flavour.

**Table 2.2 Characteristics of Different Types of Fermented Sausages**

| Type of sausage | Characteristics |
|---|---|
| Dry; long ripening, e.g. dry or hard salami, saucission, pepperoni, shelf stable | Chopped and ground meat |
| | Commercial starter culture or back inoculum |
| | U.S. fermentation temperature 15 – 35°C (59 - 95°F)for 1-5 days |
| | Not smoked or lightly smoked |
| | U.S. bacterial action reduces pH to 4.7-5.3 (0.5-1.0% lactic acid,total acidity 1.3% which facilitates drying by denaturing protein resulting in a firm texture, moisture protein ratio <2.3:1, moisture loss 25-50%,<br>Moisture level <35%<br>European bacterial action reduces pH to 5.3-5.6 for a more mild taste than U.S., processing time 12-14 weeks |
| | Dried to remove 20-50% of moisture; contains 20-45% moisture, fat 39%, protein 21%, salt 4.2%, $a_w$ 0.85-0.86, yield 64% |
| | Moisture protein ratio no greater than 2.3 to 1.0 |
| | Less tangy taste than semi dry |
| Semi dry; sliceable, e.g. summer sausage, holsteiner, cervelat (zervelat), thringer, chorizos, refrigerate | Chopped or ground meat |
| | Bacterial action reduces pH to 4.7-5.3 (lactic acid 0.5-1.3%, total acidity 1%), processing time 1-4 weeks |
| | Dried to remove 8-30% of moisture by heat; contains 30-50% moisture, 24% fat, 21% protein, 3.5%, salt, $a_w$ 0.92-0.94, yield 90% |
| | Usually packaged after fermentation/heating |
| | Generally smoked during fermentation |
| | No mold |
| | Moisture protein ratio no greater than 2.3-3.7 to 1.0 |
| Moist; undried; spreadable e.g. | Contains 34-60% moisture, production time 3-5 days |

| | | |
|---|---|---|
| teewurst, mettwurst, braunschweig, frische | Weight loss ~ 10%, $a_w$ 0.95-096 | |
| | Usually smoked | |
| | No mold | |
| | Highly perishable, refrigerate, consume in 1-2 days | |

Modifed from American Meat Institute, 1982; Gilliland, 1985; Campbell-Platt and Cook,1995; Doyle, *et al.*, 1997; Farnworth. 2003.

**Table 2.3 Types of Fermented Sausages and Areas of Production**

| Type | Area | Production | Sausages | Sensory |
|---|---|---|---|---|
| Dry Ferment-ed, Mixed Culture | Southern and Eastern Europe, psychro-trophic lactic acid, optimum growth 10-15°C (50-59°F) | 40-60mm, pork, 2-6 mm particle, nitrate, starters, fungi, ferment 10-24°C (50-75°F), 3-3 days, ripen 10-18°C (50-64°F), 3-6 weeks, Weight loss higher than 30%, low water activity ($a_W$), higher pH, 5.2 to 5.8, lower lactate, 17mmol/100g of dry matter | Italian Salami | Fruity, sweet, odour, medium butt-ery sour, and pung-ent, more mature |
| | | | Spanish Salchichon, Chorizo (usually no starter) | |
| | | | French Saucisson, 9 mg/g of lactate/g | |

| | | | | |
|---|---|---|---|---|
| | Northern Europe, LAB (*Lactobacillus plantarum* or *Pediococcus)* and Micrococcaceae (*Staphylococcus carnosus* or *Micrococcus*) | 90mm, pork/beef, 1-2 mm particle, nitrite, starters, smoked, ferment 20-32°C (68-90°F), 2-5 days, rapid acidification to below 5, smoking, ripen 2-3 weeks, weight loss higher than 20%, lower pH, 4.8 to 4.9, higher lactate 20-21 mmol/100g of dry matter | German Salami, 15 mg/g lactate/g | Buttery, sour odor, low levels of spice and fruity notes, more acid |
| | | | Hungarian Salami | More acid |
| | | | Nordic Salami | More acid |
| Mold Ripened | Europe, U.S. | Usually with starters | French Salami | |
| | | Usually with starters, bowl chopper | Germany Salami | |
| | | Without starters, bowl chopper | Hungarian Salami | |
| | | Usually with starters, ground | Italian Salami | |
| | | Usually with starters | California Salami | |
| | | Usually with starters | Yugoslavian Salami | |
| Semi Dry | U.S. | Usually with starters | Summer Sausage, M/P ratio 2.0-3.7:1.0 | |
| | | | Thuringer | |
| | | | Beef sticks | |

| | | | | |
|---|---|---|---|---|
| Dry | | Usually with *Pediococcus acidilactici* | Beef sticks | |
| | | Usually with *Pediococcus acidilactici* | Pepperoni, M/P ratio 1.6:1.0 | |

Sources: Hui, *et al.*,2004; Schmidt, Berger, 1998b; Demeyer, *et al.*, 2000; Stahnke, *et al.*, 1999

## B. Quantity of Production

Production and composition figures for fermented products are difficult to obtain, particularly, since many of these products are produced and consumed locally and quantities are often not recorded. The limited number of references available would suggest that the production and consumption is sizeable. See Table 2.4 for the quantities that are reported.

**Table 2.4 Production in X $10^3$ Tonnes of Fresh and Fermented Sausages**

| Area | Fresh and Fermented Sausages, Cooked, to be Cooked and Dry | | Only Dry Fermented Sausages |
|---|---|---|---|
| | 1998 | 1999 | 1988 |
| **Northern Europe** | | | |
| Germany | 1,202 | 1,255 | 280.0 |
| | | | 5kg/person, annually 1985 |
| The Netherlands | 123 | 139 | 20.0 |
| Denmark | 94 | -- | 2.0 |
| Belgium | 102 | 71 | 34.0 |
| Sweden | 118 | 127 | |

| | | | |
|---|---|---|---|
| | | | -- |
| Finland | 125 | 116 | -- |
| **Southern Europe** | | | |
| France | 355 | 353 | 95.0 (104.0 in 2000) |
| UK | | | <0.1 |
| Italy | 45 | 56 | 141.0 |
| Spain | 414 | 371 | 130.0 (166.0 in 1192) |
| Portugal | 20,565 | 17 | -- (18.0 in 1998) |
| Greece | 304 | -- | 9.0 |
| Irish Republic | | | <0.1 |
| **Total** | 2,909 | 2,509 | 689 to 1,000 |

-- = no data
Modified from Hui, 2004; Campbell-Platt and Cook (1995).

## C. Raw Meat

Beef, mechanically separated beef (up to ~ 5%), pork, lamb, chicken, mechanically separated chicken (up to ~ 10%), duck, water buffalo, horse, donkey, reindeer, gazelle, porcupine, whale, fish, rabbit, by-products and other tissue from a variety of species can be used to make fermented meat products. Fermented meat is often divided into three groups.

**1. Whole pieces of meat** – e.g.; country ham (sometimes fermented), biltong, and jerky. The major product in this category is hams and since these products are often uncooked, it must be examined to make sure it is free of *Trichinella spiralis.* This product is rubbed with dry salt and nitrate/nitrite, spices (pepper, allspice, coriander, mustard, sometimes juniper berries, and sugar or molasses). Curing normally takes two days per pound of the cut. Initial temperatures are usually between 5 to 10°C (41-50°F) for 10 to 15 days. Additional rubbings with cure are often used during this period and the hams are usually stored at this temperature for an additional 20 to 50 days to allow salt penetration to the interior. The temperature is gradually raised in stages over weeks or months. Hams may or may not be smoked. Cold smoking is often accomplished at 30 to 40°C (86 to 104°F) for several days. During the drying/maturation period, the temperature is usually increased from 13 to 18°C (55 to 64°F) to 30 to 35°C (86 to 95°F) in the later stages of drying. Hams are often aged from one (U.S) to two (Southern Europe) years. These procedures result in water activity($a_W$) of 0.9 in high moisture products to 0.75 in low moisture products. Many regional products can be found in the Campbell-Platt Cook book (1995) on fermented meats.

**2. Meat chopped into small pieces** – sausages, for example, salami. Product is chopped, mixed with salt, sometimes nitrite and/or nitrate, sugar, usually starter cultures, and seasoning, stuffed into casings. It is sometimes smoked which aids preservation and inhibits surface mold growth.

**3. Fermented products made from unusual animal parts** are usually local specialties – e.g. chopped, sundried bones sometimes combined with marrow and fat. Intestines are also sometimes fermented. Alkaline potash from plant material ash (probably containing some nitrite) is occasionally added during proteolytic fermentation. In some cases, sun drying is part of the process. Fermentation is often done in a pot or in an intestinal casing. The flavour is usually challenging and these products are often cooked

The predominant bacteria that appear in fresh meat are typically Gram negative, oxidase-positive, aerobic rods of psychrotrophic pseudomonads along with psychrotrophic *Enterobacteriacea,* small numbers of lactic acid bacteria, and other Gram-positive bacteria. The lactic and other gram positive bacteria become the dominant flora if oxygen is excluded. This flora is encouraged with vacuum packaging and in vacuum encased fermented sausage.

Post rigor ATP levels are approximately 1 µmol/g and pH for beef ranges from 5.5 to 5.7, for pork pH 5.7 to 5.9 [dark firm and dry pork (DFD) usually has a pH greater than 6.0-6.2 and pale, soft and exudative pork (PSE) usually has a pH 5.3-5.5)], and poultry pH ranges from 5.8 to 6.0.

Beef, lamb, and pork have more saturated fat and less moisture than chicken, turkey, and mechanically de-boned poultry and therefore the former species produce a firmer texture and are less susceptible to rancidity and off flavours than poultry products when used in fermented sausages. Mechanically de-boned poultry is usually limited to 10% (although some use 100%) due to the softer texture.

Since the production of fermented meats depends on microorganism growth, it is essential that these products are hygienically processed and chilled prior to use and maintained under refrigeration prior and during the curing operation. In the U.S., pork is not inspected for trichinae. Since some fermented products are not cooked during processing and frequently not cooked by the consumer, it is necessary that trichinae be destroyed by freezing prior to use. The U.S. government-approved conditions (USDA regulations for this destruction is:

| Temperature | | Number of days | Number of days |
|---|---|---|---|
| °F | °C | If pork is less than 5 inches in thickness | If pork exceeds 6 inches and is less than 27 inches in thickness |
| 5 | - 15 | 20 | 30 |
| -10 | - 23.3 | 10 | 20 |
| -20 or | -28.9 | 6 | 12 |

Peanut-fed hogs producing soft fat and meat containing bruised tissue, sinews, excessive connective tissue, skin, and watery gelatinous pockets are not a desirable meat source for fermented products.

Meat intended for fermentation should have a pH of 6.8 and below. Higher levels of glucose should be used in sausages that initially have a higher pH such as poultry. Also, if poultry is used, the product should be heated to at least greater than 68.9°C (156°F) or other temperature/time combinations to destroy *Salmonella* spp. PSE meat can be used up to 50%, but added sugar may need to be reduced so that the pH will not be lowered to a level that will result in quality problems. Hot boned meat can also be used for fermented sausage production. This will raise cathepsin activity approximately 30% when compared to chilled post rigor meat. Irradiated meat (0500 krad) can reduce the aerobic bacteria by as much as four log cycles and substantially reduce the coliform and staphylococci counts to give it an initial meat mix with a lower bacterial population. Mechanically deboned meat will decrease shear and tear values of fermented sausages.

