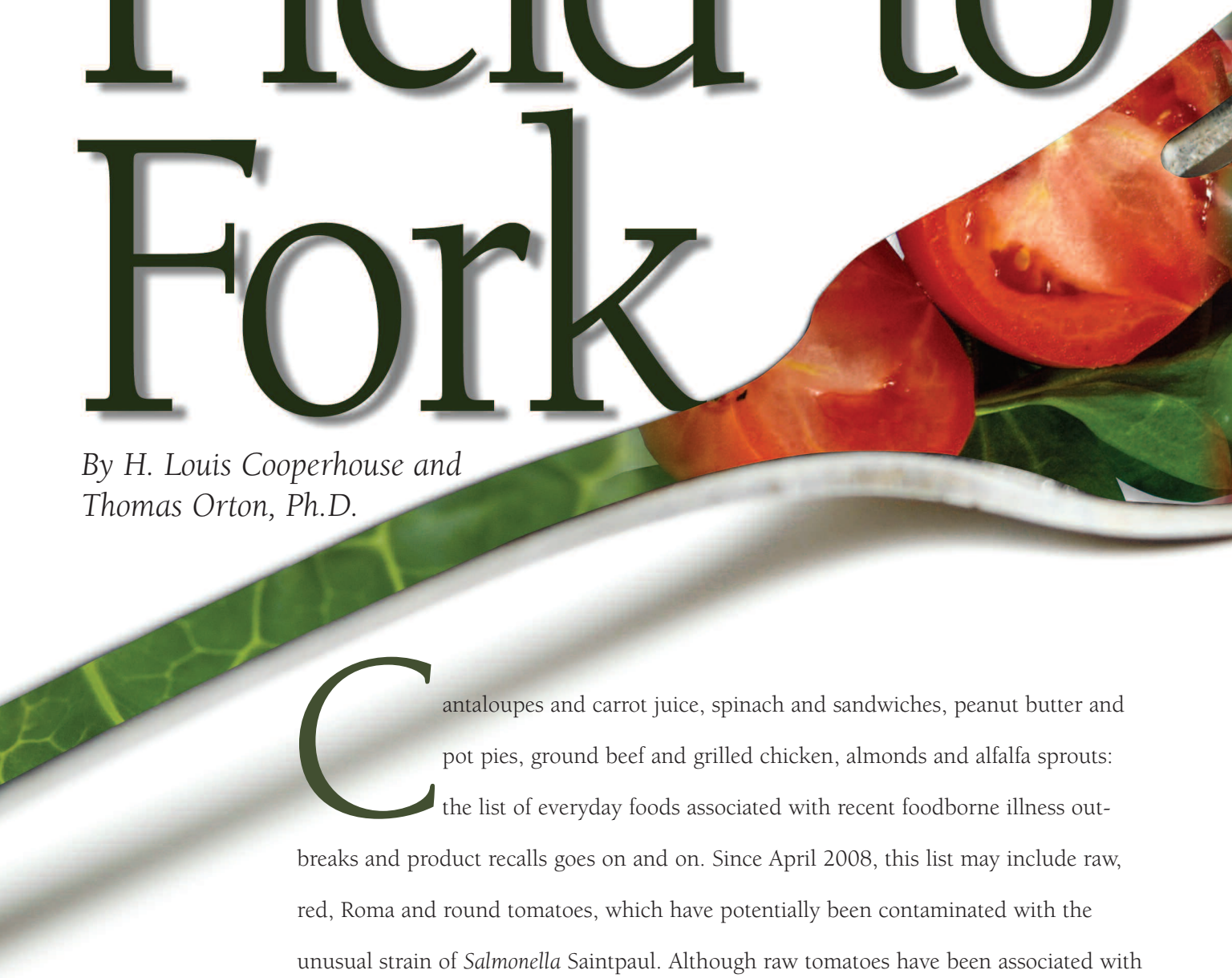
BREAKING THE PERISHABLE PRODUCTS PARADIGM:

Hurdle Technology Solutions from Field to Fork



By H. Louis Cooperhouse and Thomas Orton, Ph.D.

