

Review

Effects of Preparation Methods on the Microbiological Safety of Home-Dried Meat Jerky

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ABSTRACT

Historically, drying meats to produce jerky was considered to be a safe preservation process and the convenience and flavor of jerky has made it a popular food product for home food preservers. Recent outbreaks of foodborne illness related to both home-dried and commercially manufactured jerky have raised concerns about the safety of the product. Some traditional home recipes and drying processes were shown to be inadequate to destroy *Escherichia coli* O157, *Salmonella*, *Staphylococcus aureus*, and *Listeria monocytogenes* in both whole-muscle and ground-meat jerky. Several research studies have identified processes such as precooking meats before drying, using acidic marinades, cooking meats after drying, or some combination of these treatments that can destroy pathogens of concern to produce microbiologically safe and palatable meat jerky at home.

Drying meat for the purposes of food preservation no doubt began with the earliest civilizations. Meats were stripped or pulled, then dried with the help of the sun, wind, or fire. Native Americans would dry venison, buffalo, and elk meat as a portable, nutritious food. Pioneer American settlers described this dried meat as jerky, derived from the Spanish word “charqui.” American pioneers quickly learned to dry meat in this manner for themselves in the days before refrigeration was available.

Today, jerky is more of a convenient snack food where safe preservation, flavor, and texture are important. Jerky can be made from almost any lean meat, including beef, pork, poultry, or game. The simplest method to make jerky is to cut meat into strips and dry it. More typically, spices or marinades are used to flavor the meat and curing or smoking might be used in combination with drying to make jerky. A pound of meat or poultry is dried to approximately 4 oz after being made into jerky.

Jerky is classified by the U.S. Department of Agriculture (USDA) as a heat-treated and shelf-stable ready-to-eat meat product (29). Products may be whole or molded meats cut into strips. They may also be chopped or ground meats that are formed into strips or stuffed into narrow casings. Jerky must have a moisture-to-protein ratio of $\leq 0.75:1$ and a water activity (a_w) of ≤ 0.85 (13). An $a_w < 0.70$ is recommended to prevent mold growth (29). A typical commercial whole-meat jerky process starts with frozen meat that is thawed, sliced, and spiced (or marinated). The slices are racked, heated, and dried. The heating and drying steps are sometimes combined. Commercial manufacturers must

use Hazard Analysis Critical Control Point-based procedures to ensure *Escherichia coli* O157:H7, *Listeria monocytogenes*, and *Salmonella* destruction (29). The dried jerky is cooled and packaged for distribution. Commercially packaged jerky can be kept up to 12 months at room temperature (28).

The convenience and flavor of jerky has made it a popular food product for home food preservers. Home preservers use a variety of recipes and processes to make jerky. Faith et al. (13) surveyed 26 home jerky processors. Most respondents made jerky between 1 to 8 times per year and made jerky from a variety of meats: venison, beef, pork, turkey, and fish. Seventy-five percent prepared jerky from whole muscle and 25% said they would make jerky from ground meats. The survey respondents all used home-style dehydrators and some also used an oven or a smokehouse. Drying-temperature settings varied from 51.7 to 71.1°C, with drying time ranging from 2 to 24 h. Home drying of meat to produce jerky has been considered relatively safe; however, recent outbreaks of foodborne illness in these food products have raised questions about this safety.

FOODBORNE ILLNESSES ATTRIBUTED TO MEAT JERKY

At least eight gastroenteritis outbreaks occurred in New Mexico between 1966 and 1995 from ingestion of meat jerky. Two outbreaks were due to contamination with *Staphylococcus aureus* and six were due to contamination with *Salmonella* (12). Over 250 illnesses were reported. Primarily implicated was local commercially produced jerky made by soaking beef strips in a spicy marinade prior to dehydrating them. In all of the investigations, processing

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times and temperatures never reached a level to destroy the pathogens. Based on this series of outbreaks and investigations, the New Mexico Environment Department developed regulations for the production of jerky in 1989. Included were regulations to cook and dry jerky within 3 h to an internal temperature of 63°C for beef, lamb, and fish, and 74°C for poultry. The finished jerky should have an $a_w \leq 0.85$ (12).