## D. Inoculum

Traditionally, fermented products depend on wild [natural contaminants, natural inocula, back inocula (5 % often used), back slopping, mother batch, indigenous microorganisms] inocula obtained from the environment and/or equipment and/or from previous fermented products. These wild inocula usually do not conform to any specific species but are usually related to *Lactobacilli plantarum*. However, other species such as *L. casei* and *L. leichmanii*, as well as many others, have been isolated from traditionally fermented meat products (Anon, 1978). In the U.S., *L. plantarum*, *Pediococcus pentosaceus,* or *P. acidilactici* are the most used starter cultures [to obtain a pH 4.6-5.1 at 32°C (90°F)]. In Europe, the most used starter cultures include *Staphylococcus xylosu, S. carnosuss,* and to a lesser extent *Micrococcus* spp. (pH 5.2-5.6 at a temperature of <24°C; 75°F). Starter cultures are usually well adapted to the environment from which they were obtained and often will perform better than indigenous microorganisms previously mentioned by developing a lower pH in a shorter time. Since natural contaminants are also mixed inoculums and if the correct mixture is obtained, they can sometimes produce an excellent flavoured, unique product due to production of metabolites, in addition to lactic acid, such as volatile acids, alcohol, carbon dioxide (Gilliland,1985) which results in a more balanced flavour than can be produced by homofermentative starter cultures. Natural contaminants and starter cultures usually have catalase activity which results in the ability to decompose hydrogen peroxide that would retard oxidation and fade meat pigments. The major problem with natural microflora is knowing what mixture of microorganism is present. Since this often changes, there will be a tremendous amount of variation in the finished product. Reliance on natural flora results in products with inconsistent quality. The advantage of a starter culture is that the same microorganisms can be used repeatedly which cuts down on variation of the finished product, and a larger number of organisms can be added (e.g. $10^6$ to $10^7$/g) which is not possible with natural production. The starter culture can then overpower the natural microbial contaminates present in the meat. Now, combined starter cultures are available in which one organism produces lactic acid (e.g. *Lactobacilli*) and another improves desirable flavours (*Micrococcaceae, L. brevis. L. buchneri*). This translates into a lot of very good product and almost no undesirable fermented product. However, very little excellent product is produced since many starter cultures are often homofermentative or, in some cases, a combination of just a few species of microorganisms. In this case, only the end products of one (two or three) organism is available instead of a more balanced flavour profile of multiple types of organisms sometimes obtained with natural fermentation. However, indigenous microorganisms usually vary in type and number and consequently, variation in the acid content and other metabolic end products. Therefore, the acid level and flavour can be subjected to wide and often uncontrollable fluctuations. Organisms likely to produce off flavors are not included in starter cultures; therefore, if the other environmental factors are in control, the inoculated organism will outgrow the indigenous species in the mix and produce only a good product.

## E. Starter cultures or “seed” utilized

Gilliland (1985) suggests that the requirements for a good meat starter culture would be, non-pathogenic, phage-resistant, free from any microbial or chemical impurities that may cause health risk or inhibit manufacture, salt tolerant, and grows fast in a 6% brine, grows well in the presence of 80 to 100 ppm nitrite, has a growth temperature range from 26.7 to 43°C (80 to 109°F), produces lactic acid from dextrose. A good starter culture should also be non-proteolytic (muscle enzymes perform this function) and; therefore, do not break down amino acids into pharmacologically active amines or hydrogen sulfide, forms no gas, produces little or no acetic acid, nonlipolytic (fat enzymes from the muscle perform this function), positively affects flavour and colour, does not produce off flavours during fermentation, phenotypically and genetically stable, and has an inactivation temperature of 57 to 60°C (135 to 140°F). The primary genera of lactic acid bacteria most often used in food would include nonpathogenic *Streptococcus, Lactobacillus* (e.g. *sake*, *plantarum, gasseri*), *Leuconostoc and Pediococcus* (e.g *cervisiae* later reclassified as *acidilactici*, *pentosaceous*) and again, their main purpose is to produce lactate. However, *P. pentosaceus* can use hexoses and pentoses and to produce lactate, ethanol, and acetate. Magnesium is also required since enzymes in the glycolysis pathway contain enzymes that are stimulated by this mineral and thus, magnesium can lead to accelerated pH decline.

Flavour enhancers would include coccal Gram-positive *Staphylococcus* (e.g. *xylosus, carnosus*), *Kocuria* (e.g. *varians*) and *Micrococcus* (e.g. varians now called *Kocuria varians*). Micrococci are also used to reduce nitrate to nitrite in longer shelf life products where nitrate is sometimes used.

Lactobacilli is the starter culture often used in dry sausages that are fermented from 1 to 5 days between 15 and 35°C to produce lactic acid. This low pH denatures the protein, contributes to firm texture, and allows the meat to release moisture more readily and uniformly. Fermentation at the lower temperatures may also allow some growth and metabolism by the natural micro-flora resulting in a larger variety of metabolic end products that could influence the final flavour. Therefore, in essence, a combination of starter culture and natural contaminants working in tandem sometimes results in a more balanced flavour, but at other times produces off-flavours. Natural meat enzymatic reactions also have an environment in which they can function to modify (often improve) the flavour before they are stopped by cooking temperatures, drying, and/or pH reduction. Most dry sausages usually do not have as “tangy” a flavour which some people prefer in semi-dry sausages. Europeans also prefer a milder taste where pH values of 5.3 to 5.6 are often encountered.

Another advantage of using starter cultures over natural fermentation is that they supply large numbers of organisms($10^6$ to $10^7$ CFU/gram raw meat) that overwhelm unwanted organisms that may be present and reduce the pH value to 5.0 in the first few days. In general, starter cultures can decrease the fermentation time compared to natural fermentation by 15 to 20% and increase the product yield by 5 to 7%. This results in reduction of the time required for ripening and usually improves the sensory properties. This pH of 5 is near the meat's iso-electric point which coagulates the solublized meat proteins and reduces the water-holding capacity which encourages drying and weight loss of the product and improves firmness and slice ability.

Starters are usually available in the freeze-dried or frozen state (most popular) and must be handled carefully to maintain the organism viability. Thawing must be done gently (not in hot water) and dispensing should not be done in chlorinated water or water containing metals. Also, the culture should never be mixed with salt, cure ingredients, or other dry ingredients. The frozen cultures often use stabilizing agents such as glycerol, nonfat dry milk, monosodium glutamate, malt extract, alkali metal glycerophosphates, glutamic acid, cystine, and/or dextran for protection and to retain activity (Rothchild and Olsen 1971). Concentrations of the culture are usually $10^9$ to $10^{11}$ CFU/g. Liquid cultures are also available and often use liquid antifreeze (water freezing point depressants or cry-protective agents such as polyhydric alcohols, and/or sugars) which do not allow ice crystals to form when stored at -40°C (104°F). This technique enhances the handling characteristic for subsequent use. Mixed cultures compared to a single organism are usually preferred by the consumer from a flavour standpoint.

*Lactobacilli plantarum* is described as Gram-positive, non-motile rods, usually between 0.6 to 0.8 μm x 1.2 to 6 μm, and occurring singly or in short chains, has an optimum growth temperature of 35°C (95°F), and does not grow *at either* below 7 (45°F) or above 45°C (113°F). The thermal death time is 30 minutes at 63°C (146°F). The organism can ferment glucose, and a variety of other carbohydrates and produces 1.1 mole of DL-lactic acid, 0.4 mole acetic acid, and minor amounts of acetoin from 1 mole of glucose. There is no gas production (Buchanan and Gibbons, 1974). *Lactobacillus curvatus* and *L. sake* can use oxygen with an end product of hydrogen peroxide (can cause colour deterioration) and pyruvate.

*Pediococcus acidilactci* was one of the first commercially available starter cultures and was selected for its rapid growth and resistance to lyophilization which is not as important today since frozen culture concentrate is a major method of distribution.

*Pediococcus acidilactici* and *P. pentosaceus* are the most widely used starter cultures in the U.S. The pediococci are described as Gram-positive cocci occurring in pairs or in tetrads, are nonmotile, 0.6 to 1.0 μm, and do not form endospores. *DL-lactic acid is produced but no gas is produced from glucose, fructose, and mannose.* Other characteristics of *P. acidilactici* and *P. pentosaceus* are optimum growth temperatures of 40°C (104°F) and 35°C (95°F) respectively and the maximum temperature is 52°C (126°F) and 42 (108°F)to 45°C (113°F), respectively, with thermal death times at 70°C (158°F) for 10 minutes or 65°C (149°F)for 8 minutes (Gilliland,1985), respectively. They are also salt (5%, 4 to 8% brine level) tolerant. *Pediococus acidilactici* was developed for higher temperature processing (26 to 50°C; 77 to 122°F) which is used more often in producing semi-dry sausages. In practice, lower fermentation or greening temperatures (16-38°C; 61-100°F) are often used to produce dry sausage products which requires a longer fermentation time.

*Pediococus pentosaceus* was developed as a meat starter culture with a lower optimum temperature (35°C; 95°F) and are often used at 15 to 27°C (59 to 81°F) to make dry sausages. *P.* acidilactici was first chosen because it could be lyophilized successfully; however, it had a long lag phase because of the time needed for re-hydration. In the U.S., frozen cultures are primarily used, but in many parts of the world freeze dried cultures are still in wide use. *Pediococcus* starters are usually incubated at the optimum growth temperatures of 43 to 50°C (109 to 122°F) to achieve a desirable *rapid flavour* development and a rapid pH decline. This temperature favors the growth of Pediococci over the indigenous microorganisms and also inhibits pathogens by the rapid pH decline. Before starter cultures were used, the fermentation or greening temperatures were 16 to 38°C (100°F)which favored the natural contaminants and also resulted in longer fermentation times.

As a general rule of thumb, fermentation temperatures must be altered to the microorganisms utilized.  In Europe, temperatures of 18 to 24°C (64 to 75°F) are used and in the United States, temperatures of 32 to 37°C (90 to 77°F) are common. If no starters are used, a temperature of 10 to 12°C (50 to 54°F) is often used with salt and cure to ensure protection until pH and/or water activity($a_W$) is lowered. European fermentation is at lower temperatures with the Northern Europe producers using temperatures of 20 to 26°C (68 to 79°F), and Mediterranean producers using 5 to 24°C (51 to 75°F). A complete processing schedule can be located in Hui *et al.* (2004).

Frozen starter cultures should be thawed in the container with 21.1 to 23.9°C (70 to 75°F) water. Approximately two ounces should be added per 100 pounds of product. The thawed culture should then be mixed with ice water, used within ½ hour, and thoroughly distributed in the sausage mix for uniform performance. Fermentation is usually more rapid when using frozen cultures (6 to 8 hour lag phase) compared to lyophilized cultures (12 to 14 hour lag phase).

Chemical acidulation, sometime encapsulated (hydrogenated oils which melt at 57°C; 135°F) acids (lactic, citric, or glucona delta lactone) is periodically used in place of fermentation. In general, the encapsulated organic acid technique does decrease the processing time but many consumers do not find the flavour as acceptable as fermented products. Glucona delta lactone (GDL, 0.5%) has been used alone to provide immediate chemical acidulation (~0.6 pH unit) and with lactic acid bacteria to shorten the fermentation time, but this usually has a negative flavour effect. Glucona delta lactone (0.25%) can be combined with starter cultures for lowering the pH in concert. GDL (0.25 to 0.5%) in the presence of moisture is hydrolyzed to gluconic acid and within 24 hours the pH will be lowered to 5.0. Gluconic acid is then converted by lactobacilli to lactic and acetic acid. Examples of microbes used, shelf life of starters, and growth temperatures can be found in Tables 2.5, 2.6, 2.7.