Cantaloupes and carrot juice, spinach and sandwiches, peanut butter and pot pies, ground beef and grilled chicken, almonds and alfalfa sprouts: the list of everyday foods associated with recent foodborne illness outbreaks and product recalls goes on and on. Since April 2008, this list may include raw, red, Roma and round tomatoes, which have potentially been contaminated with the unusual strain of *Salmonella* Saintpaul. Although raw tomatoes have been associated with several significant outbreaks over the past decade, 2008 marks the first time that restaurants and grocery chains throughout the country chose to temporarily stop selling or

REPRINTED FROM FOOD SAFETY MAGAZINE, AUGUST/SEPTEMBER 2008, WITH PERMISSION OF THE PUBLISHERS.
© 2008 BY THE TARGET GROUP • www.foodsafetymagazine.com

serving tomatoes. The magnitude of this recent outbreak, which has resulted in over 1250 reported cases of salmonellosis in 43 states, has again impacted a major segment of the U.S. food industry. However, the magnitude of this outbreak, as well as the tremendous difficulty and uncertainty in isolating its cause and its source, has reinforced the need for: 1) a much more effective product sampling and testing program that would serve as a *proactive* measure to minimize the potential for such an outbreak in the first place and 2) a much more effective traceback system that would serve as a *reactive* measure to efficiently and accurately identify the source and cause of an outbreak and contain it as quickly as possible.

Outbreaks of foodborne illness continue to occur and have been documented on every continent, illustrating both the public health and social significance of these diseases. Trends in global food production, processing, distribution and preparation present new challenges to food safety, as a single source of contamination can have widespread, even global, consequences. Regulatory authorities in North America, Europe and elsewhere are continually increasing the breadth and depth of their food safety surveillance and, at the same time, employing more sensitive microbiological testing methodologies and enhancing or tightening their standards. Numerous recent outbreaks of foodborne illness have attracted significant media attention and raised consumer concern. Similarly, this has dramatically heightened the concern of food industry leaders throughout the agricultural and food chain worldwide.

REPRINTED FROM FOOD SAFETY MAGAZINE, AUGUST/SEPTEMBER 2008, WITH PERMISSION OF THE PUBLISHERS.
© 2008 BY THE TARGET GROUP • www.foodsafetymagazine.com

Outbreaks are, however, only the most visible aspect of a much broader, more persistent problem as there are large numbers of sporadic cases and smaller outbreaks that are never reported. In the U.S. where an excellent surveillance system is in place, the Centers for Disease Control and Prevention estimates that for every case of *Salmonella* infection reported, at least 30 cases go unreported, primarily due to affected individuals that choose to forego medical care. Unfortunately, many countries throughout the world do not have good reporting systems, and the total magnitude of global foodborne illnesses is therefore difficult to determine. The World Health Organization estimates that up to one-third of the world population suffers from foodborne illness annually, which leads to death with alarming frequency, particularly within countries that lack accessible health care. Numerous national and international agencies have begun to document the impact of foodborne illnesses and the substantial economic burden that they impose in the form of higher healthcare costs and the marked reduction in workforce productivity.

"Outbreaks of foodborne illness continue to occur and have been documented on every continent, illustrating both the public health and social significance of these diseases."

The increasing incidence of foodborne illness is due to a multiplicity of factors that include:

- The continual evolution of consumer eating patterns, including a preference for fresh and minimally processed ready-to-eat foods, and new types of prepared convenience products being marketed and consumed.
- Changing farm practices, particularly related to the disposal of manure from large-scale animal production facilities, which have an indirect impact on food contamination. Uncomposted or untreated manure frequently contains pathogens that can contaminate nearby agricultural operations via water, wind or direct contact. This issue is exacerbated by progressive urbanization that is occurring in developed countries, including the U.S., resulting results in increasing proximity of crops to animal husbandry operations and the potential for cross-contamination.
- Inadequate or improper refrigeration during the "field to the fork" continuum in which a single break in the cold chain can create conditions under which any existing bacterial pathogens may flourish. The potential links in the cold chain include raw material harvesting and distribution, manufacturing plant packaging and storage conditions, loading docks, trucks, distribution depots, retail and foodservice holding coolers, store merchandisers, transportation by the consumer between the store and home and home refrigerators. As the number of steps in the chain increases, the risk of abusive handling increases concomitantly. This issue is heightened in the U.S. compared with Europe and other developed regions because the distribution system is highly segmented and volume-driven. It is common for the refrigerated shelf life of a product to be 2–3 days in the UK, for example, and in the U.S. this may typically be from 10–21+ days dependant on the product, barriers used and its method of distribution.
- Insufficient workforce training, particularly in agricultural operations and in foodservice establishments. Heightened training is needed in areas such as sanitation practices and avoidance of product contamination. This problem is further compounded by the extremely high employee turnover rate, which is common in both agricultural and foodservice industries.
- An aging population that is more susceptible to foodborne illness.

Third Generation of Prepared Foods Growth

The prepared foods industry is in the midst of its *third generation of growth*. The "first generation" of prepared foods focused on *canned* foods although many food marketing experts believe that this category has reached its market potential. The "second generation" of prepared foods focused on *frozen* foods, which demonstrated phenomenal growth during the past two decades, but many experts believe that this category has also reached its maturity. We are currently in the midst of a "third generation" of technological and market innovation defined by value-added *refrigerated* prepared foods.

