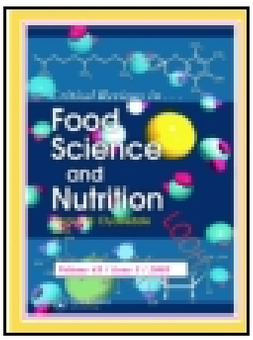

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Dehydrated Foods: Are they Microbiologically Safe?

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Abstract

Dried foods are low water activity foods with water activity ranging from 0.03 to 0.7. They are commonly misconstrued to be inherently safe from food borne pathogenic bacteria.

However, there are many reported cases where many food borne illnesses were caused by the consumption of dried foods contaminated with *Salmonella* spp., *Cronobacter* spp., *Staphylococcus* spp. and *E. coli*. In this work, we have systematically reviewed the literature dealing with the effect of drying/dehydration on the survival of pathogenic microorganisms with special focus on *Salmonella* spp. We have also reviewed and synthesized the literature dealing with the effect of drying process on microorganisms in dried vegetables, meat, fish, spices, mushroom and powdered foods. This review concludes that dried foods are not inherently safe microbiologically and required other hurdles to achieve microbial safety.

Keywords

Dehydrated foods, microbial safety, food borne illness, *Salmonella, Cronobacter sakazakii.*

Introduction

Dried foods are low water activity (a_w) foods with their water activity ranging from 0.03 to 0.70. Dried fruits and vegetables, tea, coffee, dried mushroom, dried meat products, dried fish products, dried egg powder, cereal grains and flours, spices and herbs (whole and powder), dried legumes and pulses, dried nuts, dried milk powder, and infant formula powders are common products under this category. Since these products are low in residual moisture content and water activity, they inhibit the growth of spoilage as well as pathogenic microorganisms and are generally considered to be safe from food borne bacteria. There is a common misconception that bacteria are not able to survive and grow in foods with low water activity, that is, less than 0.7. Research has revealed that food borne pathogens, including *Salmonella* can survive and persist in dried foods (Hiramatsu et al., 2005) and can be the cause of food borne outbreaks (Table 1). Table 1 lists the food borne outbreak related

to dried food from 1958 to 2017. Epidemiological evidences from these outbreaks indicated that potential cross contamination might have played a critical role in contamination of low-moisture foods, even the Salmonellosis outbreak in the United States (CDC, 2004). It has been estimated that cross contamination causes 25% of foodborne outbreaks (Carrasco et al., 2012). Cross-contamination can results from inadequate sanitation practices, contaminated equipment, lack of specific knowledge of hygiene in food handlers or improper storage conditions. Storage and display of dried products in loose packaging in which consumer or retailers handle the dried products with bare hands also cause the cross-contamination of dried foods.

As more and more cases of foodborne outbreaks related to low moisture foods are recorded worldwide, the food safety status of the commonly assumed ‘‘safe’’ dried foods is getting more attention nowadays. This review covers short introduction about drying and dried foods, drying effect on microorganism with microbiological safety issues in various dried food products including compilation food borne outbreaks.

Drying and Dehydration

Drying and dehydration are complex processes involving simultaneous heat and mass transfer to remove moisture from wet or high moisture materials (Mujumdar, 2014). The terms drying and dehydration are not identical. The US Department of Agriculture lists dehydrated foods as those with less than 2.5% moisture (dry basis) whereas dried foods applies to dried foods with more than 2.5% moisture (dry basis) up to 20% moisture content depending upon the composition of foods (Vega-Mercado et al., 2001). Although these terms have different meanings, they are often used interchangeably (Saravacos and Kostaropoulos, 2002). Food dehydration is one of the oldest methods of food preservation. In conventional food dehydration, air is used to supply heat the food and to carry moisture vapor away from the material subjected to drying (Desrosier and Desrosier, 1977). Development of industrial

food dehydration technologies has attained four generations. The first generation includes cabinet and bed driers and the second generation includes spray driers and drum driers whereas the third generation include freeze driers and osmotic dehydration. The latest advances in dehydration technology, the fourth generation which is also called novel drying technology, includes high vacuum, fluidization, microwaves, radio frequencies, refractance window drying (Vega-Mercado et al., 2001).

Effect of Drying on microorganism

In terms of microbial inactivation, dry heat is less effective than moist heat because the cell proteins, which are an important component in maintaining cell viability, are more stable in dry state (Phungamngoen et al. 2011a, 2011b, 2013; Smelt and Brul 2014). The bacterial inactivation caused by heat and dehydration was found to be less effective than that caused by shear and oxygen stress (Ghandi et al., 2012). Similarly, the presence of antioxidant such as ascorbic acid, in the food was found to affect the thermal stability of bacteria (Ghandi et al., 2013). Therefore, a more stringent heat treatment is required to destroy microorganisms during drying (Hawaree et al., 2009), depending upon the composition of food and the processes involved.