**Table 2.5 Some Microorganism Found in or on Inoculated to Fermented Meat**

| | |
|---|---|
| Lactic acid starter cultures, decreases pH to ~4.8 in one month, aroma acid production, preservation, increases firmness | *Enterococcus sp.* |
| | *Lactobacillus* spp. |
| | *Lactobacllus plantarum* |
| | *L. pseudoplantarum* |
| | *L. casei* |
| | *L. pentosus* |
| | *L. brevis* |
| | *L. farciminis* |
| | *L. alimentarius* |
| | *L. sak* –(bacteriocin producer) |
| | *L. curvatus* |
| | *Micrococcus* M53 (Baktoferment 61,Rudolf Muller) 20°C,(68°F) improve colour and flavour, reduce nitrate, ferment carbohydrates slowly |
| | *M. varians* |
| | *Pediococcus cerevisiae* (Accel, Merk) |
| | *P. acidilactici* (rename of *cerevisiae*), 38-40°C (100-104°F), reduce processing time from 6 to 2 days |
| | *P. pentosaceus* |
| | *Staphylococcus carnosus* – sensitive to phage attack |
| | *S. xylosus* – questionable pathogen |
| | *S. saprophyticis* |

| | |
|---|---|
| | *S. simulans* – questionable pahogen |
| | *Streptococusi diacetylactis* |
| | *S. lactis* |
| | *S. durans* |
| Lactic acid microorganism found in natural fermentation | *Brochothrix thermosphacta* |
| | *Enterobacteriaceae* |
| | *Leuconostoc* sp. |
| | *L. rhamnosus* |
| | *L. bavaricus* |
| | *L. sake* |
| | *L. curvatus* |
| | *L. farciminis* |
| | *L. plantarum* |
| | *Pseudomonas sp.* |
| | *Staphylococcus saprophyticus* |
| | *S. warneri* |
| | *S. xylosus* |
| | *Strepococcus sp.* |
| Flavour, aroma, colour | *Acromobacter sp., Alacigenes sp.,* Yeast |
| | Catalase positive cocci |
| | *Lactobacillus spp* |
| | *Micrococcus varians* (contains Nitrate reductase) |
| | *Mucor* spp. |
| | Non pathogenic *Staphylococcus* spp. |
| | *Pediococcus spp.* |
| | *Penicillum* spp. |
| | *Staphylococcus carnosus* |
| | *S. xylosus* |
| | *Streptomyces griseus* |
| *Penicillium nalgiovense, P. roqueforti,* Molds; that often raises pH to 6.0-6.5 due to utilization of lactate and acetate and/or production of ammonia from protein; initially $10^3$-$10^4$/cm$^2$; 25 days $10^6$-$10^7$/cm$^2$, protects from oxygen and light and delays rancidity, influences aroma | *Alternaria* spp. |
| | *Aspergillus candidus* –toxic |
| | *A.niger* |
| | *A.trnuis* – usually undesirable |
| | *Cladosporium* spp. |
| | *Eurotium* spp. – usually undersirable |
| | *Penicillium* spp.– strains should be tested for mycotoxin production, at high centrations may become allergic |

| | |
|---|---|
| | *P. camembertii* |
| | *P. candidum* |
| | *P. chrysogenum* - ~10%, objectable green colour above 15°C (59°F), often produce mycotoxin and/or penicillin(some are allergic), most also produce cyclopiazonic acid |
| | *P. commune - ~3% of strains are* toxigenic |
| | *P. expansum* |
| | *P. nalgiovense*- ~50% are white,some times allergic, some strains produce mycotoxins |
| | *P. oxalicum - ~3%* of strains are toxic |
| | *P. virrucosum* - ~5% of strains are toxic |
| | *Mucor* spp. |
| | *Rhizopus spp.* |
| | *Scopulariopsis spp.* |
| Yeast; initially $10^3$-$10^4$/$cm^2$; 25 days $10^5$-$10^6$/$cm^2$, may reduce moisture loss, use up oxygen, protect from light, and may contribute to flavour and colour. Increase ammonia, decrease lactic and acetic acids which increase pH. | *Candida famata* |
| | *C. utilis* |
| | *Debaryomyces cantarelli* |
| | *D. hansenii* or *D. kloekeri* |
| | *D. kloeckeri* |
| | *D. pfaffii* |
| | *Hansenula* spp. |
| | *Torulopsis* spp. |
| Visual appearance | *Penicillium chrysogenum*<br>*P. nalgiovensis* |
| Reduce nitrate to nitrite, nitrite degradation, removes hydrogen peroxide produced by lactic acid bacteria. | Catalase positive *Staphylococcus* spp., some are toxigenic |
| | *Lactobacillus pentoses* |
| | *L. plantarum* |
| | *Micrococcus varians* |
| | *Pediococcus acidilactici* |
| | *P. pentosaceus* |
| | *Staphylococcus carnosus* |
| | *S. sciuri* |
| | *S. simulans* |
| | *S. xyosus* |
| | *Vibrio costicolus* |

| | |
|---|---|
| | Nitrite can also be added Directly |
| Degrades hydrogen peroxide produced by lactic acid bacteria | Catalase positive staphylococci |
| | *Micrococcaceae* |
| Oxygen consumption, lipolysis, delays rancidity | Catalase positive cocci |
| Produce bacteriocins which are low molecular weight antimicrobial compounds with activity against various bacteria | *Lactobacillus curvatus* |
| | *L. sake* |
| | *L. plantarum* |
| | *Pediococcus acidilactici* |
| | *P. pentosaceus* |

Modified from Erkkila, 2001; Campbell-Platt and Cook,1995; Doyle *et al.* 1997; Farnworth. 2003.

**Table 2.6. Shelf Life of Starter Cultures**

| Form | Temperature | Shelf life |
|---|---|---|
| Lyophilised | 5°C (41°F) | 3-7 months |
| | -18°C(-0.4°F) | 1-2 years |
| Frozen | -25°C (-13°F) | 6 months |
| Pellet (obvious if they have been thawed) | -45°C (-49°F) | 3 months |
| Liquid mold | 0-5°C (32-41°F) | 6 weeks to 6 months |
| Factors Effecting | | |
| Time (greatest loss initially), temperature, vacuum and nitrogen storage gave better survival than air. Hypertonic solutions are sometimes helpful | | |

Adapted from Campbell-Platt and Cook, 1995.

**Table 2.7. Appropriate Growth Temperatures for Some Common Starter Cultures.**

| Strain of microorganism | Optimum growth temperature |
|---|---|
| *Lactobacillus plantarum*, pH 4.3-4.9 | 30-37°C (86-99°F) in some cases up to 43°C (109°F) |
| *L. saka* | Less than 25°C (77°F) |
| *L curvatus* | Less than 25°C (77°F) |
| *Lactococcus*, pH 4.3-4.9 | 35-43°C (95-109°F) |
| *L. sakei* | Less than 30°C (86°F) |
| *L. curvatus* | Less than 30°C (86°F) |
| *Pediococcus acidilactici* | 38- 40°C (100-104°F) |
| *P. pentosaceus* | 30-35°C (86-95°F) |
| *Penicillium miczynskii* | 20°C (68°F) |
| Staphylococci | 30°C (86°F) |
| *Staphylococcus* + *Lactobacillus casei*, pH <5.2 | 20°C (68°F), RH >95%, fermentation 1 day or 16-18°C (61-64°F), RH 85%, fermentation 15 days |
| Europeans often ripen at | Higher pH and at 20°C (68°F) |
| American often ripen at | Lower pH and at 12-15°C (54-69°F) |

Campbell-Platt and Cook,1995; Luo-Xin, *et al.*, 2003; Wang, *et al.*,1998.

## F. Yeast and Fungi

*Atoxicgenic* yeast and fungi can be applied by dipping or spraying to a limited extent (particularly in the European countries) on meat products that are fermented for only a couple of days usually at 5°C (41°F). This gives them a chance to grow before the pH drops too far. Yeast and fungi are also used more frequently during the ripening and drying process that usually last for several months. Mold cultures (used in the U.S. to provide the desirable white mold on salami products) tend to suppress natural molds and consequently, reduces the risk of producing mycotoxins. Due to this extended ripening and drying, the final pH is usually higher (pH>5.5), even if the pH was lower after incubation, because molds can use lactic acid and produce ammonia. This requires the final (aW) to be low enough for preservation.  The yeast, *Dabaryomyces hansenii,* and *Candida,* and molds *Penicillum nalgiovens, P. chrysogenum,* and *P. cemembertii* are the major species used for meat production (Hui, 2004. Kerry *et al.*, 2004) and are used for surface inoculation. Their contribution to a desired flavour is still being investigated and the main argument for using fungal starters is the prevention of mycotoxin-producing fungi (Kerry, *et al.* 2002). If mold and/or yeast inoculation is used, or if spontaneous growth is encouraged on fermented products, these sausages are usually not smoked since these microorganism are sensitive to the smoke constituents and their growth will be retarded, or uneven growth will be encountered. If smoke is used, the sporadic colonies are usually spread by brushing to get a more even growth. If mold growth is desirable, the production process requires strict temperature and humidity control. For example, too low of a temperature and humidity, will result in a retarded desired mold growth and undesirable microbes may flourish. Too high of a temperature and relative humidity would encourage pathogenic and spoilage organism to grow (Hui, 2004). If water activity ($a_W$) is not low enough, molds will metabolize lactate which would encourage growth and toxin production of staphylococci (Rodel, 1993). If a well-developed mold layer is present, it can influence aroma and taste, and be helpful in future processing steps. These steps include retail storage by reducing moisture loss and loss is more balanced, possible reduction of case hardening, oxidation (rancidity) is decreased because of catalase activity, reduced oxygen penetration, and the product is protected from changes caused by light.

Mold and yeast used can also be found in Tables 2.5, 2.6, and 2.7.

## G. Other ingredients

**1. Additives such as salt** (2 to 4%), 2% minimum for desired bind, up to 3% will not retard fermentation. Four percent salt may encourage contaminating staphylococci to grow faster than the LAB. Five to 6% salt will lengthen fermentation time and is used for anti-microbial protection and is the first hurdle against undesirable microorganisms. Salt will also increase the bind (myosin extraction which forms a gel between meat particles and meat and fat particles. Salt is very important for flavour purposes of the end product, and is often used as a carrier for curing and flavouring agents. Sodium chloride is the major additive that will allow lactic acid bacteria to grow and will inhibit several unwanted microorganisms. Sodium chloride is added for flavour and texture and inhibits Gram negative bacteria while allowing Gram positive lactic acid bacteria to grow. Salt levels above 3% often cause some concern since *Staphylococcus aureus* is also salt tolerant and could grow during fermentation, but *S. aureus* is often inhibited by lactobacilli. Other factors used to help control this organism include using only clean low microbial level raw materials, proper sanitation, and controlled fermentation with starter cultures or acid addition. Sausages with lower levels of salt showed faster fermentation at both 24 and 38°C which also resulted in less staphylococcal growth (Marcy, 1985).

**2. Nitrite** 80 to 240 (in U.S. 156) mg/kg is used for antibacterial, colour, and antioxidant purposes. Nitrate (U.S. ¼ oz/100 lbs, EU potassium nitrate maximum of 300 mg/kg) and nitrite (U.S.1/8 oz/100lbs, EU sodium nitrite 150mg/kg) can be added to the product, but nitrate is usually not necessary except as a reservoir for nitrite which could be useful in long term processing. Initial nitrite level is ~100 ppm; however, as little as 50 ppm improves flavour and appearance, 30-50 ppm is sufficient to produce cured colour, and 100 ppm will produce a desirable flavour and appearance. After 10 days, nitrite is reduced to 10 to 20 ppm and less than 10 ppm after 30 days. The reaction of nitric oxide with meat pigments produces the desired final product colour and also contributes to a desirable flavour. Nitrite is also a hurdle which inhibits bacterial growth and retards salmonellae multination. Nitrite in the un-dissociated nitrous acid form can pass through the bacterial cell wall and retard bacterial enzymes and growth. Also, during initial fermentation, the microorganism growth uses all the oxygen that was incorporated during chopping and mixing (Lueck and Hechelmann, 1987) which reduces the redox potential (Eh) making the nitrite more effective at restricting the growth of aerobic spoilage organisms(e.g. pseudomonads bacteria). Nitrite can retard starter culture growth if not handled properly. It is usually recommended that nitrate and/or nitrite not come in contact with the starter culture during mixing. This risk can be reduced by mixing the nitrite (and/or nitrate) with meat thoroughly prior to adding the starter culture, thus preventing high levels of local nitrite content. Fermentation can be produced with only salt but there is a greater microbial risk if no nitrite is used. In the absence of nitrite, if the product is dried, muscle pigments will be concentrated and result in a darker colour. If smoke is used, compounds from the smoke are deposited on the surface and diffuse inward resulting in a dark red colour. If nitrite level is decreased, this will minimize nitrosamine formation, but will also increase the potential for botulinum toxin formation. Nitrite oxide combines with metmyoglobin producing nitric oxide metmyoglobin which is further reduced to nitric oxide myoglobin, and at a low pH, is further denatured to stable nitric oxide myochromogen. These tie up the iron from myglobin which reduces oxidation and thus rancidity. Hydrogen peroxide can be a source of oxidative potential in fermented meat and oxidation can result in an undesirable green and yellow colour in the product which often appears as gray spots or gray cores. The quantity of hydrogen peroxide can be reduced by catalase which is a component of micrococcus. Catalase is also produced by *S. aureus.*

**3. Simple sugars** such as glucose (dextrose, 0.5 to 1%, a minimum of 0.75% is often recommended) which is the fermentation substrate can be readily used by all lactic acid bacteria. The quantity of sugar influences the rate and extent of acidulation, and also contributes favorably to flavour, texture, and yield properties. The amount of dextrose added, up to ~ 0.7%, will directly influence the final product pH and additional sugar will not decrease pH further since bacterial cultures can not grow in excess acid. Additional sugar may be added to increase the sweetness of the final product and this can also moderate the tartness of lactic acid and produce a less astringent flavour. Other sugars such as sucrose, maltose, and lactose (0.5 to 1.0%; however, not all lactic acid bacteria can utilize lactose) will also result in acid production, but the rate of production is usually slower and the final pH is usually higher. Fermentation is often slower with sucrose and the ultimate pH is frequently higher, but sucrose can be used by some lactic acid bacteria and often contributes to a less acid taste of the sausage due to its greater sweetness.