Each "generation" of prepared foods has taken considerable time to move through its life cycle–from technological breakthrough, to market entry, to consumer acceptance and finally to commercial success. Typically, this learning phase is followed by rapid growth in the category. The refrigerated prepared foods category is achieving commercial success faster than prior generations of prepared foods, driven by rapid advances in technology and evolving consumer preferences.

Consumer demand for products offering even greater convenience and higher quality has increased dramatically in recent years. "Convenience" is widely recognized as a major purchasing motivator for prepared foods today. In addition, the term "fresh" has been equated with higher quality, better taste, improved nutrition and a positive benefit that consumers demand. "Freshness" and "convenience" are attributes that are inherent in this third generation of refrigerated prepared food products, particularly products that are ready-to-eat and do not require microwave or oven heating prior to

REPRINTED FROM FOOD SAFETY MAGAZINE, AUGUST/SEPTEMBER 2008, WITH PERMISSION OF THE PUBLISHERS.
© 2008 BY THE TARGET GROUP • www.foodsafetymagazine.com

consumption. In addition, refrigerated foods offer the promise of premium quality, because they do not undergo the same quality-limiting processes that result from canning and frozen food practices, which impact potential food texture, color and flavor.

Pre-cut and prepackaged lettuce, for example, served as the pioneering product of the fresh-cut segment of the refrigerated foods industry and is an outstanding example of the dramatic growth that can be achieved in a very short time. This segment grew from essentially a zero baseline in the mid-1980s to a $15+ billion dollar industry over the past 25 years, and represents the fastest growing segment of the $80+ billion fresh produce industry. The convenience of product use, and the quality and variety offered by prepackaged items, have changed consumer purchasing behavior and created "halo" effects for other prepackaged products such as pre-cut fruits and vegetables.

"Refrigerated perishable products offer a unique level of complexity since there is no singular technology or "kill step" to assure product safety for the broad spectrum of products that exist."

Hurdle Technologies Key to Reducing Microbiological Hazards

Refrigerated perishable products offer a unique level of complexity since there is no singular technology or "kill step" to assure product safety for the broad spectrum of products that exist. Unlike canning and freezing technologies, the attributes of quality in a refrigerated food product will vary considerably from the beginning to the end of a product's shelf life. This variability in quality has been further increased by manufacturers of refrigerated foods in the U.S. as the need for lengthened distribution requirements has necessitated shelf life requirements that are among the longest in the world.

A number of food technologies have been aimed at preventing food pathogens from infesting food products. These technologies are identified as "hurdles" or "barriers" and have varying effects on the safety and shelf life of food products. Their level of effectiveness is dependent in part on *which* technology is used, the *degree* to which these technologies are applied and whether *multiple* hurdle and barrier technologies are used. Just as their name implies, "hurdle" technologies can in fact be "overcome" by food pathogens. Nevertheless, deployment of these technologies can make foods increasingly impenetrable by pathogens, based on which ones and how these prophylactic factors are applied. While a bacterial pathogen may overcome a single hurdle, or maybe even two hurdles, the use of multiple hurdles in a food product greatly reduces the probability that a pathogen will overcome them all. To a food marketer and/or manufacturer, integration of a hurdle technology offers tremendous value and may be considered as: 1) a potential critical control point (CCP) in a product's Hazard Analysis CCP (HACCP) plan, and/or 2) a weapon in an arsenal of technologies that provides for enhanced food safety and/or enhanced food sensory characteristics for a greater period of time and/or 3) a technology that provides a company with a distinctive competitive advantage.

- Agricultural Practices at the Farm
- Postharvest Agricultural Practices
- Product Formulation Procedures
- Processing Procedures
- Packaging Procedures
- Distribution

Table 1: Food Product Hurdles

Hurdles are proactively determined, preventative tools designed to minimize microbial and/or sensory degradation, and enhance or extend the potential shelf life of a food product. They are effectively "tools in the toolbox" that can be used by manufacturers of perishable foods and others involved in the product's refrigerated distribution chain. It is essential that hurdle technologies be used, because we cannot rely exclusively on the maintenance of refrigerated conditions throughout the distribution cycle to assure the safety of perishable foods. In fact, refrigeration alone is not enough to prevent the growth of some infectious or toxigenic microorganisms. Therefore, hurdle technologies and processes must be incorporated into these foods to yield a safe and stable system. Hurdles can be applied in various phases or potentially in all phases of the life cycle of a food product, from field to fork (Table 1).

