PRINCIPLES OF PRESERVATION OF SHELF-STABLE DRIED MEAT PRODUCTS

In general, the term “shelf-stable product” refers to those products that do not require refrigeration or freezing for safety and acceptable organoleptic characteristics. Most often, the products are stored at “room temperature” (ambient). This shelf-stability also is often dependent upon the proper packaging to control oxidation and potential mold growth. The shelf-life for these types of products is usually defined for acceptable quality, not safety because the safety has been addressed in the production process. FSIS is concerned with product safety and not quality attributes, which are concerns of the establishment.

The shelf-life of the product is defined as the time the specific product can be stored under specified conditions that retains organoleptic acceptability. Shelf-life is determined by two kinds of deterioration: microbiological (spoilage) and chemical (oxidation and physical).

This chapter describes the principles of food preservation as they relate to dried meat products. It will cover:

1. the interaction of factors that affect shelf-stability;
2. the relationship between drying, acidification, and heating;
3. the minimum a_w and pH values required for microbial growth;
4. how additives affect shelf-stability;
5. how moisture/protein ratio applies to these products;
6. process validations for these products; and
7. the critical process parameters for dried meat products.

The objectives of this section are for you to be able to:

1. Identify the relationship between, drying, acidification and heating in the production of shelf-stable products.
2. Recognize how moisture/protein ratio relates to product water activity.
3. Recognize that microbial thermal resistance will vary due to product characteristics.

Shelf-stability and Hurdle Effect

Shelf-stability is due to a combination of factors, otherwise known as the “hurdle effect”. The interaction of these factors affects specific microorganisms and chemical reactions. Controlling the various factors and interactions maximizes the total effect and achieves shelf-stability.

Food preservation technologies usually are classified into three types.

1. Prevention/removal of contamination
   e.g., decontamination of raw materials (steam treatment and organic acid washes of carcasses, irradiation of spices), aseptic processing
2. Inactivation of microorganisms
   e.g., heat (pasteurization, sterilization), high pressure processing
3. Slowing or complete inhibition of microbial growth
   e.g., low temp, water activity, redox potential, pH, or preservatives

For dried meat products, preservation is mostly due to the slowing or complete inhibition of growth, although inactivation of pathogens such as *E. coli* O157:H7 is also involved. The following are the most common factors relating to the safety/shelf-stability in dried meat products.

- water activity (a_w)
- pH
- time/temperature/relative humidity
- salt/brine strength
- microflora types

Other factors, such as the following, can also be important in the safety/stability of certain products.

- titratable acidity (% acid)
- moisture content
- packaging: modified atmosphere/vacuum
- preservatives
- hydrostatic pressure (high pressure processing)
- spices and spice extracts

With dried meat products, water activity probably is the most important factor contributing to shelf-stability over the total range of products. (If pathogens are still viable, the product is adulterated.) For the most common microorganisms associated with these products, the minimum water activity for growth is as follows.

Campylobacter	0.98	*E. coli* O157:H7	0.95
Pseudomonas	0.97	*Listeria monocytogenes*	0.92
Clostridium botulinum (non-proteolytic)	0.96	Some LAB	0.92
C. botulinum (proteolytic)	0.93	*Staphylococcus aureus* (anaerobic)	0.90
Clostridium perfringens	0.93	*S. aureus* (aerobic)	0.85
Most LAB	0.95	*Aspergillus flavus*	0.80
Salmonellae	0.94		

The product pH is the second most important factor, particularly considering that many of these dried meat products are fermented to some extent, or exhibit some microbial activity to yield the final product characteristics. Minimum pH values for growth for the relevant microorganisms are as follows.

Clostridium perfringens	5.0
Campylobacter	4.9
Clostridium botulinum (proteolytic)	4.6
E. coli O157:H7	4.0-4.4
Pseudomonas	4.4
Listeria monocytogenes	4.4
Yersinia enterocolitica	4.2
Staphylococcus aureus	4.0
Salmonellae	3.8
Most LAB	3.0-3.5
Aspergillus flavus	2.0

Inhibition of microorganisms by pH depends on many factors, including the type of acid and the temperature. The minimum pH for growth of *E. coli* O157:H7 is generally closer to 4.4, but it will survive well at lower pH values, especially if refrigerated.