Since the type and amount of sugar can determine the final pH and if simple sugars are employed, a 1% addition will result in an approximate decline of 1 pH unit. The more complex carbohydrates may be fermented to a lesser extent and will ferment slower. Therefore, the concentration of organic acids produced is inversely proportional to the molecular weight of the carbohydrates used during processing, and directly related to storage time. High molecular weight carbohydrates helps stabilize fermented sausages during long storage. Maltose will yield approximately 78% as much acidity as dextrose. Excess carbohydrates can retard fermentation due to the binding of water. The fate of glucose during fermentation can be found in Table 2.8.

**Table 2.8. Fate of Glucose During Fermentation**

| Treatment | Glucose fermented | Metabolites | | |
|---|---|---|---|---|
| | | Acids | $CO_2$ | Other |
| First 4 days | ~50% | 74% to acids, mainly lactic | 21% to $CO_2$ | 5% to C2 compounds |
| 5-10 days | -- | -- | -- | Maximum aldehydes and ketones (Maximum organoleptic properties) |
| Smoking | ~18% | 18% to lactic acid | 17% to $CO_2$ + others | |
| Storage, 10 days | ~21.5% | -- | 27.5% $CO_2$ | -- |

Modified from Goepfert and Chung, 1970b.

**4. Spices** (e.g black, red, and white pepper, cardamom, mustard, all spice, paprika, nutmeg, ginger, mace, cinnamon, garlic), are often included in fermented meat formulas. Purified, or sterilized, or decontaminated spices are often recommended. Spices are used for flavour, an anti-oxidant properties, to stimulate growth of lactic bacteria, and have an antimicrobial effect on some microorganisms, and they are usually incorporated into the batter. They can result in a faster rate of lactic acid production and also influence the ultimate pH. Often, a synergetic effect is obtained by a combination of spices.

The degree of boost in fermentation can depend on the microorganism involved, the type and source of the spice, and, in some cases, the magnesium content of the spice. Generally, longer fermentation time is required with liquid spice blends compared to their equivalent natural spice quantities.  Some spices have been shown to have a stimulating effect on fermentation (pepper, mustard, garlic, allspice, nutmeg, ginger, mace, cinnamon; Bacus, 1984) because they contain manganese which is a growth factor for cultures (Zaika *et al.*, 1978) and an inhibitory effect on *L. monocytogenes* and *S. aureus* (Kang, Gung, 2000). If spices are not added, $1x10^{-5}$M $Mn_2$ can result in similar level of activity (Zaika, Kissinger, 1984).

**5. Sodium ascorbate** (also in U.S., sodium erythorbate, 7/8 oz/100 pounds, in EU sodium ascorbate maximum is 500 mg/kg) or ascorbic acid (also in U.S. erythorbic acid, ¾ oz/100 lbs.) are used for improvement and stability of colour and retardation of oxidation.

**6. In addition to the normal additives, other additives** are also sometimes incorporated such as phosphates (0.5% in the U.S.), to retard oxidation. The alkaline ones will raise pH and will also retard moisture loss. These phosphates will also increase shear and tear values. Mechanically-deboned meat produces a softer product and phosphates are sometimes used to help stabilize sausages containing this product. Sodium lactate has an inhibiting effect on lactic acid bacteria and reduces the decrease of pH.

Vegetable proteins (e.g. soya isolate) may accelerate fermentation (Hui *et al.*, 2004). Dry powders such as soy protein and milk powder can also slow fermentation due to their water-binding properties. Soya isolates would reduce cost and fat content and in the U.S. 2% may be incorporated to fermented "standard of identity" products, products. Added antioxidants can also retard fermentation rate.

Added water will increase fermentation rate, but in dry products, water needs to be removed later in the drying process.

Dry acid whey (pH 4.0) is sometimes a direct acidulant in fermented sausage. For every 1% dry acid whey added, the pH is reduced 0.11 to 0.13 units and if 3.5% is added, to a product to be fermented this results in a reduction of 1 to 2 hours for the product to reach a pH of 5.0.

Potassium sorbate (2.5% in a dip) may be added in the U.S. to casings prior to, or after stuffing to control mold growth, but this inhibition will only last for a short period of time. However, 5.0% in a dip will completely inhibit mold growth. Other countries recommend 10 to 20%

potassium sorbate (Romcek and Skrinjar, 2002). Leistner *et al,.* (1975) reports that a 5% solution prevented mold growth for 10 days, 10% for 16 days, 15% for 24 days, and 20% for 30 days when stored at 20°C (68°F), 75 to 85% relative humidity.

**7. Meat** can also exhibit desirable and undesirable characteristics which can discourage or encourage fermentation. Due to fermentation temperatures that also encourage contamination microorganisms to grow and speed up chemical reactions, raw meat materials should be of high quality and have a minimal bacterial load and also minimal chemical deterioration. Meat should be well-trimmed of glands, blood clots, and connective tissue (some processors use desinewing machines). Colour of lean and fat is also important with yellow fat being objectionable and intense red lean being preferable. Oxidation of fat is also usually objectionable (however not in all regions of the U.S. or world) in the raw materials and this can particularly be a problem in tissue previously frozen. Initial pH of raw tissue is also important and a low pH is desirable. For this reason, dark cutting beef and dark, firm, and dry (DFD) pork which normally has a high pH are also avoided. Pale soft and exudative pork (PSE) is often not used; even though this tissue has a low pH and loses moisture readily.

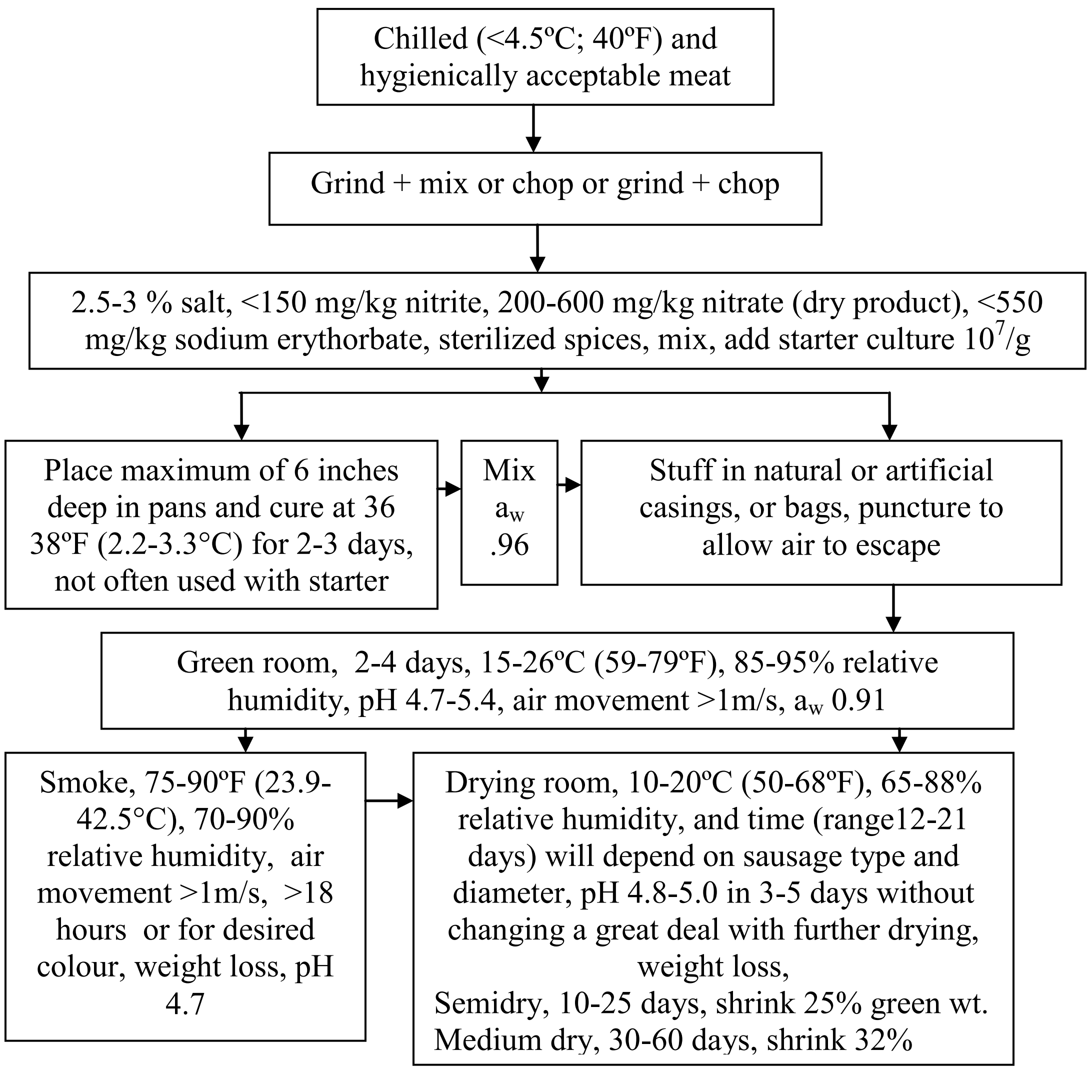
PSE pork often results in a crumbly, mushy texture since the meat proteins have been damaged and also the light colour can be undesirable. Lean meat (less fat) contains more moisture and will ferment faster. Glycogen in meat can also act as a carbohydrate source and contributes slightly to acidity.  Meat with greater buffering capacity (e.g. beef is greater than pork) will resist pH change and more acid production will be needed to lower the pH.

**8. Unintentional contaminants** such as chlorine or metal in tap water, boiler treatment compounds, and sanitizers can retard and sometimes destroy starter cultures. Therefore, water should be periodically analyzed and all equipment should be thoroughly rinsed before use. Chlorine can be removed from tap water by water treatment systems and by allowing water to sit over night before use, to allow the chlorine to dissipate.

## H. Processing

Formulations are numerous even fermented products with the same names are different and some times they are held in confidence. Examples of formulations and processing procedures can be found in Komarik *et al.*1974, Rust (1976), Ockerman (1989), Campbell-Platt and Cook (1995), and Klettner and Bumgartner (1980) and a variety of products can be found in Table 2.1.  Processing conditions can influence the rate of acid production and also the ultimate pH in traditional products. The type of microorganism will also influence fermentation and the final flavour. Time, temperature, humidity, and smoke are also variables that control the quality of the final product. Figure 2.1 will illustrate a general processing flow chart.