Hurdle Applications—From Farm to Fork

Agricultural Practices at the Farm: First Line of Defense

Microbial loads on fresh produce can vary considerably by product, by degree of maturity, by geographic location, by field and location in the field. Crop plant physiology, morphology, proximity to soil and other conditions in which contamination can occur are significant, as pathogens have been shown to be internalized via roots, flowers, stem scars, pores, channels, bruises, air cells and temperature differentials.

In the case of fresh-cut produce products, it is critical to prevent fruits and vegetables from becoming contaminated with pathogens in the first place. The focus of efforts needs to be on prevention, particularly at the farm and

REPRINTED FROM FOOD SAFETY MAGAZINE, AUGUST/SEPTEMBER 2008, WITH PERMISSION OF THE PUBLISHERS.
© 2008 BY THE TARGET GROUP • www.foodsafetymagazine.com

packing shed level, because once contaminated, fresh produce cannot be reliably decontaminated by any current technology except heat. For this reason, the focus of industry is on prevention, including good agricultural practices (GAPs) and HACCP programs, implemented at the farm level. GAPs comprise a systematic production protocol that cover all farming steps from seed sowing through the loading of palletized boxes of harvested produce onto trucks. GAPs stress the implementation of measures that promote human and farm animal sanitation and segregation from crops, especially direct contact and management of nearby wastes. Enforcement by a system of third-party audits is accomplished to ensure compliance with the terms of the GAPs. However, because there are so many possible routes of contamination on a farm, and because there is a dearth of good research into on-farm food safety, there is no general agreement as to what GAPs should encompass and how they should be applied. Consequently, many versions of GAPs have evolved, and in-house and third-party auditing practices are not standardized, creating further industry confusion. In such an environment, it is quite difficult to differentiate the food safety programs of one supplier against another.

As in any HACCP program, there must be a continuous chain of prevention throughout all of the steps involved in the growing and harvesting process. Pathogens can contaminate produce via adulterated water from irrigation, spray water or runoff from areas grazed by animals; by fecal contamination of soils due to grazing animals, human waste or uncomposted manure used as fertilizer; by infected workers who practice poor personal hygiene; and by contamination that occurs in processing from hydrocooling, wash water and pathogen harborage that may occur on product contact surfaces and in the environment.

Postharvest Agricultural Practices

The efficacy of sanitizers in mitigating human pathogenic microorganisms on a wide range of whole and fresh-cut fruits and vegetables has been studied extensively. Numerous challenge studies to determine the effects of storage conditions on survival and growth of pathogens on raw produce have also been reported. Al-though there are a number of sanitation treatments for fresh-cut produce in use today, once fruits and vegetables have been contaminated with bacterial pathogens or parasites, only thorough cooking will eliminate these organisms, although heating will not necessarily remove microbial toxins.

It has been demonstrated that pathogens can be internalized into the produce. Therefore, it is possible to reduce the numbers of pathogens on produce by washing in a sanitary solution, but it is not possible to eliminate them. Furthermore, biofilms have been demonstrated to protect pathogens against bactericidal agents used in postharvest sanitation. Even abrasive scrubbing in a sanitary solution can only reduce, but not eliminate, bacterial counts.

U.S. Food and Drug Administration (FDA) guidance documents indicate that a series of washes may be more effective than a single wash. An initial wash treatment may be used to remove the bulk of field soil from produce, followed by an additional wash or washes containing an antimicrobial agent. Vigorous washing of produce (so long as it is not easily bruised or injured) will increase the likelihood of pathogen removal. Furthermore, different methods may be used to wash different types of produce, including submersion, pressurized spray or both. Regardless of the method used, however, maintaining the quality of the wash water is important to minimize the potential for contamination, and maintaining its effectiveness is a CCP as well. Wash water must also be applied at the appropriate temperature, as produce is susceptible to infiltration of wash water if warm produce is placed in water that is cooler than the produce. This temperature difference creates a pressure differential causing air spaces inside the fruit or vegetable to contract, thereby allowing water to be pulled into the fruit or vegetable.

Because water-based sanitizers can only kill those bacteria that they contact, and because microorganisms can quickly become internalized or lodged in hydrophobic niches on produce, the best sanitizers can only achieve a 1–3 log (10- to 1000-fold) reduction of microorganisms. This limitation makes wash water sanitizers an unreliable method for removing and killing pathogens on fresh produce. In fact, a primary function of wash water sanitizers in the produce industry is to prevent the water from becoming a vector for cross-contamination. If a single contaminated fruit or vegetable is introduced into wash water, the contaminating pathogen can spread into the water and contaminate any produce that is subsequently introduced into that water. Maintaining sufficient sanitizer activity in the water prevents the spread of microbial contaminants, but it does not reliably disinfest fruits or vegetables that are already contaminated.