Microbiological minimum or maximum limits for growth are primarily due to temperature, water activity, pH and/or the presence of preservatives. The limits of water activity and pH as shown above apply only when all other factors are optimal for growth of the specific microorganism. In food materials, especially dried meats, the environmental conditions are hardly optimal and if more than one preservative effect (i.e., hurdle) is present, the effects may be added together (synergistic), and may even be more effective than the two factors alone. For example, in a dried fermented meat product, the competitiveness of commonly occurring microorganisms varies with storage temperature, water activity, pH, presence of additives (e.g., salt, nitrite) and lack of oxygen.

The hurdle effect occurs when the combination of inhibitors is more restrictive than the individual inhibitors alone – a synergistic effect. Often, the hurdle effect allows the use of lower levels of the individual inhibitors that can result in a more organoleptically acceptable product, e.g., dried meats can have a higher water activity with lower pH. In other words, the meat product is more acceptable at the higher water activity (e.g., more tender), but normally this higher water activity would not give shelf-stability. By lowering the pH, the combination of the final water activity and the pH results in a shelf-stable product.

The most important hurdles in food preservation are.

- high temperature
- low temperature
- reduced water activity
- increased acidity
- reduced redox potential
- preservatives
- competitive microflora

For shelf-stable dried meats, the last five hurdles are of primary importance, since these products are not sterilized, often not pasteurized, and certainly not distributed frozen.

The main objective in the formulation and processing of a shelf-stable, dried meat product is to arrive at a combination of hurdles that favor desirable microorganisms over undesirable microorganisms while also maintaining a consumer acceptable product. There are many combinations of hurdles that can achieve product stability.

►Fermented Sausages

Fermented sausages demonstrate a lowering of product pH due to fermentation, followed by weight loss and decrease in water activity during drying. These vary in their rate and extent depending upon the specific formulation and process.

►Water Activity

Water activity probably is the most important single factor for shelf-stability (as indicated by microbial stability) in most dried meats. Water activity, expressed as a_w, is the vapor pressure of the product divided by the vapor pressure of pure water. Relative humidity measurement is expressed as a_w x 100%.

Water activity values in foods vary: fresh meats, fruits and vegetables, greater than 0.98; dried sausages and condensed milk, 0.85 – 0.93; honey and chocolate, less than 0.60. For dried meats, semi-dry sausages exhibit a_w values from 0.95-0.97 while dry sausages generally show values of 0.85 – 0.93. Dried hams, coppa and beef jerky generally have a_w values less than 0.88. Pork rinds have a_w values less than 0.30.

When other environmental conditions are optimal, most microorganisms do not exhibit growth below 0.91 water activity, with a few relevant exceptions, notably the staphylococci and fungi. *Staphylococcus aureus*, a common meat pathogen, can grow as low as 0.86 water activity depending upon the other growth conditions, particularly if oxygen is present.

►Moisture/Protein Ratios

Moisture/protein ratios – MPR – are commonly used in the U.S. to classify dried sausages and other meat products. These ratios express the percent moisture divided by the percent protein. Dried meat MPR values vary from 3.7:1.0 for Thuringer to as low as 0.75:1.0 for beef jerky. These MPR values are currently FSIS labeling standards and are historical in nature, representing average values of a market basket survey of representative products exhibited at the time of initial classification for labeling. Although the MPR values do indicate the degree of product drying, they are not necessarily indicative of microbial safety or stability, as is the case with a_w values. Nevertheless, FSIS, in its Food Standards and Labeling Policy Book, identifies criteria for a shelf-stable product based on MPR. Shelf-stable dry sausage must have an MPR ≤ 1.9:1 and semi-dry sausage must have an MPR ≤ 3.1:1 with a pH ≤ 5.0, or be commercially sterilized (unless another MPR is specified for a product).