During drying, the removal of water can induce DNA and RNA breakdown, protein denaturation, cytoplasmic membrane alteration, and cell wall damage (Abee and Wouters, 1999; Guchte et al. 2002). However, many compounds found in fruits and vegetables may increase the survivability of the microorganisms during dehydration. Indeed, sugars, polypeptides, polyalcohols, amino acids, glycerol, and carboxylic acids have been shown to increase the survivability of bacteria during the drying of pure cultures (Lievense and Riet, 1994; Morgan et al.,, 2006). Lactose and trehalose were found to act as protectants from thermal stress in yeasts (Wiemken, 1990; Rapoport et al., 2009). Ghandi et al. (2012) reported similar thermal stress resistance of *Lactococcus* spp. during drying from the

protecting agents such as lactose and sodium caseinate. But, the acids from acid-rich fruits cause decrease in pH, which would hasten the death of microorganism when combined with thermal stress. Therefore, one may expect a great variability in the survival of microorganisms during drying of food products depending on their structure and composition. It is commonly accepted that dried foods retard or prevent the growth of microorganisms but when a sufficient number of pathogenic microorganisms are present after the drying, this may pose a threat to the consumer. In dried condition, microbial growth is inhibited, but spores and also the vegetative cells can remain viable for months (Beuchat et al., 2013). Moreover, when dried materials are used to prepare foods with a high final water activity, the growth of surviving organisms may be promoted. This can lead to a quicker spoilage and/or a higher risk of consumer infection.

During drying, the decreasing water activity is not the only stress applied to the microorganisms. Depending on the applied technology, microorganisms may be exposed to temperature and pressure variations, atmosphere changes such as increased CO_2 or N_2 concentrations and/or electromagnetic waves. It has been shown that the oxygen-stress to microorganism greatly increases at higher temperatures and when their cells are dehydrated (Ghandi et al., 2012). The presence of several stresses on bacterial cells at the same time makes the interpretation of inactivation results difficult because these stresses could act synergistically or antagonistically (Lievense and Riet, 1994). However, a reduced water activity could enhance heat resistance of microorganisms. Indeed, at water activity values between 0.2 and 0.4, both spores and vegetative cells are more resistant to thermal stress (Murrell and Scott, 1966). Hence, the inactivation of spoilage organisms and pathogens for heat pasteurization applied to high water environment cannot be extended to thermal drying processes without verification in actual drying conditions. Such effects could be observed for other stress combinations. Therefore, there is a need to study drying processes to grasp the

individual and conjugated effects of the decreasing water activity and other stresses (Smelt and Brul, 2014; Syamaladevi et al., 2016).

Microogranisms of concern

Based on literature, *Salmonella* is the foodborne pathogenic microorganism of greatest interest in low moisture foods. Salmonellosis outbreaks associated with low-moisture foods have compelled industry, regulatory agencies, and food microbiology community to re-examine the basic assumptions about controlling pathogenic microorganisms through modification of water activity. Although *Salmonella* do not multiply in an environment with water activity (a_w) below 0.92, they may survive in that environment for a very long period of time (Juven et al., 1994). In addition, dehydration makes *Salmonella* more resistant to other stresses induced by food processing (Gruzdev et al., 2011).

Desiccated *Salmonella* can survive at very high temperature when subjected to dry heat (Kirby and Davies 1990). *Salmonella* spp. was found to survive almost 5 min at 130 ^{0}C during roasting of cocoa beans (Silva and Gibbs 2012). Similarly, *Salmonella Tennessee* was reported to get inactivated in peanut butter only after subjecting it to 90 ^{0}C for 120 min (Ma et al., 2009). Gruzdev et al., (2011) reported that only 3.1 log reduction of desiccated *Salmonella* was achieved compared to 8 log reduction of non-desiccated cells when carried out on a dry surface at 100 ^{0}C for 1 hour. Hawaree et al., (2009) also reported, in the case of cabbage, that *Salmonella* were destroyed more rapidly during initial stage of drying when the moisture content was high than during later stage when the moisture content was low. Therefore, many dried food products such as cornflour (van Cauwenberge et al., 1981) and egg powder (Jung and Beuchat 1999) have also been found to be contaminated with *Salmonella*. Furthermore, high fat content was found to protect *Salmonella* from the action of gastric acid in human stomach. As a result, *Salmonella enterica* has been identified to cause severe diseases even at very low bacterial load (1 to 2.8 cfu/g) (Kapperud et al., 1990).