Good manufacturing practices are certainly required in the postharvest processing of produce. Ideally this includes a segregated area for sanitizing produce, the creation of "low risk" and "high risk" processing operations and the utilization of "cleanroom" practices that will be described in the following section. Furthermore, slicing and dicing and other food contact equipment needs to be effectively sanitized and monitored as it can be a source of cross-contamination.

Product Formulation Procedures

As a product is being formulated at the manufacturing level, a number of natural or synthetic barriers can be introduced that can significantly extend shelf life and provide greater assurance of product safety. Some of these formulation hurdles are defined by the United States Department of Agriculture (USDA) and FDA as "food additives," while others involve modifications to the intrinsic properties of the food itself (Table 2).

Processing Procedures

The USDA Food Safety and Inspection Service (FSIS) and FDA provide direc-

REPRINTED FROM FOOD SAFETY MAGAZINE, AUGUST/SEPTEMBER 2008, WITH PERMISSION OF THE PUBLISHERS.
© 2008 BY THE TARGET GROUP • www.foodsafetymagazine.com

- Acidulants – natural or synthetic
- Antimicrobial agents
- Sodium benzoate, potassium sorbate, sodium nitrite, etc.
- Sodium lactate, nisin, liquid smoke, sodium propionate
- Salt, certain spices
- Pre-treatment of components used in process
- Irradiated spices and other ingredients approved by the FDA/USDA
- Blanching of vegetables
- Chemical/preservative dips
- Water activity control
- Antioxidants
- Application of competitive microorganisms

Table 2: Formulation Hurdles

tives to verify the adequate cooking of meat, poultry and other products to ensure a safe process. These directives follow a time and temperature matrix that is destructive to pathogenic organisms. However, in following these guidelines, product can be processed either *before* or *after* it has been packaged, and the processing means can either use thermal or non-thermal processing technologies (Table 3).

Packaging Procedures

In addition to playing a critical role in "communicating" quality in refrigerated prepared foods, packaging clearly plays a critical functional role as well. A few decades ago, equipment and packaging materials designed for refrigerated foods were extremely limited. The growth of the refrigerated food industry would not have been possible were it not for advances that occurred in the packaging industry. Packaging plays a unique role in the case of fresh-cut produce, due to the obvious fact that produce is living, respiring tissue. Harvested produce takes in oxygen, and releases carbon dioxide, water, heat and metabolites. The rate at which these processes occur is known as the respiration rate. Packaging plays a unique role by matching the respiration rate of the product with the gas transmission rates of the packaging material. This is critical to achieve an appropriate balance of gases in the package. As a result, a wide variety of packaging materials is used today, and the concept of "one film fits all" is clearly not applicable in the refrigerated foods industry.

Depending on the product, and on the approach that is used to provide for safety and shelf life, the packaging phase may occur before or after the thermal or non-thermal processing steps. One, some or all of these packaging hurdle technologies can be employ-ed to improve product quality and/or safety. These packaging hurdles are:

• *Modified atmosphere packaging (MAP)* in which product is packaged in an atmosphere that is different from that of air, which normally contains about 78% nitrogen, 21% oxygen and 1% percent of other components including carbon dioxide. MAP helps to delay the onset of product degradation, typically by reducing the amount of oxygen exposed to the product during its shelf life. In high-moisture products, such as cooked entrees and fresh-cut produce, MAP may delay microbial and sensory spoilage, reduce browning, slow respiration rate and lower ethylene production. In high-fat products, MAP delays rancidity and preserves the smell, taste, texture and appearance. MAP also helps to delay staling in bakery products. Elevated carbon dioxide above about 10% selectively inhibits the growth of Gram-negative bacteria, such as pseudomonads and other related psychrotrophs, which otherwise grow rapidly and produce off-odors and off-flavors. Elevated carbon dioxide is not effective in preventing the growth of most human pathogens such as *Listeria*, *E. coli* or *Salmonella*. In addition, because resultant oxygen levels can be extremely low, and product can be held for an elongated period of time, an atmosphere that is conducive to growth of anaerobic bacteria, such as *Clostridium botulinum*, may evolve. Therefore, competing organisms and/or incorporation of other barriers and/or the testing of product via challenge studies will minimize such risks. Vacuum packaging and vacuum-skin packaging are other forms of modified atmosphere packaging in which the overall quality and safety objectives are the same. However, a different and potentially more aesthetically pleasing product may result.