Formulation Ingredients Important for Shelf-Stability

►Salt

Salt (sodium chloride) is the most important ingredient used in the manufacture of dried meat products. Salt exhibits many functions including suppressing microbial growth, reducing water activity, releasing salt soluble proteins, penetrating easily into meats enhancing cure penetration, flavor and showing a pro-oxidant effect. The percent salt in a meat product is not as important as the brine strength. The brine strength (sometimes referred to as water-phase salt) is the percent salt divided by the percent salt plus percent moisture in the same product. In dried meats that are manufactured with an injected or immersed brine, the salometer reading expresses the strength or salt content in the brine. A 100 degree brine contains the maximum 26.3% salt and a 50 degree brine contains 13.15% salt.

►Nitrate (NO_3^-)

Potassium nitrate, or saltpeter, was the original curing agent and was generally added to the meat unintentionally as a contaminant in the salt. This chemical is very stable and must be converted to nitrite to effect meat curing. This conversion usually is done by specific microorganisms, including the *Kocuria* and staphylococci. Originally, these microorganisms were also contaminants in the meat, other ingredients, and/or the processing environment. Although today we realize that nitrite is the active curing ingredient and that it can be added directly to the meat, the use of nitrate salts (sodium or potassium) is still somewhat common, mainly in dried meat products. The primary reason for its continued use is that residual nitrate in dried meats can serve as a “nitrite reservoir” in non-cooked products and the conversion of nitrate to nitrite in meat processing is a slower process and can yield a deeper red cure color. For the necessary nitrate reduction to nitrite, the specific microorganisms that produce nitrate reductase always must be present and active. Nitrate is a restricted ingredient and its use is regulated by the relevant government agency in different countries.

►Nitrite (NO2-)

Sodium nitrite is the active curing ingredient for typical meat curing. This is a highly reactive chemical that reacts with meat to produce nitric oxide (NO) which replaces the oxygen molecule in the meat pigment structure (heme) yielding the typical cured “pink” color when the meat product is heated. Nitrite also functions for meat flavor, helps provide microbial stability and acts as a potent antioxidant. Because of the highly reactive nature and toxicity of the nitrite, it is usually first combined with a portion of the salt prior to meat addition and should never be added to anything other than salt prior to the addition to the meat.

►Curing Accelerators

Compounds such as sodium erythorbate, sodium ascorbate, ascorbic acid, sodium acid pyrophosphate, chemical acidulants, etc., are added to dried meats to enhance the curing reaction by either serving as a reducing agent, oxygen scavenger and/or reducing the product pH.

►Meat Starter Cultures

Microorganisms typically are active participants in the processing of dried meats. Specific starter cultures are added in the formulation to control the product microflora and function for safety and preservation, product consistency (fermentation, drying, texture), product color and/or product flavor. Generally, the two types of starter cultures used for dried meats are the lactic acid microorganisms and the staphylococci and *Kocuria* (micrococci). The presence of antibiotic residues in meat may inhibit growth of the starter culture, resulting in inadequate drop in pH.

►Sugars (carbohydrates)

The role of added sugars or carbohydrates in meat curing and drying often is underestimated. Carbohydrates, or “sugars,” used in dried meat processing generally consists of dextrose, cane sugar/sucrose, brown sugar, corn syrup, lactose, honey, molasses, maltodextrins, starches, etc. The added sugars function for flavor, reduce harshness of salt, lowering water activity, yield, and as a source of energy for functional and spoilage microorganisms. Added sugar type and amounts are critical for fermented products to control fermentation and final product pH. This is clearly demonstrated in pepperoni, whereby the added dextrose generally is limited to achieve a desired final pH without subsequent charring or burning when the pepperoni is cooked on a pizza.