Salmonella will likely continue to pose the greatest threat in dried foods, due to its unusual ability to survive desiccation compared to *Enterobacteriaceae* or other non-spore forming pathogens (e.g., *E. coli* O157:H7, *Listeria monocytogenes*, *Campylobacter jejuni* , *Vibrio* spp., *Yersinia* spp., *Shigella* spp. , and *Staphylococcus aureus)* (Gurtler et al., 2014). One exception is the bacterial genus *Cronobacter* (previously known as *Enterobacter sakazakii*), which has caused rare but often severe instances of foodborne illness in infants and a very small number of severely immune-compromised adults. *Cronobacter* is listed among those pathogens under the category "severe hazard for restricted populations, life threatening or substantial chronic squeal or long duration" (ICMSF 2001). Nevertheless, the threat of foodborne illness associated with *Cronobacter* spp. in healthy adults and children is exquisitely small. Thus, it is not regarded as a major threat to the general human population when compared with the danger of foodborne illness from *Salmonella* spp. Although, *Cronobacter* spp. was isolated from cereal, fruit and vegetables, herbs, spices and marine products as well as from milk, meat and fish products (Friedemann, 2007; Kim et al., 2008; Jung et al., 2012), a strong association was found only with powdered infant formula (PIF) (Iversen and Forsythe, 2004). *Cronobacter* spp. appeared to be highly resistant to dried environment compared to other *Enterobacteriaceae* (Kandhai et al., 2010). Therefore desiccated foods require stricter microbial standards prior to being used for ingredients for infant food or for direct consumption to ensure their safety, especially in specific population (Jung et al., 2012).

World Health Organization (WHO) and the Food and Agriculture Organization (FAO) of the United Nations categorized *Enterobacter sakazakii* and *Salmonella enterica* as potentially dangerous contaminants for powdered infant formula (Cahill et al., 2008).

Further, although some spore-forming foodborne pathogens are able to survive in low water activity foods (e.g., *Bacillus cereus*, *Clostridium perfringens* and *Clostridium*

botulinum), these microorganisms must multiply to relatively high populations before they are able to produce toxins that cause illness.

Mechanism of the microorganisms survived in low activity

Both *Salmonella* and *Cronobacter sakazakii* can survive in food and the food processing facilities with low water activity for long periods of time and their survival increases as water activity decreases and the total solids increase (Barron and Forsythe, 2007; Steenackers et al., 2012). The mechanisms used by these pathogen to survive in low a_w were reviewed by many authors (Burgess et al., 2016; Giaouris, and Nesse, 2015; Grant, 2004; Finn et al., 2013). The mechanisms hypothesized include, but may not be exclusive to, the accumulation of osmoprotectant molecules (Csonka and Hanson, 1991), biofilm formation including encapsulation (Steenackers et al., 2012; Villa-Rojas et al., 2017) and filamentation (Eriksson de Rezendeetal., 2001; Kieboom et al., 2006; Burgess et al., 2016) which are briefly summarize in the following section.

When bacteria are exposed to a low- a_w environment, they must balance the osmolarity of their internal cell composition with that of the external environment in order to avoid the loss of water. Bacteria possess numerous cellular mechanisms that are involved in this process of osmoregulation. As an example, the accumulation of electrically neutral, low molecular weight compatible solutes (osmoprotectants), such as proline, glycine-betaine, ectoine, KCl, glutamate and trehalose which can facilitate the bacterial cell to limit the loss of water (Csonka and Hanson, 1991; Finn et al., 2013). It was speculated that the extent and strength of the vibration of water molecules in dry bacteria are limited substantially because of the very low water contents. The low water content thus prevents denaturation of cytoplasmic and membrane proteins even at very high temperatures (Archer et al., 1998). Osmoprotectants can concentrate to high levels within the bacterial cell without affecting enzyme function (Csonka, 1989).

Biofilms are defined as matrix-enclosed bacterial population adherent to each other and/or surfaces or interfaces (Lechevallier et al., 1988). Biofilms are formed when stressed bacterial cells start attaching to a surface and secrete a protective layer constituted by extracellular polysaccharides (EPS), proteins and nucleic acids; this layer encapsulates the bacterial community and provides both protection and a means to interact with their environment (Billi & Potts, 2002; Potts, 1994). Curli fimbriae and cellulose and the cell surface protein BapA are matrix component of *Salmonella* biofilms (Jonas et al., 2007). The thin curli fimbriae allow the bacterial cells to attach and colonize surfaces (Ambalam et al., 2012; Villa-Rojas et al., 2017). Production of curli fimbriae was shown to enhance long-term desiccation survival of different Salmonella spp. (Vestby et al., 2009). The encapsulated *Cronobacter* strains recovered in the long term study of low aw environments shows the mechanism of its survival during low water activity environments (Barron and Forsythe, 2007).

Filament formation may occur due to the inhibition of cell division as a result of number of stresses including low water activity (Eriksson de Rezendeetal., 2001; Kieboom et al., 2006). The formation of filaments leads to an increase in the overall biomass, but without any increase in cell numbers. Following an increase in the water activity during reconstitution, septation could resume resulting in a large number of viable bacteria (Burgess et al., 2016). It has been shown that formation of filaments prior to entrance into a dried state may lead to increased desiccation tolerance in comparison to non-filamentous cells on a stainless steel surface (Stackhouse et al., 2012).