**Figure 2.1 Fermented Sausage Processing Flow Chart.**




For production of shelf stable, semi-dry sausage, use encapsulated citric acid but the flavor is not as desirable

For comminuting, a cold temperature is desirable (-5 to -2°C (23 to 28°F) and sometimes frozen meat is used as part of the mix) and a vacuum bowl chopper is used to achieve a particle size of 1-25 $mm^2$ which can be accomplished in a few minutes. A meat grinder can also be used if a larger particle size is desired and, in some cases, whole muscles are fermented which is the case in some hams. Particle size differences of 3.6 mm and 9.5 mm seems to have no effect on fermented products that can be observed during production. After meat is reduced in partial size, curing ingredients and spices should be added to the meat and they should be thoroughly mixed in the product to obtain uniform flavour. Salt is added near the end of chopping and well mixed into the batch. The starter culture should be added last and thoroughly mixed to obtain uniform fermentation.

Temperature primarily determines the metabolic activity of the lactic acid bacteria and also contaminating bacteria. Lactobacilli, as a starter, has an optimum growth temperature of 32°C (90°F). The further the temperature deviates from the optimum temperature, the slower the pH decline. In spite of this, lower temperatures are often used which results in a lower fermentation rate, but the lower temperature helps to control pathogenic organisms and to obtain a desirable flavour, colour, or other characteristics. Higher finishing temperatures are often used to stop fermentation. In spite of the fact that an internal temperature of 63 to 68°C (145 to 154°F) is required to kill lactic acid organisms, lower temperatures of 46 to 52°C (115 to 126°F)for longer periods of time will halt acid production.

Along with temperature controlling fermentation rate, time needs to be adjusted to ensure the desired pH. When time is considered, the “come up” time that is required to obtain the desired internal temperature must be incorporated into the calculations which are influenced by diameter of the product, initial product temperature, desired fermentation temperature, load in the house, air circulation, humidity, and these same variables are altered by a change in the external climate environment.

Higher humidity and the less drying air will accelerate the fermentation rate. High air circulation will reduce the “come up” time to achieve the appropriate temperature but it will also tend to dry out the product which will cause uneven drying and reduced fermentation rate.

## I. Stuffing

Type of casings available include natural casings (cleaned intestines of meat animals, including horse), artificial casings (made from cotton linters), collagen casing (collagen usually from beef hides which is extracted and extruded into tubular casing), fibrous casings (synthetic, inedible) for use in the smokehouse or cooker, sometimes netted, pre-stuck (pin pricked) to allow for better smoke penetration and elimination of air pockets, and cloth bags. Many diameters are used and they range from 25-110 mm and different products use different sizes such as spreadable 35 mm, mold fermented 30-40 mm, and sliceable 65-90 mm.

Casing diameter is important in determining fermentation rate, time, and controlling ultimate pH. Large diameter sausages will normally have a slower fermentation rate due to lower temperature penetration rate and fermentation will also be more difficult to stop with a heat treatment or drying due to slow heat transfer rate.

Vacuum mixing and vacuum stuffing (oxygen exclusion) should be accomplished at -2°C (28°F). Anaerobic fermentation encourages lactic acid bacteria growth, colour, and flavour development.

In some traditional methods, if nitrate is used, a pan curing step which exposes the mix to refrigerated temperatures for 24 hours to encourage colour development is used prior to stuffing. But in most cases, vacuum stuffing is used immediately into natural (traditional appearance), collagen (more uniformity), or cellulose (more uniformity and stronger) casings, which are permeable to moisture and air. A smaller (2 to 15 cm) diameter casing is used to encourage fermentation and drying. Stuffing horns should be of appropriate size to fit the casing and be free of defects.

Natural pork casings compared to artificial casings allowed more proteolytic processes to occur since mold colonization is more extensive and appears to penetrate the pork casing and disintegrate the tissue. A fibrous collagen casing compared to a natural casing encourages a more rapid pH decline (~0.3 pH units).

## J. Fermentation

Facultative or obligate anaerobes which belong to the Gram-positive acidogenic (primarily lactic acid) bacteria such as the genera *Lactobacillus*, *Streptococcus*, *Pediococcus*, *Leuconostoc*, *Lactococcus*, and *Enterococcus* are used which can metabolize several *saccharides*(with different degrees of efficiencies) into lactic acid, alcohols, aliphatic compounds, lipids, and some amino acids. In fermented sausage, this group of organisms simultaneously perform two functions, reducing nitrate and nitrite to nitric oxide and when combined with myglobin is responsible for cured colour, and by anaerobic glycolysis to produce DL-lactic acid from glucose which reduces the pH.

Incubation of sausages at the optimum growth temperature for the lactic acid bacteria, coupled with reduced oxygen, causes exponential growth of the lactic acid bacteria which causes conversion of simple sugars into lactic acid and the lowering of pH. See Table 2.9. The postmortem glycogen level (4.5 to 7 μmol/g) is not enough to reduce pH significantly. Simple sugars are added as substrate for LAB to reduce the pH to 4.6 to 5. To reduce the pH by 0.1 unit requires 0.62 g glucose/kg of meat. Effective carbohydrate fermentation coupled to appropriate levels of phosphorylation is the primary mechanism for lactic acid metabolism. The fermentation route is glyolysis (Embden-Meyerhof-Parnas pathway) for the homofermentative lactic acid bacteria and the sole end product is lactic acid. This produces a sharp tangy taste. The heterofermentative lactic acid bacteria can also use the 6-phosphogluconate/phosphoketolase pathway and produce lactic acid but also produces approximately 10% acetic acid (e.g. acetate, can contribute to an off taste) from hexoses. Lower pH in the mix, inhibits some pathogens (*S. aureus*, *Clostridium* spp., *Salmonella* spp.) and also some spoilage bacteria such as gram negative pseudomonads and enterococci. The low pH results in the uncharged undissociated state of the weak acids which is able to penetrate the cell membrane. Once inside the cell (pH ~ 7.0), the acid dissociates resulting in the release of charged protons (and anions) and results in retarded microorganism growth. Unfortunately, at the typical dry sausage pH of 4.8, only 10% of lactic acid is undissociated which moderates the inhibitory effect (Lueck. 1980).

Temperature, time, and relative humidity combinations are quite variable in industrial productions. In general, the higher the fermentation temperature and water activity ($a_W$), the faster the lactic acid organism reproduces which lowers the pH. In Europe, the fermentation temperatures ranges from 5 to 26°C (41 to 79°F) with lower temperatures used in the Mediterranean area and higher temperatures in northern Europe. Fermentation is often conducted for about three days at a relative humidity of 10 to 90% with the lower values used in the Mediterranean area. It is recommended that the relative humidity be no lower than 10 points below the water activity($a_W$) level of the sausages to retard case hardening (Hui *et al.,* 2004). When the pH is below 5.3, a steeper relative humidity gradient may be used.

In general, the higher the temperature, up to the optimum growth temperature, the shorter the fermentation times. Rapid fermentation (*P. pentosaceus*) results in sulfides, ketones, and methyl-branched acids while slow fermentation (*S. xylosus*) results in methyl branched alcohols, aldehydes, and esters (Tjener *et al*., 2004). In the U.S., semi-dried products are usually fermented with slowly rising temperatures to over 35°C (95°F) to shorten the fermentation time, which is frequently 12 hours or less. The U.S. half or semi-dried summer sausage is fermented three days at 7°C (45°F), three days at 27 to 41°C (81 to 106°F), and two days at 10°C (50°F), then heated to 58°C (136°F) for 4 to 8 hours. The Australian Code of Manufacturing Practices of 1982 requires that the pH decreases to 5.2 within 24 hours and that the fermentation temperature be kept below 25°C (77°F). For salami, the same requirements must be met except the time frame is 48 hours. The American Meat Institute recommends that good manufacturing practices should reduce the pH to ≤ 5.3 with times determined by fermentation temperature, for example, (Buchanan and Gibbons, 1974) 80 hours at 24°C (75°F) and 18 hours at 43°C (109°F). To obtain a pH of 4.8 to 5.0 it requires approximately 25g of lactic acid per kg (dry weight). In some areas of Europe, fewer carbohydrates are added and the sausages only achieve a drop in pH of 0.5 unit.

**Table 2.9. Total and lactic bacterial count during processing**

| | **Total bacterial count log 10** | **Lactic bacterial count log 10 lactic** |
|---|---|---|
| Initial mix | 3.72 | <1.00 |
| Inoculated mix | 7.68 | 7.53 |
| Fermented mix | 8.81 | 8.75 |
| Heat processed | 6.78 | 6.69 |
| Dried 12 days | 6.89 | 6.85 |

Modified from: Acton and Dick, 1975.

# K. Smoking

Smoking depends on tradition and product type in the area the product is produced and can vary from no smoke to heavy smoke. If smoked, it is used to contribute flavour and to retard surface bacteria, molds and yeast. Smoke adds hundreds of antimicrobial and aroma compounds including organic acids (e.g. formic, acetic, propionic, butyric, isobutyric) and phenols (antioxidants), and carbonyls. These compounds contribute to coagulation of the surface proteins and inhibit the growth of microorganisms,

Smoke schedules vary widely but conditions often used are dry bulb temperatures of 110 to 115°F (43.3 to 46.1°C) and wet bulb 105 to 110°F (40.6-43.3°C) resulting in a relative humidity of 85 to 90%. For many products, the temperatures must be raised gradually to prevent product failure. Smoking time is often varied depending on the rate of fermentation achieved, which is influenced by the starter used and the time necessary to reach the desired pH. Often 12 to 20 hours is used. The desirable colour (which is often obtained at 24 hours) is also influenced by smoke density). Temperature is sometimes raised 10°F (~5.5°C) every two hours during smoking until an internal temperature of 137°F (58.3°C) is reached.

Smoking of a small diameter product (13 to 18mm) will inhibit microorganisms such as slime-producing micrococci, yeast, provide antioxidative properties, reduce oxidation, and enhance sensory characteristics. In larger products, smoking will not exert as large an effect on flavor since it is primarily a surface treatment. Smoking at the beginning of fermentation often retards microbial activity and tends to dry the product. Fermented northern European products are smoked utilizing wood burned at 300 to 600°C (572 to 1112°F) which contributes to antimicrobial, antioxidant, flavour and colour properties. Southern European products are not smoked. Hungarian and Romanian fermented products receive a light smoke prior to fermentation (Leistner, 1995). Generally, liquid smoke flavourings retard fermentation rate and the flavour is not identical to natural smoke.

In the U.S., semi-dry products are often smoked after fermentation and colour development (low pH maximizes colour development) and is often applied during final heating. Heating is often finished at 60°C (140°F), but to ensure more safety, many processors of semi-dry products are now using temperatures of 68.3°C (155°F) or more. Firmness and lowered pH decreases sarcoplasmic, and myofibrillar protein solubility which is also lowered with increased smoking time.

High temperature and humidity, which can sometimes be caused by positioning in the smokehouse, will generally ferment faster to a lower pH.

After smoking, the product may be briefly showered in 180°F (82.2°C) water to wash exuded fat from casing surface, held at room temperature until the casings are dry, and then chilled at 45°F (7.2°C) for 24 hours. To retard mold growth, potassium sorbate solution (20%) is often applied to the casing.

# L. Heating

Most semi-dry sausages are heated after fermentation and/or smoking and this often increases the pH. Often, an internal temperature of 137°F (58.3°C) is used. Most semi-dry sausages need to be fully cooked to ~ 160°F (71°C). If heated to 160° (71°C), the total viable and lactic acid bacterial content is reduced by five log cycles and will be reduced an additional log during 60 days of drying. This heat reduces solubility of both myofibrillar and sarcoplasmic proteins.

# 1. Drying/ Ripening

European drying temperatures of 14°C (57°F), and 78 to 88% relative humidities are often used. Air velocity of 1 m/s is also used. This results in a final water activity($a_W$) of less than 0.90 in the finished fermented product (Klettner and Baumgartner, 1980). A semi-dry product can usually be produced in 10 to 12 days. During warmer weather and in warmer climates, these processes require air conditioning and, with increased energy cost, consideration is being given to use of fresh air in areas where local climatic conditions are favorable.