►Chemical Acidulants

Chemical acidulants are specific acids that are added to some dried meat product formulations to lower pH for various functions, including flavor, shelf-stability, color, and drying enhancement. Typically, chemical acidulants are designed or chosen to “mimic” the action of the lactic acid microorganisms (i.e., biological fermentation), thus the specific chemical acidulant demonstrates a somewhat slower release than just adding the pure acid. The slower release allows for some meat matrix formation prior to acidulation. This is accomplished by either adding a cyclic compound (e.g., glucono-delta-lactone, GDL) and/or adding an encapsulated acid. Chemical acidulants most often are utilized to replace the starter culture in a typical fermented dried product to eliminate the fermentation phase and, thus, shorten the process.

►Oxidation Prevention Additives

Oxidation is a major problem with dried meat products which adversely affects color and flavor. Additives that retard oxidation are classified as either primary antioxidants or secondary antioxidants. Primary antioxidants are either synthetic (BHA, BHT, TBHQ, etc.) or natural (rosemary extract, tocopherols, smoke, etc.). These primary antioxidants react with the free radicals generated in the fat oxidation process and “break” the chain reaction. Secondary antioxidants act as oxygen scavengers, synergists, and/or curing accelerators to enhance the curing reaction. These compounds include citric acid, ascorbic acid, ascorbates, erythorbates, phosphates, lactates, starter cultures, etc., and function to either “scavenge oxygen,” thereby removing it from the system; “chelate” (i.e., tie up) the catalysts that initiate oxidation; and/or create low redox potential/reducing conditions that enhance the curing reactions. Many of these compounds can act in several ways to prevent oxidation. Specific starter cultures contain the enzyme catalase that removes peroxides from the meat system (oxygen scavenger), promotes the curing reaction, and prevents rancidity development.

The proper use of any antioxidants is critical to its effectiveness. Usually a combination of primary and secondary antioxidants is employed for maximum effectiveness. The specific antioxidant should be employed for a specific meat system based on any flavor attributes, solubility, type of fat, and type of oxidation. The respective antioxidant must be stable before and after addition to the meat system and the delivery system must be appropriate for the application (e.g., fat soluble for direct addition to sausage versus water dispersible/water soluble for use in injected brines and marinades). Adding the antioxidant early in the processing is recommended for maximum efficacy as well as to achieve optimum distribution.

►Preservatives

Certain preservatives, particularly anti-mold agents, are commonly used in dried meats since mold can grow on almost any dried meat product that is not in an anaerobic pack. Typical mold inhibitors used include potassium sorbate, propyl parabens, and cultured whey/cultured corn syrup/cultured dextrose. These latter cultured products contain naturally produced proprionic acid and other organic acids that retard mold growth.

►Packaging

The packaging system for dried meats is very important for chemical and microbial shelf-stability. Although most dried meats are shelf-stable with regard to food safety regardless of packaging (due to lower water activity, pH), the proper packaging prevents potential mold growth (that can increase the pH, and potentially allow growth of pathogens) and product oxidation that is undesirable organoleptically. Generally, the products are packaged under vacuum or modified atmosphere where the oxygen is eliminated. In MAP (modified atmosphere packaged) products, the total elimination of oxygen often is accomplished through the use of oxygen scavengers, which are added in the packaging process, either in packets or incorporated into the film. These scavengers remove any residual oxygen that may still be present after packaging.

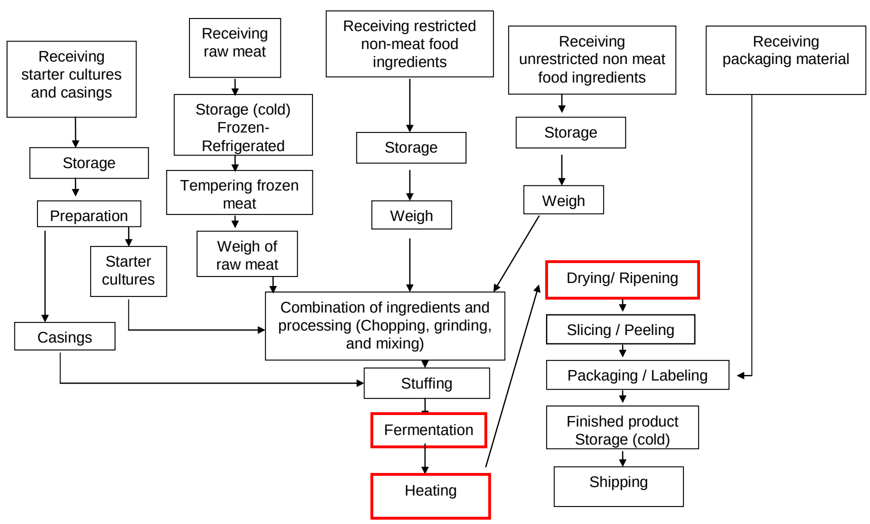
Critical Processing Stages for Shelf-Stability and Safety