Issues with Dried Fruits and Vegetables

Vegetables are mostly dried by hot air in tray or tunnel where the product temperature rarely exceeds 35 - 45 ^{0}C because of water evaporation. Therefore, drying rarely reduces the

number of microbial load; instead, it may apparently increase because of decrease in volume. However, the blanching of vegetables before drying destroys the non-sporulating pathogens such as *E. coli* and *Salmonella*. The bacterial population commonly isolated from dried vegetables include lactic acid bacteria, *Enteroccoccus faecalis*, *Staphylococci*, spores of *Bacillus* spp., yeastes and molds (*Penicillium* and *Aspergillus* spp.). With regard to pathogens in dried vegetables, the vegetative cells are rarely present, however, cross-contamination through soil and food processing facilities may get the spores of *Bacillus cereus*, *Clostridium botulinum* and *Clostridium perfringens* which remain harmless unless permitted to grow when the dried vegetables are reconstituted during cooking. Some of the fruits such as peaches, apricot, pears and banana are treated with high level of sulphur dioxide before drying to prevent them from browning by Maillard reaction. Such products are comparatively stable microbiologically compared to those without sulphur dioxide treatment such as prunes, dates, figs and vine fruits. Sun drying is extensively used throughout the world for fruit drying. The microflora composition depends on the sunlight strength. E. coli O157:H7, *Aspergillus*, yeast, filamentous fungi are the types of microorganisms found in dried fruits. However, mechanical drying reduces the total microbial load but the extent of the reduction depends on the type of fruit and the severity of the process (Roberts et al., 2010).

The survival of *Salmonella* in many food products has been studied in considerable detail as a function of pre-drying treatments, different drying methods and drying parameters. For example, Phungamngoen et al., (2011b) compared the effect of convective air drying, vacuum drying, and low-pressure superheated steam drying on *Salmonella anatum* populations in white cabbage and suggested that the use of lower drying temperature to avoid heat damage of chemical and physical properties may not be effective for microbial inactivation. Therefore, a suitable drying method at appropriate drying temperature along

with pre-treatment prior to drying as well as implementation of Good Manufacturing Practice (GMP) should be designed for microbial safety.

DiPersio et al. (2005) studied post-heating treatment (80 °C, 15 min) combined with or without pre-drying treatment (3.23% NaCl, 25 °C, 5 min) comparing with blanched (Water or Steam - 88^0C, 3 m) carrot slices inoculated with *Salmonella* and reported that steam blanching gave the highest reduction (4 - 4.7 log cfu/g) owing to the combined effect of the heat of blanching, heat of dehydration and low water activity. On a common 30 day long of storage, the lowest *Salmonella* population was observed in blanched carrot slices. However, *Salmonella* was still detected in blanched carrot samples at the end of the 30 days long storage which indicated that these pretreatments were not sufficient to reduce food safety (DiPersio et al., 2005) because even as few as 1-2.8 cfu/g cells can cause illness (Kapperud et al., 1990). The pre-treatment of carrot with NaCl solution (3.23% w/v) before dehydration was also found to be insufficient to kill *Salmonella*, thus, such treatment could pose a safety risk. Therefore, it was recommended that modified pre-treatments should be evaluated for their effectiveness to inhibit or destroy *Salmonella* during drying (DiPersio et al., 2005).

Pre-treatment of fruits and vegetable with sodium metabisulfite, citric acid (0.21%, w/v) or ascorbic acid (3.4%, w/v) of apple slices inoculated with *Salmonella* before drying showed complete inactivation of *Salmonella* in dried products and up to 28 days of storage (DiPersio et al., 2003). Yoon et al. (2004) reported the complete inactivation of *Salmonella* in tomatoes pretreated with ascorbic acid or citric acid solutions during drying. Similar results of complete destruction of *Escherichia coli* O157:H7 was reported in apple slices when pre-treatment was carried out with ascorbic acid, citric acid or lemon juice before drying. Moreover, it was reported that acid treatment alone was not sufficient to destroy *Escherichia coli* O157:H7 in apple slices but it did inhibit the growth of the organisms during holding

time before drying and the complete destruction was owing to the combined effect of heat of drying and acid stress (Derrikson-Tharrington et al.,2005).

Out of pre-drying treatments such as blanching, dipping in NaCl and sodium metabisulfite solutions or gas sulfuring, the dipping in sodium metabisulfite solution was found to be the best for the reduction of microbial population in sun dried tomatoes. The 3 months storage of those sun dried tomatoes revealed that sulfur treated tomatoes showed no significant changes in microbial population (Guadalupe and Diane, 2006). Another study reported a huge reduction of bacteria and fungi in fresh tomato pulp with carboxy methyl cellulose (CMC), egg white and milk as foaming agents and foam mat dried at different temperatures of 65, 75 and 85 ^{0}C, indicating CMC as the foaming agent and 85^{0}C drying temperature as the best suited for industrial application (Kadam et al., 2010b). Similar results on the reduction of microbial population were reported in foam mat dried pineapple powder (Kadam et al., 2012) and mango powder (Kadam et al., 2010a) as well as solar dried cauliflower (Kadam et al., 2005) and dried onion (Kadam et al., 2009) pretreated with potassium metabisulphite. However, Ginger dried in a solar dryer without any pre-drying treatment showed less than1 log CFU/g reduction in microbial population (Eze and Agbo, 2011) indicating that drying alone is not sufficient for microbial inactivation.