Ripening is controlled by muscle enzymes, metabolic activity and the type, and concentration (a lot destroyed during cooking) of inoculated or spontaneous microorganisms. Ripening factors are influenced by time, previous heating, and drying/ripening temperatures, relative humidity, and air flow, and these factors also influence drying rate and finished product and water activity ($a_W$) levels. The low pH decreases the water-holding capacity, which in turn increases the rate of drying, thus lowering the water activity ($a_w$) which is the final hurdle for the growth of bacteria. Microorganisms are usually reduced in the order of less resistance ones such as enterobacteriaceae, pseudomonads, and bacill. Microorganisms that will survive for a longer period of time are micrococci, strephylococci, enterococci, listeriae, and enterohemorrhagic *E. coli*. In long-ripened dried sausage, spoilage and pathogenic microorganisms have little chance of additional growth, but the possibility of pathogen presence still causes a concern (Hui, 2004). The USDA (Food Standard and Labeling Policy Guide) suggests that a product with a pH of 5.0 and with a moisture/protein ratio of 3.1 or less does not require refrigeration.

Often, there is an increase in pH in dry sausages during the aging process, which can be due to yeast and mold growth. Some molds produce toxic materials such as mycotoxins as well as antibacterial agents. Metabolites from some molds may prevent the growth and survival of undesirable Gram-positive bacteria. Myofibrillar and sarcoplasmic protein solubility, and peptides decrease during ripening, but free amino N, non-protein N and volatile basic N levels, and total free acids increases. Lipolysis also occurs during ripening and is primarily due to endogenous meat enzymes.

The concentration of total heme pigments are increased during dehydration due to the concentrating effect associated with moisture loss. However, the percentage of total pigments converted to the cured nitric oxide heme pigment decreases, suggesting nitric oxide dissociation from the heme pigment.

## 2. Packaging

Fermented, semi-dry sausages after chilling need to be packaged to prevent further weight loss, exposure to oxygen, and contamination. Clear, high-barrier films are the most common packaging material for both intact sausage and sliced product since they contain high oxygen and moisture barriers and will retard flavour and colour losses. Gas flushing with an inert gas (often nitrogen), and vacuum packaging also make very good packages for semi-dried products. Mold ripened sausage, however, cannot be vacuum-packaged. Since moisture cannot escape, this wet surface causes mold to be loosened, comes off, and deteriorates appearance. For short-term storage, use cellophane or perforated polypropylene

## 3. Storage and Marketing

It is usually recommended to hold most fermented products at refrigerated temperatures during storage and marketing even though dried products are often shelf stable. Good hygiene to prevent cross-contamination and bacterial growth is necessary. If fermented products are stored in the same room or come in contact during distribution with cooked meat, cross contamination will become a concern.

## M. Metabolism and acidulation

Fermentation is caused by lactic acid bacteria, metabolizing glucose, producing lactic acid, and causing acidulation, which interacts with the salt soluble proteins. Glucose concentration, temperature and the time held at that temperature are the most important factors influencing the metabolic activity of the bacteria in the meat mix. The sarcoplasmic proteins decrease ~10% in solubility during acidification. When this acidification is in the presence of NaCl, the reduction is ~60%. The myofibrillar proteins at a pH of 5.7 decrease 40% in solubility and an additional 10% at a pH of 4.4. Most lactobacilli have an optimum growth temperature of 32°C (90°F). The further the product temperature gets from the microorganism growth optimum temperature, the slower the fermentation rate. In some cases, lower temperatures and slower fermentation are desirable in controlling ultimate pH, flavour, colour, and additional *sausage* quality characteristics. Internal product temperature “come up” time has to be considered in the *time x temperature* relationship and this is influenced by initial product temperature, air circulation (static air usually ferments faster), humidity (high humidity increases fermentation), and the diameter of the casing (generally larger diameter casing product exhibits slower fermentation and therefore lower ultimate pHs than small diameter casings). The amount of lactate and ammonia present determines pH changes. Lactate which can be converted to lactic acid, is primarily produced from added carbohydrates, but may be produced from bacterial fermentation of glycerol and in concert with ammonia from fermentation of amino acids. Fermentation also produces acetic acid. Oxygen consumed by metabolism along with processing conditions affect the type of microorganisms and their metabolism and this influences the amount of carbohydrate fermented and lactate produced. Concentration of D-lactate may be five times higher in high acid sausage than in the low acid types. Several models have been developed and can be used to characterize rates, and are important factors in this complex biochemical matrix (Demeyer, 1991,1992; Verplaetse, 1990). In general, the more lean tissue (less fat, more moisture) will result in a more rapid drop in pH values. See Table 2.10. The higher, the buffering capacity (ability to neutralize acid, of the meat), will result in slower fermentation. The greater the ratio of frozen meat (usually with lower initial temperature and containing less moisture due to drip loss), the slower the fermentation rate. Pork products usually ferment faster than beef and it is postulated that this is caused by pork having higher lactic acid bacterial contamination, higher thiamin content, lower initial pH, and less buffering capacity. In general, bacterial growth increases up to day 14 and then remains almost constant for the next 21 days of the ripening period. Some yeast, before or after fermentation, produce basic end products, which will raise or retard pH drop, and sometimes produce off-flavours. High oxygen content in meat will encourage oxidation and *Micrococcus* can contribute to the conversion of carbohydrate to basic compounds. Both will cause an undesirably higher than normal pH in the finished product. Smoke will also inhibit microorganisms and have a tendency to dry the product. These are more noticeable on small diameter products. Generally, fermented product internal temperatures of 63 to 68°C (145 to 154°F) are required to kill lactobacilli and in larger diameter casings this temperature is more difficult to control due to slower heat penetration rate, but lower temperatures for an extended period of time will also halt the production of lactic acid. A negative relationship is often found between moisture content and pH and is possibly caused by dissociation of the acid. This might also explain the slight increase in pH during aging and also cooking. Non-uniformity, within a product and between products, can often be caused when products are not mixed properly, or when the location in the smokehouse or drying room results in different temperatures, since higher temperatures and humidity will usually ferment faster and to a lower pH. A pH of 4.8 to 5.0 will usually have 25g of lactic acid/kg dry weight. The ratio of lactate to acetate ranges from 7 - 12 to one. Campbell-Platt and Cook (1995) reported that butyric and propionic acids are approximately one thousand times less (50-200μmo/kg dry weight) after fermentation.

**Table 2.10. Fat Influence on Acid Level**

| Fat level | 15% fat | 30% fat |
|---|---|---|
| Fermentation days | Percent acid, fat-free basis | |
| Day 0 | 1.60 % | 1.63% |
| Day 12 | 3.22 % | 3.17% |

Modified from: Acton and Dick, 1975.

"Normal" starter culture fermented product is formulated with meat tissue that has an initial pH of approximately 5.7. This product passes through the microbial lag phase in about 1.5 days, and then the pH decreases rapidly in about eight days to a pH of 4.95. The fermented sausages then starts a slow pH rise to about 5.05 at approximately 23 days during ripening of the product. With the same type of product, the water activity ($a_W$) initially is approximately 0.99 and decreases almost linearly to about 0.91 in 23 days. This is normally accelerated for modern-day semi-dry production. Water-holding capacity is positively correlated to pH. Lactobacillus in this same product is initially approximately $10^3$/g and increases rapidly to approximately $10^9$/g in two days. These numbers remain fairly constant at this level for 23 days. Micrococcaceae on the surface of the fermented product is initially $10^4$/g, and increases fairly rapidly to $10^6$/g by the seventh day and then decreases only slightly up to 23 days. Micrococcaceae in the core is also initially $10^4$/g, has only a modest rise at 3 days, and then decreases back to its initial level and remains there for the 23 days. Enterobacteriaceae is initially approximately $10^4$/g and decreases to an undetectable level at about seven days. Hexoses are initially approximately 25m moles/100g dry matter and decreased to about 15 in 23 days. Acetic acid was initially at zero and increased to 1.5 m moles/100g dry matter in 23 days. Both myofibrillar and sarcoplasmic protein as percent of total soluble protein decreased approximately 50% during this same 23 day time period. Peptides initially increased and then decreased to approximately the initial level during 23 days of ripening, but free amino nitrogen increased steadily and ammonia increased approximately five fold. Triglycerides decreased approximately 15% and free fatty acids, diglycerides, phospholipids, and monoglycerides all increased. Naturally, the initial contamination, starter culture type, and quantity used, temperature, and humidity, as well as other environmental factors, will have a major influence on these values.

## N. Sensory

**1. Flavour** is a combination of taste, aroma, and texture. A variety of compounds contribute to flavour. Some are added (e.g. salt, nitrite, spices,) to the formulation mix and others are formed by abiotic reactions caused by tissue or microbial enzymes (which contribute mostly during the ripening stage), and the quantity of lactic acid (2.4-8.9 g/kg). Flavour is influenced by the quality and type of raw material, smoking, fermentation rate and time, and the rate and extent of drying. Production of $CO_2$ and $H_2S$ and excesses of ethanol, acetic acid, biogenic amines are undesirable. Hydrogen peroxide and hydrogen sulphide can cause off-colour and flavour problems. Proteolysis and lipolysis usually improves flavour.

2. **Aroma** The very important aroma is sensed by nasal receptors, which respond to very small quantities of volatile compounds in the product. Volatile fatty acids as well as saturated and unsaturated aldehydes make a significant contribution to aroma. *Micrococcus* sp. seems to influence the aroma of fermented meat, and it is postulated that lipolytic enzymes transform triglycerides into glycerol and fatty acids and these acids are sequentially broken down into carbonyls which have a distinct aroma.

Alcohols, for example, methyl alcohol, produces fermented fruity odors.

**3. Taste**. Taste is a response to non-volatile compounds, which consist mainly of inorganic salts, nucleotide metabolites, sugars, acids, amino acids, and peptides, which react with receptors on the tongue. The quantity of acid in fermented sausage is between 8.9 to 79 mg/kg of dry matter (Schmidt, and Berger, 1998). The acid level is higher in Northern European than it is in Southern European products. Too much acid production (e.g. lactic, acetic, other short chain acids) results in an off-flavour and is controlled by the amount of carbohydrate added to the initial mix, technological factors, and strains of bacteria which are responsible for the fermentation.

**4. Proteins** Myofibrillar proteins are broken down into polypeptides by the muscle's endogenous enzymes, primarily cathepsin D, and this is encouraged by a low pH. Protein proteolysis, resulting in peptides and free amino acids, clearly has an impact on fermented sausage and contributes to volatile and non-volatile flavours. It has been reported (Fadda, *et al.* 2000b) that *Lactobacillusi casei* and *L. plantarum* can break down sarcoplasmic and myofibrillar proteins, which has a major influence on flavour and aroma compounds. Myofibrillar proteins are more important than sarcoplasmic proteins in the development of the structure of fermented sausages. Other reports (Fadda, et al., 2002; Nielsen and Coban, 2001; Ordonez *et al.*, 2000) suggest that *Penicillium nalgiovense* and *P. aurantiogriseum also* have strong proteolytic and lipolytic activity. The peptides are further broken into free amino acids by both endogenous and microbial enzymes and this degradation of proteins is primarily controlled by pH. Proteolytic activities of the starter culture strains can lead to distinct flavour profile differences in fermented sausages.

**5. Lipids** In meat fermented products, lipolysis, caused by endo- and exoenzymes from muscle tissue and microbial enzymes are involved and fatty acids can be oxidized into aldehydes, alkanes, alcohols and ketones. Flavours and aromas liberated is related to the hydrolytic and oxidative changes (may produce both good and bad flavours) and are usually related to unsaturated fats and are autocatalytic. Free fatty acids increases during processing storage; however, vacuum packaging can moderate this increase. TBARS (thiobarbituric acid reactive substances is a measure of oxidation) will increase slightly in non-vacuum and will remain stationary in vacuum packages. Release of fatty acids seems to be primarily influenced by lipolytic enzymes naturally occurring in meat which would be minimal in semi-dry products that are fully cooked. Oxidation can be reduced by smoking and mold ripening due to the ability to reduce light penetration and also direct oxygen consumption. The diameter of the sausage also influences biochemical reactions involved with larger diameter (anaerobic) sausages where less oxidation is likely to occur. Also, a small diameter sausage, due to more rapid moisture loss, has less time for aroma to develop. Glucose concentration is important for rapid lipase production, but does not influence the maximum lipase activity.