In 1995, an outbreak of *E. coli* O157:H7 occurred in Oregon involving jerky made in a home from deer meat (21). As many as 11 persons were infected. The home processor dried the venison in a home-style dehydrator set between 51.7 and 57.2°C for 12 to 14 h. *E. coli* O157:H7 was recovered from the deer jerky, deer meat, and the deer carcass. Nine percent of sampled deer fecal pellets taken from the area where the deer was harvested also tested positive for *E. coli* O157:H7. In laboratory experiments, a single strain of *E. coli* O157:H7 was inoculated onto jerky strips and dried at temperatures up to 62.8°C for 10 h. Viable organisms were recovered under all conditions tested. This report indicated that deer can be a reservoir for *E. coli* O157:H7. They concluded that some traditional home-drying processes for jerky were insufficient for killing *E. coli* O157:H7 and recommended precooking deer meat to 74°C before drying.

STUDIES ON THE MICROBIOLOGICAL SAFETY OF HOME-DRIED MEAT JERKY PROCESSES

Effects of time-temperature on pathogen reduction in whole-meat jerky recipes. Recommendations from science-based sources for home drying meat to produce jerky have been quite general and have included drying in the sun, oven, or dehydrator. Sun drying is no longer recommended due to a lack of a steady heat source and the potential for contamination from animals, insects, dust, and bacteria (22). One of the first studies on pathogen reduction in home processing of jerky was done by Holley in 1985 (20). Holley studied the fate of a strain of *S. aureus* in whole-strip beef jerky dried 4 h at 68.3°C, then 4 h at 60°C in a home-style dehydrator. After 8 h of drying, 15% of the inoculated *S. aureus* was recovered and this was reduced a further 5% after 7 days of 2.5°C storage. Despite recovering viable *S. aureus*, Holley concluded that the home jerky process studied was safe as long as wholesome meat was rapidly dried (20).

In 1996, researchers studied the fate of single strains of *E. coli* O157:H7, *Salmonella enterica* serovar Typhimurium, and *L. monocytogenes* in the home preparation and storage of whole beef strip jerky using a Cooperative Extension System recommended recipe (15). Meat strips (900 g) were placed in a marinade (60 ml soy sauce, 15 ml Worcestershire sauce, 0.6 g ground black pepper, 1.25 g ground garlic powder, 1.5 g ground onion powder, and 4.35 g hickory–smoke-flavored salt) for 1 h at 4°C and then dried at 60°C in a home-style dehydrator. Populations of all three pathogens were reduced by at least 5 log to undetectable levels after drying 10 h at 60°C. This however, conflicted with the report by Keene et al. (21), where viable *E. coli* O157:H7 were recovered after drying whole venison

strip jerky 10 h at 62.8°C. Other researchers found a marinated whole beef strip jerky recipe inadequate to destroy *E. coli* O157:H7 after drying strips 8 h at 62.5 or 68.3°C (1, 23). These studies indicated that more research was required to develop safe home-dried jerky processes. Discrepancies may have been attributed to differences in the heat resistance of pathogen strains.

Effects of time-temperature on pathogen reduction in ground-meat jerky recipes. Home-style drying procedures for jerky made from ground meats may be insufficient to eliminate bacterial pathogens due to possible distribution of pathogens throughout the product. In 1997, Harrison et al. published research on the fate of five strains of *L. monocytogenes* and five species of *Salmonella* in ground-beef jerky (17). There was less than a 4-log reduction of the populations in the pathogens for ground-meat jerky dried at 60°C after 8 h. In control studies, ground-beef jerky that was first oven heated to 71°C, then dried, reduced the pathogen populations to undetectable levels. This study indicated that the traditional drying process for whole-meat strip jerky (10 h at 60°C) was insufficient for destruction of pathogens in jerky made from ground meats. The authors concluded that ground-meat jerky should be oven heated to 71°C prior to drying to ensure microbiological safety.

E. coli O157:H7 outbreaks of foodborne illness due to ground dried-meat products during the mid 1990s underscored these products as likely vehicles for this pathogen (13). Faith et al. (13) studied the viability of *E. coli* O157:H7 in ground-beef jerky dried in home-style dehydrators. Ground and formed beef jerky prepared at levels of 5 and 20% fat and dried at 52, 57, 63, or 68°C were assayed (13). Higher drying temperatures produced greater lethality of a five-strain mix of *E. coli* O157:H7. Higher fat content of meats reduced the lethality of the drying process. The researchers concluded that jerky should be prepared from leaner cuts of meat and dried at temperatures of 63°C or greater for at least 8 h. An important fact discovered was that the temperature on the home-style dehydrator control dial and the actual empirical measurement was significantly different, by 3 to 22°C, and that a reliable food thermometer should be used to measure temperature rather than relying on dehydrator thermostats.