Duan et al. (2007) studied the survival of microorganism in freeze dried white cabbage where freeze drying was combined with microwave. They found that the microwave treatment was found to have sterilization effect probably due to thermal and biological effect on microorganisms whereas the freeze dried alone showed increase in microbial population, probably due to the long sublimation phase. Similar results of sterilization effect was reported when drying was carried out along with microwave for carrot and parsley (Yaghmaee and Durance, 2007) and with infrared for onion (Gabel et al., 2006).

From the information derived from the above literature, it can be concluded that the acid stress, sulfur stress and radio waves might make the microbial cells sensitive enough to be killed by low temperature drying (50 to 60^0C). But the convective air drying at low temperature alone is inadequate to inactivate pathogens present in food and also inadequate in reducing the spoilage microorganisms significantly. However, the drying of foods at higher temperature (e.g. 80^oC) showed increased reduction of microbial population in number of dried foods (Gabel et al., 2006; Hawaree et al., 2009; Phungamngoen et al., 2011a, 2011b, 2013). However, even the high temperature drying would not reduce the microbial load to meet the legal standard.

The foodborne bacteria survived during drying process may get chance to proliferate during reconstitution but the reconstituted vegetables are usually cooked fully which ensures the destruction of these pathogens. However, the reconstitution process should be practiced should be practiced for shortest optimum time period.

Issues with Meat and Fish

The traditional dried meat products include Jerky (USA), Kilishi (Nigeria), Dengdeng (Indonesia), Kaddid (Morocco), Biltong (South Africa), Rou Gan (China), Sukuti (Nepal). The microbial flora found in dried meat products include gram positive micrococii, aerobic mesophilic counts, yeast, fungi, *Aspergillus glaucus*. Sometimes, the temperature high enough to cook the meat are used in smoking and drying of meat. Proper load of dryer and rapid drying is needed to prevent the microbial growth from raw meat because the drying chamber are warm and moist until drying is well advanced. However, there is little change in bacterial numbers during freeze-drying because of low drying temperature. The spores of pathogens namely *Clostridia*, *Bacilli*, *Staphylococcus aureus*, *Salmonella* may survive the drying process if they are originally present in raw meat or are contaminated during

preparation. Similarly *E. coli* O157:H7 and *Listeria monocytogenes* are the pathogens encountered in dried meat products (Roberts et al., 2010).

Drying of meat and fish with or without salt and spices has been in practice all over the world as traditional foods. Fish drying in an open sun is one of the oldest methods of fish preservation (Rahman, 2007). Open sun drying of fish was reported to result higher microbial count when compared with improved methods of drying such as close cabinet drying under controlled condition of heat and air flow. The open drying environment, low air velocity, longer time at higher moisture content, ambient temperature and unhygienic handling are conducive to microbial growth resulting into higher risk of foodborne illness in an open sun dried fish products (Nagwekar et al., 2017; Haque et al., 2013; Guizani et al., 2008).

Studies on the effect of salt pre-treatment on drying of shark meat reported that salt pre-treatment reduced the population of *Staphylococcus* spp below detection level and mold and aerobic plate counts were also maximally reduced (Nejib et al., 2008; Rahaman, 2005). The presence of *Staphylococcus* spp in food is used as an indicator of inadequacy of food processing (Hambleton et al., 1983).

Studies on smoked and dried Salmon reported the presence of *Micrococci, Staphylococci* and non-fecal coliforms as predominat microflora and the use of gloves during handling was found to minimize the contamination (Himelbloom et al., 1996; Himelbloom and Crapo, 1998). *Micrococcus* is halophile and desiccation tolerant nonpathogenic bacteria found in smoked fish as post-processing contaminant (Okafor and Nzeako, 1985). Moreover, enterotoxin production is typically associated with coagulase-positive *Staphylococcus aureus* at populations of 10^5/g (Jablonski and Bohach, 1997). The *staphylococcal* isolates in dried salmon were found to be coagulase-negative *S. warneri*, *S. xylosus*, *S. intermedius* and *S. epidermidis* which are not associated with enterotoxin production (Himelbloom et al., 1996).

The U.S. microbiological standard for shellfish meat is 2.3×10^2 per 100 g for faecal coliform group and 5×10^5 CFU/g for aerobic plate count (Wood, 1976; Wentz et al., 1983). Similarly, FDA set a standard on *S. aureus* for ready-to-eat seafood as up to 10^4 cells/g (FDA, 1994).