**6. Combination of taste and aroma.** These two sensations of taste and aroma have to be integrated by the consumer to obtain the flavour evaluation. Acid and breakdown products of protein and fat are the key components of product flavour. Meat enzymes with lipase activity, which can produce carbonyls, are more important than bacterial enzymes particularly in dry sausage that is not fully cooked. In the case of protein breakdown, cathepsin D activated by a drop in pH, is responsible for myosin and actin break down. Further metabolism to peptides and amino acids is aided primarily by bacterial enzymes.

**7. Volatiles** More than 200 volatile compounds have been identified from fermented meat products, but not all are important for aroma. Spices and smoking contribute to a number of these compounds. Others that are thought (Hui, 2004) to be characteristic of fermented sausages and are derived from carbohydrate metabolism (e.g. acetic acid contributing a vinegar aroma) are propionic and butyric acids, acetaldehyde (0.7 to 1.5 ppm), diacetyl (0.1 ppm), and acetoin. Diacetyl and acetoin contribute a buttery aroma at levels of 1300 to 1400 ng/g. Break down of phenyl alanine results in aldehydes. For example, methyl aldehyde produces malty and fruity aroma. Acid production, for example, can result in methyl acids which result in a cheesy and sweaty aroma. Lipid degradation results in alkanes, alkenes, straight chain aldehydes, which can result in a green colour, and metallic, fruity, rancid flavour. Alcohols (e.g. ethanol, 55 ppm, 3 methyl-butanal), which yields malty flavour which result in a green colour and a fruity, mushroom, malty aroma, and ketones (e.g. methyl ketones associated with *Staphylococcus carnosus*) which contribute a fruity, musty, and cheesy aroma. Acids which result in methyl ketones, and hexanal from oxidation of linoleic acid which yields green colour and a fruity, metallic, musty, cheesy, and rancid aroma. Ketones produced from 2-pentanone to yield 2-nonanone result in a green colour and a fruity, mushroom aroma. Ketone production by chemical or bacterial means is often encouraged by mold growth. Most are ethyl esters metabolized from ethanol but longer chain ketones are also present. Esters are also found in fermented sausages and contribute a fruity note. Lipid oxidation can be chemical or enzymatic, which generates hydroperoxides and ultimately, aldehydes, ketones, and many other end products. Oxidation is influenced by oxygen content (diameter of sausage), prooxidents (e.g., salt, metals), antioxidative materials (e.g., nitrite, spices) and the amount of unsaturated fatty acids connected to the glycerol. Oxidation is usually characterized by a rancid aroma. The type of microorganisms also has a major influence on the oxidative pathways encountered. Higher processing temperatures contribute other compounds such as diacetyl.

**8. Nonvolatiles** Short chain fatty acids are the taste that distinguishes fermented from non-fermented - sausages. Ranges in organic acids found in fermented sausages have been reported at 11.9-46.3 g/kg for total organic acids, 6.1-34.4 g/kg for lactic acid, 1.9-7.5 g/kg for gluconic acid, and 1.0-5.5 g/kg for acetic acid. In some samples, 0.1-0.25 g/kg pyruvic acid has also been reported (Erginkaya, 1993). Lipase levels that liberates free fatty acids are also correlated to the flavour complex. Non-volatiles are the acid taste, which is correlated with D-lactate and acetate and is related to low-molecular weight peptides, and free amino acids which are also associated with amino acids. Non-protein nitrogen will affect pH and aroma determining acid compounds. ATP metabolites (e.g. IMP, hypoxantine) also influences taste. Initial proteolytic activity with myosin and actin degradation, caused by cathepsin D-like enzymes from the raw materials, also influences taste. Protein metabolism of such compounds as amines, and ammonia particularly, with sausages that have a long drying phase and aromatic branched aldehydes, acids (such as leucine, isoleucine, valine), and alcohols also contribute to the flavour. Catabolites of branched chain amino acids in fermented sausages are aldehydes and branched alcohols, and methyl acids. Meat enzymes that produce free amino acids are also involved. Long chain (16 to 18C; 61 to 64°F) free fatty acids are liberated (27 to 37 mg/g, Demeyer, *et al.*, 2000) from triglycerides by both endogenous and bacterial enzymes. The rate and amounts of liberated free fatty acids are determined by raw material and length of the ripening period but frequently have little flavour.

**9. Both volatiles and non-volatiles.** Smoke, if used, contributes a wide variety of volatiles and natural taste characteristics. Bacteria metabolism down to the end product of ammonia also influences flavour and odour.

# III. Physical properties

**A. Texture** The rate and extent of pH decline influences both sausage texture and gel formation. Salt solubilizes muscle proteins during comminuting, which later denature due to lower pH (5.3 with 3% salt, Solignat and Durand, 1999). Release of moisture causes coagulation and forms a gel around fat and meat particles, which is responsible for texture. This change of pH also effects gel formation in two different directions. Cathepsin D is activated and degrades myosin by accelerating proteolic cleavage of the myosin molecules, which lowers the gel strength, and reduces firmness. The coagulation of the myosin sol into a gel results in increased firmness. Overall, there is a direct relationship between initial rates of pH decline and firmness as the product dries. The use of PSE pork (lower pH and higher temperatures at 45 minutes post mortem which encourages denaturation), spices, starter cultures, and soy protein all increase rates of acid development and drying which influences texture development. Increase in sausage diameter decreases rate of drying and development of texture hardness.

**B. Colour** The stable red colour (nitrosomyoglobin) is caused by nitrosylation and the sequential denaturation of myoglobin. For this to occur, nitrate (if added) has to be reduced to nitrite, reduced to nitrous acid, and to nitric oxide which combines with myoglobin. It is believed that *Micrococceae* is responsible for these reactions, but their reductases are inhibited by pH below 5.2. It is estimated that 50 ppm of nitrite is sufficient to obtain full colour. Addition of sodium ascorbate also accelerates these reactions. Discoloration can be caused by the formation of peroxide, but this can be eliminated by catalase produced by coccal gram-positive bacteria (Nychas and Arkoudelos, 1990). Exposure to light will alter all colour properties and reduce the level of nitrosohaem pigments.

# IV. Pathogens

Leistner *et al*. (1975) reported that pathogenic bacteria were controlled by 110 ppm of nitrite in finely-ground fermented sausages, 65 ppm in sliced Bruehwurst, and 400 ppm in covering brines.

**A.** ***Trichinate spiralis*** could be a problem in unheated products, but heating to 62.2°C (144°F) which is usually accomplished in semi-dry products, will inactivate this organism.

**B.** ***Staphylococcus aureus*** is widely distributed in meat, is very salt and nitrite tolerant, and produces a heat stable enterotoxin that can survive a heat treatment even though the organism is killed. This organism could be a problem when high water activity ($a_w$), and/or pH are encountered. Fortunately, this organism is not very tolerant of acid and has been shown to be inhibited at a pH of 5.1 and a water activity ($a_W$) of 0.86 in aerobiosis and at a pH of 5.7 and a water activity ($a_W$) of 0.91 in anaerobiosis. A health risk is usually associated with levels of ~ $10^5$ to $10^7$ CFU/ g. Toxin production is limited at a water activity ($a_W$) of 0.87 for toxin type A, 0.90 for type B, and 0.94 for type C. In Northern Europe, the large diameter products encourages aerobiosis and the product has a rapid pH decline to below 5.0 which will inhibit the growth of *S. aureus*. In Southern Europe, the smaller diameter favors aerobiosis and pH is often above 5.1 and water activity ($a_W$) is 0.84 to 0.88. This is accomplished at the end of the drying period suggesting that all toxin is not totally inhibited in this production process. In addition to toxin persistence, this organism can also survive the fermentation process. It is important to lower the pH to 5.3 before the toxin can be produced. During fermentation to 5.3, it is essential to limit the time that the sausage is exposed to temperatures at or above 15.6°C (60°F). The U.S uses "degree-hours" which can be used as a measure to prevent toxin production(AMI). An example is a product which reached a pH of 5.3 in 24 hours at 100°F (37.8°C) and would have a 100°F-60°F (initial temperature) x 24 hours = 960 degree hours. For semi-dry sausages fermented at 80-90°F (23.9-32.2°C), the degree-hour requirement is 1200; for fermentation at 90-100°F (32.2-37.8°C), the degree-hour is 1,000; and for fermentation from 100-110°F (37.8-43.0°C), the degree hour is 900. Therefore, products that reach a pH of 5.3 in 24 hours at 100°F are considered safe from enterotoxin production during fermentation (Hui, 2004). Methods suggested for control of this organism is using clean raw materials and control of pH decline with starter cultures or direct addition of an organic acid. At a pH of 5.3 or less, the organism is controlled.

**C*. Clostridium botulinum*** is also a potential problem in fermented sausage but lactobacilli has been shown to have an inhibitory effect against *C. botulinum.* Also, this organism cannot multiply at awater activity $a_w$ level of 0.94-0.95.

**D*. Clostridium perfringens*** can often survive the typical fermentation process.

**E. *Salmonella* strains** can be found in pork and poultry and can survive fermentation, but is usually only a problem when high water activity ($a_w$) and pH are encountered (or when lethality hasn't occurred before drying, e.g., jerky?). See Table 2.11. Fortunately, a rapid pH drop below 5.3 can be accomplished at temperatures above 18°C (64°F), which inhibits *Salmonella* growth. Lactobacilli has demonstrated inhibitory effects against *Salmonella.* Growing conditions are minimal at a pH of 5 with a water activity ($a_W$) of 0.95. *Salmonella* inhibition is obtained by acidification in Northern Europe and by drying in Southern Europe.

**Table 2.11. Fate of Salmonellae During Fermentation and Storage in Thueringer.**

| Treatment | Influence | Due to |
|---|---|---|
| 18-24 hours, fermentation | Decreased 0.75-5.4 logs | Acidity and NaCl |
| | Little effect | $NaNO_2$, $NaNO_3$ and ascorbic acid |
| Sucrose reduced to 0.25%, final pH 5.2-5.4 | Multiply | Lack of sufficient decrease in pH |
| Heating 46°C (115°F) | Multiply | Insufficient temperature |

| | | |
|---|---|---|
| Heating 52°C (126°F) | Reduced number | More effective in both high and low acid products |
| Refrigerated storage | Declined | Not sufficient for complete destruction |

Modified from: Goepfert and Chung, 1970a.

**F. *Escherichia coli* O157:H7** and *Listeria monocytogenes* are ubiquitous, cold tolerant, and can survive fermentation. *E. coli* is found in both cattle and, to a lesser extent, in pigs and has been implicated in disease outbreaks linked to fermented meat since it can survive the fermentation process. Even though lactic acid production and drying can accelerate the destruction of *E. coli,* this is not always sufficient for total elimination. If *E. coli* O157:H7 is present, even in low numbers, in the sausage batter, it can survive fermentation, drying, and storage. As few as 10 to 100 bacteria can cause serious illness. The U.S.D.A. FSIS regulations require a 5 log reduction of *E. coli* O157:H7 to produce a safe product when using beef in the formula and this is usually accomplished by heating. One U.S. time temperature regulation for inactivation is 145°F (62.8°C) for 4 minutes (United States Code of Federal Regulations. Title 9 – Longer time and a lower temperature has also been reported (Getty, *et al.*, 1999) to be effective such as 8 hours at an internal temperature of 26.7°C (80°F), then 24 hours at an internal temperature of 37.8°C (100°F) followed by 24 hours at an internal temperature of 43.3°C (110°F). *Tomicka et al.* (1997) suggest that lower temperature and longer fermentation time (European style) is better for elimination of O157:H7 than higher temperature, shorter time (American style). It has also been suggested that lower pH during growth can confer cross protection against heat for O157:H7 (Duffy, *et al.*, 2000). If heating is not practical, a low irradiation dose of 1.25 kGy will also result in a 5-log reduction (United States Department of Agriculture, 1999). Another possibility is to test and hold the final product or to have a critical control point that tests raw material, but also requires a 2-log destruction.