Harrison et al. (18) also analyzed ground-beef jerky inoculated with a five-strain mix of *E. coli* O157:H7 before processing. Lean (90%) ground beef was mixed with a commercial spice mix (dextrose, salt, spices, hickory flavor, onion powder, garlic powder, monosodium glutamate, hydrolyzed vegetable protein, and imitation maple flavor) and extruded into strips. Ground-meat strips were dried in a home-style dehydrator for 8 h at 60°C. After drying, there was only a 2.5- to 4-log reduction of the pathogen populations. They concluded that, for ground-beef jerky prepared at home, safety concerns related to *E. coli* O157:H7 are minimized if the meat is precooked to 71°C prior to drying. Citing research from Harrison (15, 17), Holley (20), and Keene et al. (21), the USDA recommended that whole-muscle or ground jerky meats be first heated to 71.1°C and then dried in a 54.4 to 60°C dehydrator (28).

Effects of salt, sugar, and sodium nitrite on pathogen reduction in ground-meat jerky. Harrison et al. (18) analyzed ground-beef jerky made with a commercial spice mixture with and without a curing mix containing salt and sodium nitrite. Ground beef was inoculated with a five-strain mix of *E. coli* O157:H7 before processing. The authors found that ground-beef jerky made with a curing mix had greater destruction of bacteria than jerky made without it. Jerky made with the curing mix and heated to 71°C before dehydrating had the highest rate of destruction of *E. coli* O157:H7.

Because there is continuing interest in low-sodium food products, Rose investigated the fates of *E. coli* O157:H7, *L. monocytogenes*, and *Salmonella* spp. in reduced sodium home-style beef jerky (27). Ground or whole beef strips with different salt levels were inoculated with the pathogens. Samples were either dried in a 60°C dehydrator or heated to an internal temperature of 71.1°C prior to drying in a 60°C dehydrator. Population reductions of the pathogens were greater in ground-beef jerky with nonreduced salt levels compared with those from products with reduced salt levels. In most cases, greater pathogen reduction (1.0 to 1.5 log) was observed for ground-beef strips heated prior to drying. There may be greater risk associated with ground-beef jerky with reduced salt levels because the lower salt level did not reduce the pathogen population as much as the regular salt marinade. For dried whole jerky strips, there generally were no significant differences in pathogen populations between the nonreduced and reduced salt treatments. In similar studies, sugar addition also increased the lethality of the drying process on inactivation of *E. coli* O157:H7, *L. monocytogenes*, and *Salmonella* (27). These studies indicate that salt, sugar, and sodium nitrite can increase pathogen destruction in meat jerky processes, but that none alone were sufficient to achieve the necessary lethality.

Effect of marinade on destruction of *E. coli* O157:H7 in whole-meat jerky. Albright et al. (1) inoculated whole beef slices with four strains of *E. coli* O157:H7 and compared the effects of marination on pathogen destruction. Whole beef slices were either marinated (4°C, 24 h) or not, then dried at 62.5°C for 10 h. Marination alone did not result in significant reduction of the pathogen compared with whole beef slices that were not marinated.

Effect of acidic marinades on destruction of *E. coli* O157:H7 in whole-meat jerky. Researchers investigated marinade recipes modified with acids for their effectiveness in enhancing destruction of *E. coli* O157:H7 during drying of jerky (11). Beef slices were inoculated with a three-strain mixture of *E. coli* O157:H7, marinated for 1 h (4°C) in a nonacid marinade, or in the same marinade with added ascorbic acid (7.7% by weight) or citric acid (3.7% by weight), then dried 10 h at 62.5°C. The acidified marinades generally promoted greater inactivation of bacteria during drying than was seen using the nonacid marinade. The authors concluded that the use of an acidified marinade may enhance bacterial destruction during drying and that house-

hold acidulants might be beneficial to enhance pathogen destruction in home jerky processes.