Jerky is salted dried lean meat strips produced by low temperature drying in which the salt and low a_w play a primary role to prevent the microbial growth. To decrease the risk of foodborne pathogens in Jerky, USDA/FSIS (2004) proposed a guidelines of either preheating meat slices in marinades to achieve an internal temperature of 71.1 ^{0}C or dipping the meat slices in 5% acetic acid for 10 min before marination, or drying the slices in the presence of moisture. Others reported the inactivation of *E. coli* O157:H7, *Salmonella* and *Listeria monocytogenes* in Jerky with the use of lactate, acetic acid, Tween 20 as pre-drying marinades. Moreover, the inactivation rate was found to be directly proportional to the drying temperature (Calicioglu et al., 2002a, 2002b, 2003, Yoon et al., 2009). Lara et al. (2003) reported the absence of *Staphylococcus aureus* and *Clostridium botulinum* at a_w of 0.70–0.75 in laboratory made Jerky. But Nummer et al. (2004) reported the presence of *Eschericia coli* O157:H7, *Salmonella*, *Staphylococcus aureus* and *Listeria monocytogenes* in homemade Jerky which was in compliance with the presence of aerobic bacteria, yeast and molds in Kilishi (a Jerky from Nigeria), probably due to the spices used in its preparation and the degree of hygienic processing. Jerky was found to cause several foodborne outbreaks (Table 1).

Dengdeng is an Indonesian spicy dried meat made from sliced or ground beef by marinating or mixing with salt and spices before drying. Dengdeng products were reported to contain high microbial contamination possibly from ambient temperature storage of raw meat and the use of contaminated spices including open sun drying (Purnomo, 2011). It is reported that *Staphylococcus aureus* and thermoduric bacteria are also present in Dengdeng samples

(Bintoro et al., 1987). Similarly, Kaddid (adried meat of Morocco) was found to contain *Staphylococcus* counts (Bennani et al., 2000) and Biltong (a dried beef from South Africa) was reported to contain high bacteria count (Prior, 1984).

Sugar acts osmotically against microbial cells at high concentration (20-80%) but most dried meat products contain only 1-10% sugar (Ockerman, 1983). However, Kuo and Ockerman (1985) reported the inhibition effect of high sugar (30%) and salt (2.5%) against anaerobic microorganisms in dried pork. These anaerobes remained constant during 21 days storage but aerobic counts were found to increase. Aerobic bacteria are responsible for off-odor and slime on meat surface (Banwart, 1979).

The use of salt, spices and sugar in various concentrations, which possess antimicrobial properties, to these dried meat and fish products let them safe to a large extent, if proper handling, processing and post processing steps are performed.

Issues with spices and herbs

Most of the microflora in spices and herbs consists of aerobic mesophilic spores such as *Bacillus subtilis, B. licheniformis, B. megaterium, B. pumilus, B. brevis, B. polymyxa*, and *B. cereus*. Thermophilic anaerobes and aerobes are found occasionally, sometimes in moderate numbers. *Clostridium perfringens, Cl. botulinum, Salmonella, Staphylococcus aureus* and *Listeria monocytogenes* are the pathogens found in spices. Psychrotrophic non-spore-forming bacteria are generally less numerous in spices and herbs than mesophiles and Escherichia coli is less frequent. Other microflora found in spices and herbs are *Enterobacteriaceae*, fecal *Streptococci*, *Staphylococci* and lactic acid bacteria, thermophillic actinomycetes. Spices are a major source of mold contamination in foods in which they are added. *Eurotium* species, *Aspergillus niger* and *Penicillium* spp. are usually most prevalent (Roberts et al., 2010).

Although spices and herbs are not major contributors to foodborne disease, a potential hazard exists, particularly if the spice or herb is added at the end of cooking or added to

ready-to- eat foods (Little et al., 2003) or when they are mixed with high moisture containing foods (Van Doren et al., 2013). And, the hazard could be more serious if they are contaminated with pathogenic microorganisms (Banerjee and Sarkar, 2003). Outbreaks of Salmonellosis were reported due to the foods seasoned with black pepper (Gustavsen and Breen, 1984), chilli and turmeric powders (Little et al., 2003). Therefore, particular attention needs to be paid on spices used for ready-to-eat foods (Little et al., 2003). The microbiological quality of dried herbs and spices mainly depends upon hygienic practices adopted during their cultivation, harvesting and post-harvest processing (Bhat, 2013).

In practice, dried spices and herbs are usually stable from microbial attack due to their antimicrobial properties (Gupta, 2010; Koffi-Nevry, 2012). However. high microbial count of up to 10^8 cfu/g was reported in black pepper, paprika, chili powder, cumin seeds (Gupta, 2010; Koffi-Nevry, 2012), cinnamon powder (Mi-Seon et al., 2014) and oregano sample (Jerkovic et al., 2001), even the pathogenic contamination (Isabel et al., 2010), probably due to poor hygienic practices during handling, processing, storage and distribution . However, cinnamon and basil were reported with no microbial contamination owing to their antibacterial effects (Friedman et al., 2002). In addition, the antimicrobial properties of spice oils were reported in cinnamon and basil (Lachowicz et al., 1998; Montes-Belmont and Convajal, 1998), thyme and oregano (Sagdic, 2003), ginger and turmeric (Chen et al., 2008) and bay leaf (Bagamboula et al., 2004). It was recently reported that the antimicrobial properties of dried spices can cause the inactivation of non-spore forming bacteria but not the spores (Thanh et al. 2018). Moreover, the spices reported to contain spoilage and pathogenic microorganism are mostly used for South East Asian cousine where the foods are cooked for a long time which ensures the destruction of these foodborne bacteria.