Most of the dried meat products rely on the interaction of several parameters to achieve stability and safety. Many steps are controlled, but only a few are truly critical. Generally the critical control points for fermented shelf-stable products are fermentation, heating and, sometimes, drying. For non-fermented salt-cured products, the salting step is critical, and for dried products the drying step is critical. For some products, such as freeze-dried products or bacon bits, a cooking step may also be critical.

The main control points in the manufacture of most shelf-stable dried meats are primarily focused on the initial formulation stages where the ingredients are combined with the meat and subsequently processed. The proper combinations of salt, cure, sugars, starter cultures, etc., for the respective product must be assured. When using a starter culture, the receipt, storage, and preparation of this ingredient is essential to its function. However, although these are important parameters to control, the critical control point is at the fermentation stage, where the rate of pH drop to 5.3 or below is critical to prevent growth and enterotoxin production by *S. aureus*. The rate of pH drop can be expressed in "degree-hours". If the critical pH is not reached in the specified time, there may have been an error in the formulation process or with the starter culture.

This is the concept of degree-hours – the number of hours at a temperature above 60°F (the temperature at which staphylococcal growth effectively begins) multiplied by the number of degrees above that temperature. A process is acceptable if the product reaches pH 5.3 within a certain number of degree-hours. Processes attaining a temperature less than 90°F before reaching pH 5.3 are limited to 1200 degree-hours. Processes reaching a temperature of 90°F-100°F prior to reaching pH 5.3 are limited to 1000 degree-hours. Processes exceeding 100°F before reaching pH 5.3 are limited to 900 degree hours. For example, a product processed at a constant 80°F reaching pH 5.3 in 55 hours would meet the guideline of 1200 degree-hours, since 80°F-60°F=20°F and 20°F X 55 hours = 1100 degree-hours. More information on this can be found in the American Meat Institute's Good Manufacturing Practices for Fermented Dry and Semi-dry Sausage Products:
http://www.aamp.com/documents/AMIF_degreehours.pdf

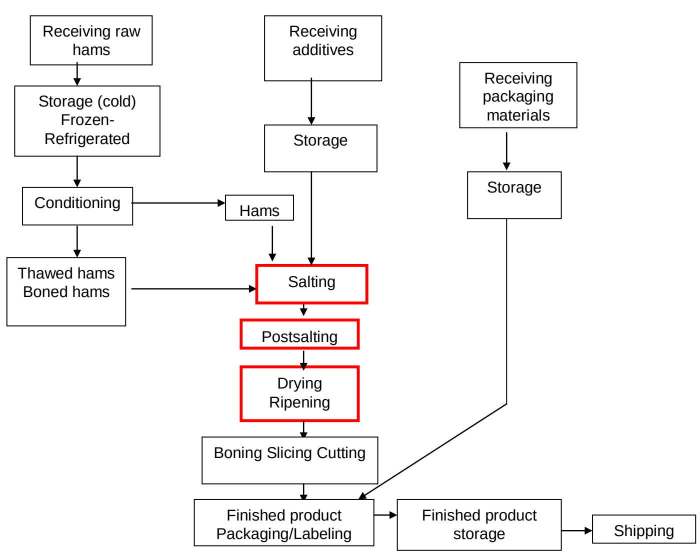
Critical Stages: Safety in Fermented Sausages



Note: This flow diagram is for teaching purposes only.