Effects of multihurdle treatments on pathogen reduction in whole-meat jerky. Many consumers objected to the cooked flavor of meat jerky where the meat was first cooked to 71.1°C and then dried as recommended by the USDA-FSIS (28). In an effort to bridge the gap between safety and quality, studies were conducted to examine the effects of predrying treatments on the destruction of pathogens in the jerky process. Albright et al. (2) evaluated the survival of inoculated *E. coli* O157:H7 populations in whole-strip beef jerky prepared using four multihurdle, predrying treatments. The four treatments were (i) immersing in boiling water (94°C, 15 s), then marinating (4°C, 24 h); (ii) seasoning (4°C, 24 h), then immersing in a hot pickling brine (78°C, 90 s); (iii) immersing in a vinegar-water (1:1) solution (57.5°C, 20 s), then marinating (4°C, 24 h); and (iv) marinating (4°C, 24 h), then immersing in a vinegar-water (1:1) solution (57.5°C, 20 s). All samples were dried in home-style dehydrators 10 h at 62.5°C and then stored at 21°C for up to 90 d (2). Treatment 2, using a hot pickle brine, resulted in the greatest population reduction (5.7 to 5.8 log) of bacteria during drying. The remaining three methods resulted in bacterial population reductions of 4.3 to 5.2 log. Bacterial populations continued to decline during storage and were not detectable by direct plating (<1.0 log CFU/cm²) on any treatment after 30 d storage at ambient temperature (2). A consumer panel ($n = 120$) rated the four jerky products as being moderately acceptable (3.7 to 3.9 on a seven-point scale with 7 = extremely acceptable) (3). The authors concluded that these predrying treatments had significant effects on the destruction of *E. coli* O157:H7 in home-dried whole-muscle beef jerky processes.

Effect of postdrying heat on pathogen reduction in whole-meat jerky. Researchers evaluated four jerky methods for effectiveness in inactivating *L. monocytogenes*, *Salmonella*, and *E. coli* O157:H7 and the resulting palatability (19). They compared drying marinated whole beef strips at 60°C, boiling strips in marinade at 71°C, heating strips in an oven at 71°C before drying, and heating strips to 71°C in an oven postdrying. They concluded that both a safe and consumer-acceptable whole-meat jerky can be made by oven heating jerky strips to 71°C after drying.

STUDIES ON COMMERCIALY DRIED-MEAT JERKY PROCESSES

In 2001, Levine et al. reported that the cumulative prevalence from 1990 to 1999 of *Salmonella* and *L. monocytogenes* in jerky produced in federally inspected plants was 0.31 and 0.52%, respectively (25). These data suggest that these pathogens can survive the more moderate drying temperatures (approx. 60°C) used by commercial jerky manufacturers despite good manufacturing practices and Hazard Analysis Critical Control Point plans.

Effects of multiple stress factors and moderate drying temperatures on pathogen survival in whole-meat jerky. Researchers conducted a set of studies designed to

investigate the effectiveness of multiple stress factors that could destroy pathogens using moderate (60°C) drying temperatures. Four chemically-based predrying treatments (modified marinades) were examined for the inactivation of *E. coli* O157:H7, *L. monocytogenes*, and *Salmonella* inoculated on beef jerky prior to marinating and after drying. The predrying treatments included (i) no treatment, (ii) traditional marinade (pH 4.3), (iii) double-strength traditional marinade modified with added 1.2% sodium lactate, 9% acetic acid, and 68% soy sauce containing 5% ethanol (pH 3.0), (iv) dipping meat slices in 5% acetic acid (pH 2.5) for 10 min followed by traditional marinade, and (v) dipping meat slices in 1% Tween 20 solution (pH 6.6) for 15 min, then in 5% acetic acid 10 min, followed by traditional marinating. After treatments, slices were held 24 h at 4°C and then dried at 60°C in home-style dehydrators for 10 h. For jerky products inoculated with *E. coli* O157:H7, bacterial population reductions after treatments and drying ranged from 2.8 to 6.7 log. The authors concluded that the use of antimicrobial chemicals or preservatives in jerky marination improved the effectiveness of drying at moderate (60°C) temperatures in inactivating *E. coli* O157:H7 (7). Similar trends were seen with whole-beef slices inoculated with *Salmonella* (9) and *L. monocytogenes* (8).

Effects of antimicrobial hurdles on acid-adapted pathogen survival in whole-meat jerky. Researchers studied the potential that acid-adapted pathogens might be more resistant to the antimicrobial hurdles employed. Acid-adapted inoculated and non-acid-adapted inoculated bacterial populations were added to whole-beef strips prior to marinating in five different marinades. The results indicated that acid adaptation may not increase survival of *E. coli* O157:H7 (7), *Salmonella* (9), or *L. monocytogenes* (8) to the treatments studied. Additional studies were also done to examine the survival of acid-adapted pathogens inoculated postdrying to simulate postprocessing contamination. The results indicated that using predrying marinades together with drying to a low a_w provided antimicrobial effects against possible postcontamination of *E. coli* O157:H7 (5), *Salmonella* (10), or *L. monocytogenes* (6). Acid adaptation did not increase survival of the pathogens and may have enhanced their inactivation during storage (5, 6, 10).