• *Packaging in a "high care" or "clean-room" environment* in which product should flow in one direction from raw material receipt, to raw material preparation, to processing, to packaging and air pressure should be positive to the outside. Typically, this environment will utilize this positive air pressure and also high-efficiency particulate air (HEPA) filters that are over 99.97% effective for particles one micron or greater. Makeup air is one of the central issues in maintaining clean airflow in the processing plant and this can be quantitatively measured. There are also products on the market that are much less expensive, and purify the area utilizing UV and/or ozone air-cleansing systems.

• *Barrier or respiration-enabling packaging*

Thermal Processing

Hot Fill, Quick Chill processes in which product is heated to a desired internal temperature, held for a desired period of time and then quickly chilled to meet or exceed USDA/FDA requirements.

Cold Fill, Post Packaging Pasteurization processes in which raw or cooked product is heated to a desired internal pasteurization temperature (or cooked product is heated again post-packaging to a desired surface temperature) and then quick chilled. Sous vide and microwave pasteurization are examples of this technique.

Non-Thermal Processing

Ultra High Pressure (high hydrostatic pressure) Processing, Irradiation (Electronic beam pasteurization, Gamma Ray or X-Ray) and Pulsed Light and Pulsed Electric Fields.

Table 3: Processing Technology Hurdles

REPRINTED FROM FOOD SAFETY MAGAZINE, AUGUST/SEPTEMBER 2008, WITH PERMISSION OF THE PUBLISHERS.
© 2008 BY THE TARGET GROUP • www.foodsafetymagazine.com

materials in which materials are used to minimize or maximize transmission of light, oxygen, carbon dioxide, moisture, fog, etc. Some of these materials may even allow the incorporation of antimicrobial compounds. Microperforation is a technology that can be used with high-respiring, fresh-cut produce where high gas transmission rates are needed. Innovations in film resin formulation, extrusion methods and post-extrusion modifications, such as lamination and perforation, are constantly being developed.

- *Active packaging systems* that involve an interaction between the packaging used and the food may include a visible or invisible packaging additive. The intent is to extend the shelf life and quality of foods while simultaneously insuring product safety. Methods may enable, for example, oxygen scavenging, carbon dioxide production, moisture/relative humidity control, ethylene control, ethanol release, odor removal or venting and steam release microwaveable packaging.
- *Intelligent packaging systems* utilize a sensor to provide information about the product to the consumer, foodservice operator or other user. The most widely known intelligent packaging system is the time temperature indicator, which uses a visual indicator to correlate with the acceptable quality, or lack thereof, of perishable foods. These indicators use physical, enzymatic or chemical reactions that correlate to the time-temperature degradation of the product. Other indicators that have been commercialized or are in the research phase include ripening, spoilage and pathogen indicators. In the future, radio frequency identification (RFID) technology may enable the incorporation of such quality measures.

Distribution and Temperature Control

Temperature control is the most important, and perhaps the most obvious, intervention for assuring product safety and maximizing shelf life potential in refrigerated value-added prepared foods. The effects of temperature are, however, frequently misunderstood and overlooked. The temperatures encountered at each link of the food distribution chain have a direct bearing on the shelf life, quality and potential safety of all perishable food products.

Distribution, including all operations that occur from the manufacturing plant to the retail/foodservice operator and ultimately to the consumer's home refrigerator, has frequently been regarded as the "Achilles heel" in cold chain management. The distribution system has, in fact, been attributed by many to be a major limiting impediment to the potential growth of the entire refrigerated foods category. Despite the standards and information provided by federal, state and county agencies, training efforts have been deficient, and various surveys have shown that temperatures of foods in U.S. chilled food distribution channels are frequently in the range of 40–55 °F, which is simply unacceptable. Stringent temperature controls need to be implemented at each link of the chain (Table 4).

As the cold chain is "only as strong as its weakest link," one can easily recognize the potential for temperature abuse to occur during the distribution process, and see how a single event in this chain can be a contributing factor for a foodborne illness.

The design and functionality of the retail case itself has a major impact on product shelf life. Studies have shown that the refrigerated cabinets in the produce section of the store, for example, maintain some of the warmest temperatures of any refrigerated cases in the entire supermarket–even though products sold there are among the most susceptible to spoilage and foodborne disease outbreak. Built into most systems are defrost cycles, lights, ballast, etc. that impair their effectiveness, and air curtains that are easily disturbed during normal operation. Proper circulation of cooling air is essential if temperature control is to be maintained

"Superchilling," also called "sub-zero degree chill," "deep chilling" and "supercooling," is generally agreed to be the temperature from about 28–34 °F (-2 °C to +1 °C), which is just above the freezing point of the product or raw material. As products freeze at different temperatures, the suggested storage temperature of 29–33 °F (or 31 °F ± 2 °F), will be acceptable for most perishable products. The USDA has specifically defined the freezing temperature of poultry, for example, at the slightly colder temperature of 26 °F (-3.3 °C). Below 26 °F, the USDA indicates that raw poultry products become firm to the touch because much of the free water is changing to ice. At 26 °F, however, the product surface is still pliable and yields to the thumb when pressed. The USDA has determined that most consumers will consider a product to be fresh, as opposed to frozen, when it is pliable and is not hard to the touch.