Spices and herbs are currently treated with ionizing radiation to eliminate microbial contamination. The ionization treatment of spices and herbs was found more effective than

the thermal treatment because it does not leave any chemical residues in the food (Olson, 1998). Moreover, irradiation prevents the loss of aromatic volatile compounds from spices and herbs owing to its minimal temperature rise, compared to the thermal decomposition during heat treatment (Sádecká, 2007). Gamma rays up to the dose of 10 kGy is considered the maximum safe dose without significant chemical and sensory changes (EC, 1999).

Issues with Mushroom

Mushrooms are produced and sold as fresh, dried, marinated, or canned. Aseptic growth conditions are not used for mushrooms and frequently other microorganisms play an essential role. Mushrooms are contaminated with microorganisms from their growth substrate. The commonly found microflora in mushroom are *Pseudomonas* spp., yeasts, and molds. Mushrooms may also contain spore-forming bacteria, of which *Cl. botulinum* is the greatest concern, followed by *Staphyloccus aureus* and *Campylobacter jejuni*. Dried mushroom were also found to be vehicles for *Salmonella* spp. (Roberts et al., 2010).

Fresh mushrooms have very short shelf life (3 days) at ambient temperature (Fernandes et al., 2012) because it is highly susceptible to microbial growth (Venturini et al., 2011). Preservation of fresh mushroom to fulfill the global demand by drying is one the common practices because of its low-cost and simplicity (Kumar et al., 2013). However, the misconception about the dried mushroom being microbiologically safe, could be the main reason for the poor microbial quality and safety. Ajis et al. (2017) reported that dried mushroom samples collected from various markets were contaminated with coliforms at various degrees depending upon the way they were handled and packed. Moreover, the practice of reconstituting dried mushroom in warm or normal water for hours could provide ideal environment for proliferation of microorganisms and pose a risk of foodborne outbreak.

However, subsequent cooking might kill these microorganisms reducing the risk significantly.

Issues with dried powdered foods

Due to the extremely low water activity (0.3-0.4) of dried dairy products, development of spoilage organisms is not possible. During storage, some vegetative microorganisms present may slowly die-off but others may survive over prolonged periods. *Salmonellosis* and *Enterobacter sakazaki* are the most potent pathogens related to dried powdered foods followed by *Listeria monocytogens*, *Staphyloccus aureus*, *Bacillus cereus* (Roberts et al., 2010).

Powdered infant formula (PIF) is a microbiologically stable nonsterile product, packaged in sealed containers. As long as the package is not opened, the product remains usable for up to the manufacturer's expiration date. The contamination of PIF with *Cronobacter sakazakii* and incidence of outbreaks due to the consumption of PIF indicates that although a majority of *C. sakazakii* was found inactivated during the dried environment storage in the sealed container, a portion of the cells was found highly resistant and survived for at least 2 years (Sharon et al. 2005). Therefore, World Health Organization (WHO) considered *C. sakazakii* as one of the pathogens of most concerned with regard to PIF. Moreover, WHO listed out *Salmonella enteric* as the second most important pathogens to be concerned with regard to PIF (WHO, 2007). The FDA also concluded that *C. sakazakii* and *Salmonella* are the most concerned microorganisms required to be considered in PIF and the microbiological standard for other organisms other than them was not needed (FDA, 2006). The WHO also published the guidelines for the preparation and storage of PIF which emphasize on the use of hot water of at least 70^0C while reconstituting PIF and if the product

is not consumed within 30 minutes of preparation, it suggests to store it in a refrigerator at 4^0C (WHO, 2007).

The risks associated with powdered infant formula for the presence of *Salmonella* and *Cronobacter sakazakii* have been studied extensively (Iversen and Forsythe, 2003, 2004; Oonaka et al., 2010; Beuchat et al., 2013). These studies reported that there was a high probability of contamination in dry mixing and/or fortification stage (Beuchat et al., 2013; Kim et al., 2008; Chap et al., 2009). Milk and powdered infant formula were reported to be responsible for 50-80% of *Cronobacter* infection (Kim et al., 2008). Food borne outbreaks associated with PIF is listed in the Table 1.

Concluding Remarks

Dried foods or low water activity foods (a_w < 0.70) were previously thought to be microbiologically safe. However, they were found to be contaminated with foodborne pathogens, and found to be the cause of numerous foodborne outbreaks. Research on dehydration shows that dehydration alone is not enough to inactivate the pathogens load in food, especially the *Salmonella* spp. Various pre-drying treatments such as NaCl, citric acid, ascorbic acid, sodium metabisulfite, sulfur as well as blanching are required to inactivate the microbial population to a required level. Among various pre-drying treatments, sodium metabisulfite and acid treatments are proven to be effective. The use of novel and hybrid drying technologies could be further studied for their hurdle effects. The microbiological quality of raw materials, processing conditions and post drying processing of the dried products are important areas to be considered. Quality control of raw materials/ingredients, processing line control, implementation of hazard analysis and critical control point (HACCP) and good manufacturing practice (GMP) in manufacturing facility, sanitation and hygiene of employees and avoiding contamination, cleaning and disinfection procedures, are

areas to be focused to ensure the safety of dried food products. Dried foods can no longer be considered that they are inherently safe from foodborne pathogens just because they are dried, rather, an "if…" sentence will always be followed.