For dried whole muscle meats, particularly dry cured products, the initial salt level and application to all exposed meat surfaces is the most critical point in the operation, along with holding the salted product at relatively low temperatures until the critical brine content is achieved uniformly.

Critical Stages: Safety in Dry Cured Hams



Note: This flow diagram is for teaching purposes only.

Many dried meat products are not heated significantly following the fermentation and/or salting process prior to drying; however with the increased emphasis on food safety, many more dried products, particularly in the U.S., do have a significant "heat step" in the total process to assure lethality of high numbers of specific pathogens. This step is usually critical to achieve inactivation of the pathogens of concern in the product, and thus would be a critical control point. Consequently, the heat resistance of the target microorganisms in specific environments is a factor in determining lethality. Heat resistance is usually expressed as D-value, or the time to effect a 1-log or 90% reduction in the number of cells. Microorganisms vary widely in heat sensitivity. Sporeforming microorganisms are much more heat resistant than non-sporeformers, and Gram positive type microorganisms are generally more heat resistant than Gram negative types. The physiological state (e.g., age, growth conditions) of the microbes also affects their heat resistance, as does whether the microorganism has been previously exposed to the specific environment and has "adapted" to the environment. The heating medium or environment (such as the water activity, pH, fat content, brine strength, proteins, etc.) dramatically affects heat resistance. In general, the lower the pH, the lower the heat resistance, while drying or lower water activity can increase heat resistance. Most often, added preservatives lower heat resistance.

The environment in dried meats can be highly variable, with many different formulations and processing variables. In addition, the microflora varies considerably, especially if not using a starter culture. Validation studies in specific products generally are required to assure food safety and product stability. Published validation studies for a similar formulation and process can be acceptable, as long as the reference validation is equal to or less severe than the formulation and process to be validated.

Dried Meat Process Validation

Validation focuses on putting together scientific and technical information to demonstrate that the hazards of concern are properly controlled. Dried meat process validation addresses lethality and stabilization "during the shelf-life of the product." Processors must assess which hazards are reasonably likely to occur for their product. For most of the dried meat products, manufacturers will consider the pathogens *Salmonella, S. aureus, L. monocytogenes* and, in beef, *E. coli* O157:H7. Pathogenic sporeformers such as *C. botulinum* and *C. perfringens* may also need to be addressed. Depending on the product and the identified hazards, it may be necessary to validate that the process controls the pathogen. Currently there is no required log reduction specified for *Salmonella*; a processor must provide documentation that this organism is controlled for the specific product/process. Some processors choose to validate their processes for *L. monocytogenes*, which is generally considered to be more resistant than *Salmonella*. Processors must validate a 5-log kill of *E. coli* O157:H7 for products containing beef. For the most part, to achieve 5-log reduction, the product must be heated to some extent. The heating effect is enhanced at lower pH; thus the final internal temperature does not have to be as high with a lower pH. The number of organisms present is important, as well as their heat resistance. Manufacturers should consider the degree of lethality for each organism of concern. Because of the nature of the finished product (low a_w) pathogenic sporeformers should not be a concern. For dried meat products it may be desirable to conduct validation studies that demonstrate lack of growth of relevant pathogenic microorganisms if the product is contaminated after the lethality step.

There are some validated processing parameters that have been published for dried meat products, including pepperoni, hard salami, Italian salami, summer sausage, Lebanon bologna, and country hams. Validation studies have also been conducted to assess the survival of *L. monocytogenes* during storage of RTE meat products processed by drying, fermentation, and/or smoking (Ingham et al., 2004. J. Food Protect. 12: 2698-2702) to help small processors classify these products with respect to FSIS' alternatives for *L. monocytogenes* control (e.g., to assess whether the processing techniques and product characteristics can serve as antimicrobial agents or processes or post-lethality treatments).

►Examples of Validated Processes

Because there are so many different combinations of variables that impact the safety and stability of these products, it can be difficult to develop validation studies that apply broadly. A commonly used process that has been validated is to achieve a pH < 5.0, followed by a heat process to achieve 128°F (53.3°C) internal temperature for 1 hour.