The International Commission on Microbiological Specification for Foods (ICMSF) recommends that up to 100 cells of *L. monocytogenes* per gram of fermented meat products can be tolerated (European report. 1999, AFSSA. 2000). *L.* monocytogenes is usually a problem when high water activity ($a_w$) and pH are encountered but can grow at a pH between 4.6 and 9.6. However, this organism cannot grow below water activity ($a_W$) levels of 0.90 (AFSSA, 2000).

Procedures recommended to control *E. coli* O157:H7 are also sufficient to control trichina, Salmonella and *Listeria*.

**G. Biogenic amines are low molecular weight compounds** that are produced by microbial decarboxylation of amino acids or by amination and transamonification of aldehydes and ketones (Eerola, *et al.* 1992; Pipek, 1992). The raw material, starter culture, larger diameter product, storage temperature, and pH in fermented sausage production all encourage the production of biogenic amines. If starter cultures are tailored (e.g. mixed cultures usually are better than natural microflora) and processing conditions are controlled, formation of these undesirable amines can be controlled. Such amine compounds would include compounds such as histamine, tyramine (is an allergen), cadaverine, and putrescine, and some are health hazards and have been isolated from fermented products (Montel, *et al*.,1999; Parente, *et al.,* 2001). The major amines isolated from fermented products are tyramine and putrescine and can combine with nitrites to form carcinogenic nitrosamines (Roig Sagues, *et al.*, 1996). *Enterobacteriaceae* (produces histamine, cardaverine) and *Pseudomonas* which produces putrescine has been isolated from sausages and can produce biogenic amines particularly during the first days of fermentation (Roig Sagues, *et al*.,1996; Marino, *et al*, 2000; Edwards and Dainty, 1987). However, it has also been speculated that amine-producing bacteria and/or amine formation can also occur after fermentation of dry sausages. Others speculate that amines can increase and then decrease in the latter state of aging. A negative relationship between total biogenic amine and potassium sorbate concentration have been reported (Shalaby, Abd-El Rahman, 1995).

Some lactic acid bacteria such as *Staphylococcus* and *Kocuria* can also produce amines (Eerola, *et al*,1996). Other organisms that can be involved include enterococci, carnobacteria, pseudomonads, enterobacteria, micrococci caps, and a great number of lactic acid bacteria. Therefore, it is essential to use raw material with as little contamination as possible. Suitable starter cultures can contribute to reduction of biogenic amines. Levels of biogenic amines in sausages can be controlled by reducing the microbial contamination of raw materials, high acidification, and by starter cultures such as *Kocuria varians, Staphylococcus xylous, Lactobacillus casei* and *L. plantarum* (Hui, 2004, Fadda, *et al.,* 2001, Leuschner, *et al*., 1998).

**H. Some surface molds and molds in black pepper** can produce mycotoxins on the surface of the product. It is important if using mold starter cultures to select safe ones such as *P. nalgiovense* and *P. chrysogenum* (Cook,1995; Paska, 1995) 'House' microflora are a concern since this is a mixed culture. However, smoking, low water activity ($a_W$) and low pH of the product will also reduce mold growth.

Quick fermented sausage (Roedel, 1975) is safe at a water activity ($a_w$) < 0.91 or pH of 5.0 and products with higher values than these must be stored at < 10°C (50°F).

## V. Composition

Composition varies widely due to the number of fermented products. Products with the same name vary considerably when made in different countries or even in the same country, or even made by the same company in different locations. The major factors influencing composition of the finished product is naturally the composition and ratio of raw materials used, processing procedures utilized, and the quantity of drying. Since most meat composition data are usually expressed on a percentage basis, the dryer(less moisture) the sausage the higher will be the other individual ingredients in the finished product. A few selected examples of average composition can be found in Table 2.12.

**Table 2.12. Nutritive Composition of an Example of Fermented Products**

| | Cervelat | | Salami, Pork, Beef | Pepperoni, Pork, Beef |
|---|---|---|---|---|
| | Soft | Dry | Dry | Dry |
| Moisture | 48.4% | 29.4% | | 30.5% |
| Calorie (kcal) | 307 | 451 | 424 | 466 |
| Protein | 18.6% | 24.6% | 23.1% | 20.3% |
| Fat | 25.5% | 37.6% | 34.8% | 40.3% |
| Mono-unsaturated | 13.0 g/100g | - | 17 g/100g | 19 g/kg |
| Poly-unsaturated | 1.2 g/100g | - | 3.2 g/100g | 2.6 g/100g |
| Saturated | 12.0 g/100g | | 12.4 g/100g | 16.1 g/100g |
| Ash | 6.8% | 6.7% | 5.5% | 4.8% |
| Fiber | 0 | 0 | - | 1.5% |
| Carbohydrate | 1.6% | 1.7% | - | 5 g/100g |
| Sugar | 0.85% | | - | 0.7% |
| Calcium | 11mg/100g | 14 mg/100g | - | 21 mg/110g |
| Iron | 1.8 mg/100g | 2.7 mg/100g | 1,5 mg/100g | 1.4 mg/100g |
| Magnesium | 14.0 mg/100g | | 17.8 mg/100g | 18 mg/100g |
| Phosphorus | 214 mg/100g | 294 mg/100g | 143 mg/100g | 176 mg/100g |
| Potassium | 260 mg/100g | - | 379mg/100g | 315 mg/100g |
| Sodium | 1242 mg/100g | - | 1881 mg/100g | 1788 mgt/100g |
| Zinc | 2.6 mg/100g | - | 3.3 mg/100g | 2.7 mg/100g |
| Copper | 0.15 mg/100g | - | .0.07mg/100g | 0.07 mg/100g |
| Manganese | - | - | 0.4 mg/100g | 0.3 mg/100g |
| Selenium | 20.3 mg/100g | - | - | 21.8 µ/100g |
| Vitamin C (ascorbic acid) | 16.6 mg/100g | - | - | 0.7 mg/100g |

| | | | | |
|---|---|---|---|---|
| Thiamin ($B_1$) | 0.3 mg/100g | - | 0.6 mg/100g | 0.5 mg/100g |
| Riboflavin ($B_2$) | 0.2 mg/100g | - | 0.3 mg/100g | 0.2 mg/100g |
| Niacin ($B_3$) | 5.5 mg/100g | - | 4.9 mg/100g | 5.4 mg/100g |
| Niacin ($B_3$) | 5.5 mg/100g | - | 4.9 mg/100g | 5.4 mg/100g |
| Pantothenic Acid ($B_5$) | - | - | 1.1 mg/100g | 0.6 mg/100g |
| Vitamin $B_6$ | 0.26 mg/100g | - | 0.5 mg/100g | 0.4 mg/100g |
| Folate | 2 DFE/100g | - | - | 6 DFE/100g |
| Viamin $B_{12}$ | - | - | 1.9 mg/100g | 1.6 mg/100g |
| Vitamin E (alpha-tocopherol) | 5.5 mcg/100g | - | | 0.3 µ/100g |
| Cholesterol | 75 g/100g | - | 78 mg/100g | 118 mg/100g |

- = data not reported
Source; Calorie-Counter.net. 2003; Nutrition Info. 2005; United States Department of Agriculture, 1963; National Livestock and Meat Board. 1984.

# VI. Future

Public health and product spoilage will be a center focus of research in the future and a better understanding of the geological mechanisms will help tremendously. Hazard Analysis and Critical Control Point (HACCP) and hurdle technology control are becoming common place in the food industry and both are particularly important in fermented sausages. See Table 2.13. The first hurdle in fermented products is the use of salt and nitrite in the formula but nitrite only has a major effect early in fermentation. Salt has a more prolonged hurdle as it assists in lowering the water activity ($a_W$). The next hurdle is the redox potential which is increased when air is incorporated during chopping therefore, vacuum chopping is often used. The addition of ascorbic acid or ascorbate, sugar, and micro-organisms using up oxygen, reduces this problem and is an additional hurdle. Next, competitive lactic acid bacteria suppress undesirable organisms by lowering the pH and formation of bacteriocins. The final hurdle is a lowering of water activity ($a_W$) during the ripening process and it steadily increases as the product dries. Since lactic acid bacteria are little affected by the hurdles, they have a selective advantage. Easily controlled fermentation chambers are gaining popularity to accurately control environmental conditions during processing.

**Table 2.13. Hurdles in Fermented Meat for Pathogens.**

| Microorganism | Hurdle |
|---|---|
| General pathogens | pH, bacteriocins produced by lactic acid bacteria, antimicrobial substances by fungi, competition for nutrients, nitrite, low oxygen, water activity ($a_W$), temperatures, smoking, cooking |
| *Salmonella* | Nitrite, low oxygen level, pH, water activity ($a_W$) |
| *Staphylococcus* spp. | Poor competitor with lactic acid bacteria (e.g. Lactocacillus) and starter staphylococci at fermentation temperatures of 20-25°C (68-77°F) |
| *Staphylococcus aureus* | High fermentation temperatures may be a risk |
| *Bacillus and Clostridium spores* | pH, water activity ($a_W$) |
| *Listeria monocytogenes* | Some will survive, cooking may be necessary |
| *Escherichia coli* O157:H7 | Some will survive, U.S. requires a 5 log reduction in numbers, cooking may be necessary |

Modified from: Erkkila, 2001; Farber and Perkins. 1991.

Genetic determinants and transfer mechanisms will be utilized to develop superior lactic acid bacteria strains. These genetically modified microorganisms have the potential to improve food safety and quality, but they must be evaluated on a case-by-case basis. Genetic manipulation to “tailor-made” cultures to be used as starter cultures and fungal starter cultures are being evaluated for elimination of toxin production, regulation of fermentation including protolytic and lipolytic activity, and bio-preservative properties.

Muscle enzyme activity of a carcass, and its influence on meat quality, have been demonstrated (Toldra, and Flores 2000, Russo 1989). Therefore, enzymes and genes can be used to select genetic lines of animals and raw materials for production of fermented sausages. In addition to lactic acid production, microorganisms with superior lipolytic and proteolytic capabilities will be sought to alter flavour. For more value added fermented products, muscle protease, muscle and fat lipase (activities) and spice influence fermented sausage flavour (Fournaud, 1978; Claeys, *et al.*, 2000). If these can be altered, a flavour modification is probably possible. In the future, lactic acid bacteria may be used in meat products, which are not treated currently with starter cultures to add an additional hurdle and to improve food safety. Bacteriocins, with a bacteriocidal activity beyond fermentation, have been found effective against Gram-positive bacteria and in some cases Gram-negative organisms. These could also be useful in fermentation as well as hurdles in meat products that are not currently fermented.

Making fermented product from ostrich (Bohme, *et al*.,1996), carp (Arslan, *et al*., 2001), and utilization of olive oil (Muguerza, *et al*., 2001) have been suggested.

Suitable strains of molds for commercial purposes need to be developed, taking into consideration lack of toxicity, colour, growth rate, competitiveness, resistance to abrasion, ability to grow on different casings, and influence on the final product are all important.

Natural antimicrobial compounds on and in food, produced by lactic acid bacteria, are described as bioprotective. With the production of bacteriocins and/or low-molecular mass, peptides or proteins could aid in the safety of non-cooked fermented meat items. These antimicrobial compounds have the additional advantage of being readily degraded after digestion to common nutrients. Selection of specific strains of lactic acid bacteria that can also produce antimicrobial compounds appear to be a useful additional hurdle in producing safer fermented uncooked products. With the past progress and the future developments, the future looks bright for fermented meat products.

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