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Table 1. Food borne outbreaks related with dried foods

Pathogen	Food	Year	Country	Number affected	Reference
Cronobacter sakazakii	Powdered Infant formula (PIF)	1958	UK	2	Urmenyi and Franklin (1961)
Salmonella enterica Derby	Dried milk powder	1973	Trinidad	3000	Weissman et al. (1977)
Salmonella enterica Ealing	PIF	1985	England	48	Rowe et al. (1987)
Salmonella enterica Tennessee	PIF	1993	USA, Canada	>3	CDC (1993)
Salmonella enterica Virchow	PIF	1994	Spain	>48	Usera et al. (1996)
Salmonella enterica Anatum	PIF	1996-1997	UK, France	17	Threlfall et al. (1998)
Cronobacter sakazakii	PIF	1998	Belgium	12	van Acker et al. (2001)
Salmonella enterica London	PIF	2000	Korea	30	Park et al. (2004)
Cronobacter sakazakii	PIF	2001	USA	10	Himelright et al. (2002)
Clostridium botulism	PIF	2001	UK	1	Brett et al. (2005)
Cronobacter sakazakii	PIF	2001	Belgium	1	FDA (1996)
Cronobacter sakazakii	PIF	2004	Newzealand	5	FDA (1996)
Cronobacter sakazakii	PIF	2004	France	4	FSA (2005)
Salmonella enterica Agona	PIF	2004-2005	France	141	Brouard et al. (2008)

Clostridium botulinum	Dried seal meat	1960	Canada	3	Dolman (1961)
Salmonella enterica Thompson	Beef Jerky	1966-1967	New Mexico	39	Eidson et al. (2000)
Salmonella oranienburg	Black pepper	1981	Norway	126	Gustavsen and Breen (1984)
Staphylococcus aureus	Beef Jerky	1982	New Mexico	15	Eidson et al. (2000)
Salmonella cerro	Beef Jerky	1985	New Mexico	44	Eidson et al. (2000)
Salmonella enterica Montevideo	Beef Jerky	1986	New Mexico	5	Eidson et al. (2000)
Salmonella enterica Newport	Beef Jerky	1987	New Mexico	4	Eidson et al. (2000)
Salmonella enterica Newport	Beef Jerky	1988	New Mexico	45	Eidson et al. (2000)
E. coli. O157:H7	Deer Jerky	1995	Oregon	11	Keene et al (1997)
Salmonella mutiple serotype	Beef Jerky	1995	New Mexico	93	Eidson et al. (2000)
Staphylococcus aureus	Antelope Jerky	1995	New Mexico	5	Eidson et al. (2000)
Salmonella saintpaul	Paprika and potato chips with paprika powder	1993	Germany	> 1000	Lehmacher et al. (1995)
Salmonella senftenberg	Spices and herbs	2007	Denmark	3	EFSA (2013)
Bacillus cereus	Spices and herbs	2007	France	146	EFSA (2013)
Clostridium perfringens	Spices and herbs	2007	France	19	EFSA (2013)
Bacillus cereus	Curry	2009	Belgium	7	EFSA (2013)
Salmonella enterica Montevideo	Black and red pepper	2009-2010	USA	272	Gieraltowski et al. (2013)
Bacillus cereus	White pepper	2010	Denmark	112	EFSA (2013)
Bacillus cereus	Turmeric	2011	Finland	23	EFSA (2013)
Bacillus cereus	Cumin powder	2011	Finland	3	EFSA (2013)
Bacillus cereus	Pepper	2011	Denmark	52	EFSA (2013)
Salmonella agona	Peanut snacks	1994-1995	England, Wales, USA	41	Killalea et al. (1996)
Salmonella agona	Peanut snacks	1994-1995	Israel	>2200	Shohat et al. (1996)
Salmonella enteritidis	Almonds	2003-2004	USA, Canada	168	Isaacs et al. (2005)

Salmonella enteritidis	Almonds	2005-2006	Sweden	15	Ledet Muller et al. (2007)
E. coli O157:H7	Shelled hazelnuts	2009	USA	8	Miller et al. (2012)
Salmonella enteritidis	Pinenuts	2011	USA	43	CDC (2011)
Salmonella enteric	Hazelnuts	2017	USA	5	FSN (2017)

Note: Out of 41 Food borne outbreaks recorded from 1958 to 2017, *Salmonella* was found to be the most frequent causative organism. The most implicated foods in these outbreaks were PIF (14 outbreaks), dried meat products (11 outbreaks), dried spices (10 outbreaks).