Summer Sausage (fermented, semi-dry sausage)

A typical process/product validation for fermented summer sausage is as follows. The product is fermented with a starter culture at 110°F (43.3°C) until the pH is 4.7 or lower, then cooked to 152°F (66.7°C) internal product temperature. The characteristics of the vacuum packaged product are as follows.

moisture	56.7%	brine strength	5.5%
m/p ratio	3.28	pH	4.4
fat	21.2%	Titratable Acidity	0.361
salt	3.4%	a_w	0.964

(Titratable acidity is a measure of the total amount of acid present.)

The process validation demonstrated complete destruction under these processing parameters of high levels of *Salmonella, Listeria monocytogenes*, *Staphylococcus aureus*, and *E. coli* O157:H7. Moreover there was no growth of the same microorganisms when inoculated at high levels post-lethality and stored at either refrigerated temperature or room temperature (the product was shown to be shelf-stable).

Pepperoni

Similar results have been observed in validation studies with pepperoni (a fermented, dry sausage) where the product is fermented with a starter culture at 102°F (38.9°C) to a pH < 5.0, then subsequently heated to 128°F (53.3°C) for 1 hour and dried to 68% final yield. Final product characteristics are as follows.

moisture	26.0%	brine strength	15.58%
m/p ratio	1.4	pH	4.7
fat	46.0%	a_w	0.896
salt	4.05%		

Country Ham

A validated process for a typical dried whole muscle product, country ham, processed with salting for 49 days at 40°F (4.4°C), post-salting drying 20 days at 85°F (29.4°C), and dried 129 days at 68-75.2°F (20-24°C) results in a final product with the following characteristics.

salt	8.0%
pH	5.5 (5.0-6.0 during process)
a_w	0.92

Jerky Products

In the past, many beef and other jerky products processors have relied upon the final moisture/protein ratio of 0.75 or below. Recently published FSIS jerky processing guidelines emphasize the importance of relying upon water activity (a_w) levels rather than moisture protein ratios as an indicator of final product safety and shelf stability. In addition the new guidelines emphasize the importance of including a humidity step at the beginning of the process. The new guidelines also include several optional processing interventions that may be used to ensure lethality in lieu of a proprietary validated process.

Workshop: Principles of Preservation of Shelf-Stable Dried Meat Products

The following questions are short-answer, True/False or fill-in-the-blanks. Record the answer(s) you believe to be correct; some questions have more than one correct answer.

1. Describe what is meant by the "hurdle effect".

2. When nitrate is used, it is converted to _____________ by microorganisms or a reducing agent.

3. Products can be characterized by both water activity and moisture protein ratio. Which of these measurements is relative to the safety of a food?

4. Semi-dry sausages exhibit higher a_w values (0.95-0.97) and dry sausages generally show lower a_w values (0.85-0.93).

   True
   False

5. Higher water activity (a_w) indicates more free water to support the growth of bacteria, yeast, and molds.

   True
   False

6. Water activity of a food is the same thing as moisture content.

   True
   False

7. When other environmental conditions are optimal, most microorganisms, with a few exceptions, do not exhibit growth below 0.91 water activity (a_w).

   True
   False

8. For a food to have an extended shelf-life without relying on refrigerated storage, it is necessary to control either its acidity level (pH) or the level of water activity (a_w) or a suitable combination of the two.

   True
   False

9. Percent salt is more important than brine strength in dried meat products.

   True
   False

10. D-value is defined as the time in minutes required to increase a microbial population by 1-log or 90% of initial value.

    True
    False

11. Aunt Eleanor's Sausage company makes two types of fermented semi-dry sausage. The formulation is the same, however the difference between the two is in the thickness of the sausage. The diameter of the smaller sausage is 1½ inch and the larger sausage is 2½ inch. Could you validate the processes using only one thickness? Which thickness would you expect to take longer to reach the desired water activity levels? Aunt Eleanor would like to reformulate the product using an encapsulated acidulant rather than a starter culture. How might the production process change with this reformulation?