Effects of humidity on the time-temperature destruction of pathogens in commercially produced meat jerky. In 2003, there was a reported outbreak of salmonellosis related to commercially produced beef jerky made in New Mexico that was contaminated with *Salmonella* Kiambu (26). At least 22 individuals were affected in this outbreak. The plant dried the jerky to a crumbling state ($a_w \leq 0.3$) in a dry 82°C oven. Twenty percent of the jerky lots tested positive for *Salmonella*. The 82°C oven measured only 30°C with a wet-bulb thermometer. In this instance, *Salmonella* was able to shed moisture during the slow drying and become very resistant to the dry heat. In response to this issue, the USDA FSIS issued a compliance guideline for manufacturers in March 2004 (29). Manufacturers using time-temperature guidelines for the destruction of pathogens must take into account the humidity of the oven, es-

pecially in high-altitude areas of the country where relative humidity is low. Both wet-bulb and dry-bulb thermometer temperatures must be taken and a difference of 1.67°C shows the needed humidity is not being maintained (29).

SCIENCE-BASED RECOMMENDATION FOR HOME DRYING MEAT JERKY

Precooking method for home-dried meat jerky.

Based on several studies into drying jerky at home, the USDA recommends cooking beef, pork, venison, and poultry to 71°C followed by drying at 54 to 60°C in a standard home-style dehydrator (21, 28). Accurate thermometers should be used to monitor temperature of both the meat and the dehydrator.

Marination methods for home drying whole-meat jerky. Research results have shown that several methods using marinades can be recommended for the safe drying of meat jerky. The hot pickle-cure method (2, 23) dips dry-spiced whole-meat slices in hot (76.7 to 79.5°C) brine containing salt, sugar, and black pepper for 1½ to 2 min. The boiling-water method immerses the meat strips into boiling water (94°C, 15 s), which is followed by marinating at 4°C for 24 h (2, 23). The vinegar-water method immerses the meat strips into a vinegar-water (1:1) solution (57.5°C, 20 s) followed by marinating at 4°C for 24 h (2, 23). The acid-marinade method involves marinating the meat strips in an acid marinade containing soy sauce, Worcestershire sauce, black pepper, garlic powder, onion powder, hickory smoked salt, and ascorbic or citric acid for 1 h at 4°C (24). Another option involves dipping meat slices into 5% acetic acid (vinegar) for 10 min followed by traditional marination at 4°C for 24 h (7). For all methods, the meat is dried in a preheated 60 to 65°C home-style dehydrator for 8 to 12 h. Of these, two of the easiest and most effective methods for enhancing reduction of bacterial populations during drying are the hot pickle-cure method and dipping beef slices in vinegar for 10 min, followed by traditional marination.

Postdrying oven-heating method for home-dried whole- or ground-meat jerky. Either ground- or whole-meat jerky strips can be heated after drying in a home oven. The strips are placed in a preheated 135°C oven and heated for 10 min so that the meat strips reach an internal temperature $\geq 71.1^\circ\text{C}$. Strips thicker than ¼ in. may require longer heating to reach 71.1°C. This method is safe, produces a palatable product, and is easy to follow for home preservers (16). The postdrying oven-heating method may not be recommended for high altitudes or very dry climates.

General consumer recommendations for home drying jerky. Detailed recipes and processes together with additional topics of concern for the safe and palatable preparation of beef, pork, and venison jerky are included in individual Cooperative Extension and USDA publications (4, 14, 16, 22–24, 28). Concerns include *Trichinella*, special handling of game meat, and advice on cuts and types of meats that make the best and safest jerky.

Without a research-based process or recipe, jerky made from poultry should be cooked first to an internal temper-

ature of 71.1°C and then dried. The hot pickle-cure method (detailed above) or another cooking method would suffice. Most consumers do not like the quality of jerky made from raw poultry. Properly made poultry jerky will retain quality for 1 to 3 weeks at room temperature and should be refrigerated or frozen to prolong its shelf life.

Jerky can be made from any nonoily fish. Consumers have reported that shark, tuna, salmon, and other species produce acceptable jerky. Because no specific research has validated home drying fish for jerky, consumers should pre- or postcook the fish to 71°C for 1.5 min to destroy pathogens (30). Oil rancidity reduces fish jerky shelf life and it would be best to store it in the refrigerator or freezer. Careful attention to proper drying is required to minimize any risks posed by nonproteolytic *Clostridium botulinum* spores.

Home preservers should always wash their hands and sanitize utensils and work surfaces before and after processing. Keep all types of meats cold ($\leq 4.45^\circ\text{C}$) before processing and during marination. Do not reuse marinades. Properly dried jerky can be stored 1 to 2 months at room temperature (28). Refrigeration or freezing can be used to prolong the quality of home-dried jerky.

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