It has been scientifically determined that at these deep chill temperatures most microbiological activities are minimal. When temperatures are continuously maintained in this range, shelf life can be extended by at least 50% compared with storage at conventional refrigeration temperatures of 39–50 °F (4–10 °C). Superchill temperatures result in greatly slowed chemical and biochemical processes and, therefore, provides for improved prod-

- At the farm, where applicable, and in transit to further-processing or packing operations
- At receipt of all perishable raw materials that arrive to the processing operation
- In storage at the processing operation and in any further processing or work-in-process operations
- Immediately following packaging
- In manufacturing plant holding coolers
- On loading docks and trucks
- In coolers at distribution centers and depots
- In retail/foodservice holding coolers
- In store merchandisers and display cases
- Between store and home
- In home refrigerators

Table 4: Points along the Food Distribution Chain where Temperature Controls are Needed

REPRINTED FROM FOOD SAFETY MAGAZINE, AUGUST/SEPTEMBER 2008, WITH PERMISSION OF THE PUBLISHERS.
© 2008 BY THE TARGET GROUP • www.foodsafetymagazine.com

uct quality in almost all cases.

The inhibition of growth of a majority of pathogenic and food spoilage microorganisms is an extremely important advantage with superchilling. The effect of low temperatures on different microorganisms is well documented in the literature. In the interval between 2 °C and just above the freezing point of a food, practically all pathogenic bacteria have lost their ability to form toxins, and the growth rates are significantly reduced, but in some cases not completely stopped. *Listeria monocytogenes*, for example, has been shown to still grow at these superchill temperatures. However, even its growth rate is reduced when compared to more typical storage conditions.

"…industry application of analytical methods like real-time PCR will enable a greater degree of assurance in the safety of our food supply."

Temperature recording devices are valuable tools, and should certainly be incorporated into each stage of the cold chain as part of an overall HACCP plan. Many such indicators exist. New systems are now available that utilize wireless sensors and sophisticated web-based tracking capabilities, providing a quicker ability for monitoring and alerting should a problem occur.

It is strongly recommended that a national awareness program be developed to encourage perishable food manufacturers, distributors, retailers, foodservice operators, consumers and all those involved in the cold chain to keep refrigerated foods at a set point of 29–33 °F (or 31 °F ± 2 °F) as "colder is better," versus the current expressed standards of 40 °F or less.

New Analytical Technologies on the Horizon

While retail food chains and food processors have long mandated spot-testing for pesticide residues, on-farm determination of microbial contamination has not been done. Lack of on-farm pathogen testing has been primarily due to the absence of accurate, practical and cost-effective methods to accomplish this daunting task, as well as the difficulty of sampling for a contaminant likely to be present at a very low incidence, if at all. Microbial contaminants have presented a significant challenge to the food system due to difficulty in detection and especially quantification. Crude techniques such as dilution and plate count methods have been used extensively, but many pathogens are difficult to culture, and the specificity is clearly inadequate.

Since the groundbreaking discovery of the polymerase chain reaction (PCR) 25 years ago, new technologies are now available that have changed testing paradigms. PCR was initially adopted by geneticists and breeders for the rapid identification of molecular polymorphisms known as random amplified polymorphic DNAs. The technology allowed for the targeting and detection of an unlimited number of copies of all potential regions of genomes of all organisms, and completely revolutionized the science of genetics. Until recently, however, these PCR methods were relatively expensive, slow, non-specific and mostly qualitative.

Refinements and adjuvants to PCR are now in the marketplace. These enhancements have taken giant steps towards abating the limitations cited above. The most widely embraced is real-time PCR wherein nucleotide base sequence homology is used to find and amplify specific DNA (or RNA) in a heterogeneous mixture, which can then be identified using a colorimetric assay. Since all organisms are genetically unique, underlying unique DNA sequences will exist in their genomes that may be used for species identification.

These molecular detection methods are now being used for on-farm testing of raw products in hold-and-release programs. The practical limitations of such programs, however, have to do with the difficulty of finding, through sampling, a contaminant that may be present at a very low incidence on a farm. Unless the farmer is prepared to collect hundreds or thousands of samples from a farm, product testing will only be able to detect very high levels of contamination. The testing schemes currently employed in the produce industry are typically designed to detect contamination at rates of 5% or greater.

Real-time PCR outputs can be integrated and correlated with known DNA concentrations to yield reliable quantitative data. For food safety applications, this degree of specificity allows for the identification of diagnostic genomic DNA sequences that are absolutely limited to an individual microbial species, thus eliminating the possibility of misidentification.

Most importantly, the elapsed time from sample preparation to results with real-time PCR has been dramatically shortened. It is possible to obtain the result and conclusion *in hours*, thus making it possible to implement a "hold-and-release" procedure for individual lots of short shelf life, perishable food products. It is speculated that the independent testing industry will embrace this technology and offer it as a service that can be used by organizations with lower product volume.

A significant issue still needing resolution is sampling protocol. For example, how would a 25-pound box of tomatoes be tested for the presence of *Salmonella* species? Alternatively, how would one effectively test an entire 100-acre field (or a 50,000-acre growing district) of tomatoes ready for harvest? Only 100 grams of tissue or a liter of wash water is actually needed for the test, but a procedure must be agreed upon that effectively estimates the amount and distribution of potential pathogens. Once this sampling proto-

REPRINTED FROM FOOD SAFETY MAGAZINE, AUGUST/SEPTEMBER 2008, WITH PERMISSION OF THE PUBLISHERS.
© 2008 BY THE TARGET GROUP • www.foodsafetymagazine.com

col has been established and agreed to by industry, government and academia, and a hold-and-release process has been implemented for short shelf life perishable products, it is realistic to believe that less foodborne outbreaks will occur in the U.S., and our nation's food supply will become safer. In the meantime, real-time PCR has already been embraced by the Association of Official Analytical Chemists (AOAC) and the FSIS, the latter having implemented the technology within their own infrastructure as the standard for food safety testing. What remains to be done is for the food industry to develop and implement rational sampling procedures and thresholds for public and economic welfare. The main technical hurdle, the ability to identify and measure pathogens in a timely and cost-effective manner, has been cleared.

Integration and Analysis of Hurdle Technologies to Create an Effective Safety Program for Perishable Foods

It is critical to understand the technologies and best practices associated with value-added processing, literally from "farm to fork", as these individually and collectively impact both product safety and product quality–and ultimately impact market potential. Technologies are continually being improved upon and new ones are being introduced, that will enable even greater alternatives in developing prepared products that meet consumer needs for safety, as well as quality, convenience and overall value. These hurdle technologies described in this article are "tools in the toolbox" that can and should be utilized by processors of refrigerated foods processors, and utilized from farm to fork. Adequate food safety of refrigerated foods can only be achieved with a high degree of assurance by formulating, adapting and using a HACCP approach. In addition, refrigerated food processors are strongly encouraged to implement and routinely test a crisis management program and traceback procedure in light of these potential food safety issues. Furthermore, industry application of analytical methods like real-time PCR will enable a greater degree of assurance in the safety of our food supply. ■

H. Louis Cooperhouse *is Director of the Rutgers Food Innovation Center, a unique and award-winning food business incubation program that offers speed-to-market new business and new technology development in a fully-equipped and professionally-staffed USDA/FDA inspected facility. He can be reached at Cooperhouse@njaes.rutgers.edu.*

Tom Orton, Ph.D.*, is Extension Specialist in Plant Biology and Pathology at Rutgers Cooperative Extension and affiliated with the Rutgers Food Innovation Center. He can be reached at Orton@njaes.rutgers.edu.*

The Food Innovation Center is an outreach program of the Rutgers New Jersey Agricultural Experiment Station, and more information can be found at www.foodinnovation.rutgers.edu.

The authors wish to thank Devon Zagory, Ph.D., Senior Vice President for Food Safety & Quality Programs at NSF Davis Fresh; Donald Schaffner, Ph.D., Extension Specialist in Food Science, Director of the Center of Advanced Food Technology, and Professor at Rutgers University; and Wesley Kline, Cumberland County Agricultural Agent at Rutgers Cooperative Extension, for their review and contributions to this article. The photographs located within this article were taken by Jack Rabin, Director of Farm Programs and Associate Director of the Rutgers New Jersey Agricultural Experiment Station.

REPRINTED FROM FOOD SAFETY MAGAZINE, AUGUST/SEPTEMBER 2008, WITH PERMISSION OF THE PUBLISHERS.
© 2008 BY THE TARGET GROUP • www.foodsafetymagazine.com