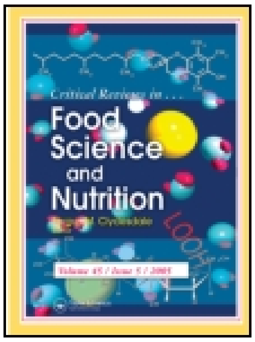

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Shiv Singh & Rachana Shalini

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Effect of Hurdle Technology in Food Preservation: A Review

SHIV SINGH[1] and RACHANA SHALINI[2,3]

[1]Department of Chemical Engineering, Indian Institute of Technology, Kanpur, India
[2]National Productivity Council, Utpadakta Bhawan, New Delhi, India
[3]Department of Agriculture Process & Food Engineering, Allahabad Agricultural Institute, Deemed University, Allahabad, India

Hurdle technology is used in industrialized as well as in developing countries for the gentle but effective preservation of foods. Hurdle technology was developed several years ago as a new concept for the production of safe, stable, nutritious, tasty, and economical foods. Previously hurdle technology, i.e., a combination of preservation methods, was used empirically without much knowledge of the governing principles. The intelligent application of hurdle technology has become more prevalent now, because the principles of major preservative factors for foods (e.g., temperature, pH, a_w, *Eh, competitive flora), and their interactions, became better known. Recently, the influence of food preservation methods on the physiology and behavior of microorganisms in foods, i.e. their homeostasis, metabolic exhaustion, stress reactions, are taken into account, and the novel concept of multi-target food preservation emerged. The present contribution reviews the concept of the potential hurdles for foods, the hurdle effect, and the hurdle technology for the prospects of the future goal of a multi-target preservation of foods.*

Keywords Hurdle technology, food preservation, homeostasis, metabolic exhaustion, stress reactions

Food products can be inhibited by various means : these include reduction in water activity (a_w), low temperature, reduction of pH, addition of competitive microorganisms and addition of preservatives. Combinations of these various means can be used. The use of combinations is called "hurdle effect" (Leistner, 1994). Intelligent use of hurdles in food product design insures that products have an adequate shelf life and remain safe (Leistner, 1994a).

Hurdle Technology is a technology by which a preservation parameter can be used at an optimum level in order to get a maximum lethality against micro-organisms by a combination of two or more such parameters so that the damage to the sensory parameters of the food is kept to the minimum.

All the parameters like water activity, pH, redox potential, heat treatment (F) etc., which are bactericidal or bateriostatic are "hurdles" (Leistner, 2000). Hurdle technology involves the application of blanching, blanching with liquid, removing oxygen, placing in barrier packaging, hermetic sealing, heating, and cooling—a combination of multiple technologies which together provide for a safe quality level throughout the distribution channel (Singh, 2004).

The preservation of almost all foods is based on combined application of several preservative methods (e.g., heating, chilling, drying, curing, conserving, acidification, oxygen-removal, fermenting, adding preservatives, etc.). These methods and their underlying principles (i.e., F, t, a_w, pH, E_h, competitive flora, preservatives, etc.) have been applied since centuries empirically, but are recently applied intelligently using the concept of hurdle technology. For the future multi-target preservation of foods is anticipated. The number of already applied and potential hurdles for the preservation of foods amounts to over 100, and thus food developers have numerous choices. At present, pulsed technologies and "natural" preservatives attract much interest. However, they are most effective in combination with traditional preservation methods (i.e. hurdles). Thus, hurdle technology will also be the key for future food preservation. A user guide for the design of hurdle-technology foods proved useful for development tasks in food industry. It combines hurdle technology with predictive microbiology (preferably boundary models) and HACCP (or quantitative GMP-guidelines if safety and quality should be covered). For industrialized countries applications of hurdle technology are topical for (i) minimally processed, convenient foods, (ii) chilled foods with "invisible

Address correspondence to Rachana Shalini, National Productivity Council, Utpadakta Bhawan, 5-6 Institutional Area, New Delhi, India, and certified Lead Auditor for Food Safety Management Systems ISO 22000:2005; and Department of Agriculture Process & Food Engineering, Allahabad Agricultural Institute, Deemed University, Allahabad, India. E-mail: rachana.shalini@npcindia.gov.in; rshalini2003@rediffmail.com

technology", (iii) healthful foods with less salt and/or fat, (iv) less packaged foods, and (v) research about lines of defense related to food poisoning. In developing countries, applications of intelligent hurdle technology proved useful for novel foods which in spite of minimally processing are ambient stable, as well as in modifications of traditional intermediate-moisture foods to make them ambient stable high-moisture foods. Much progress in these respects has been made in Latin America and India, however, interest in the application of advanced hurdle technology is also vivid in China, Taiwan, and even Africa.

Previously, hurdle technology, that is a combination of preservation methods, was used empirically without much knowledge of governing principles. Ever since, the intelligent application of hurdle technology became more prevalent, the principles of major preservation factors for food like temperature, pH, and water activity (a_w), competitive micro flora and their interactions became known. Here, the influence of food preservation methods on the physiology and behavior of microorganisms in foods, that is their homeostasis, metabolic exhaustion, stress reactions are taken into account, and the novel concept of multi-target food preservation was developed.

The disturbance of homeostasis of micro-organism is the key phenomenon of food preservation. Microbial stress reactions may complicate food preservation, whereas the metabolic exhaustion of micro organism present in stable hurdle technology foods could foster food preservation.

Hurdle technology is neither new nor daunting; they represent the application of well known technologies in reduced "doses" to interact synergistically to control safety, sensory quality, retention, and nutritional values. They include among others, pH control, water activity reduction, pasteurization, mild heat whose objectives might include enzyme destruction and reduction of microbial load, incorporation of natural antimicrobials, ultra clean/aseptic type handling and filling, rapid reduction of product temperature, maintenance of temperature throughout distribution, reduction of oxygen in and around the product, elevation of carbon di-oxide in and around the product, gas barrier packaging to maintain at deterioration rate and active packaging such as oxygen scavenger in the package material.

APPLICATION OF HURDLE TECHNOLOGY

Hurdle technology concepts have been adopted by various research investigators for the processing of various food products.

Conventional fruit preservation methods are usually based on a single preservation factor, applied at such a high level that causes noticeable sensory changes on the fruit. The hurdle technology, or combined methods technology (CMT), on the other hand, is based on combining low levels of two or more preservation factors (hurdles). No single factor is responsible for making the product stable, but rather the stability results from the synergism among the combined factors. The hurdle technology produces minimal sensory changes, which makes the products more acceptable than those obtained by conventional methods (Aguilera and Chirife, 1994).

Since the water activity is only slightly reduced, the products obtained by hurdle technology are known as high moisture products. In the context of hurdle technology, the method generally used to reduce water activity of fruits is the osmotic dehydration, which consists in dipping the fruit in a hyper concentrated solution. The resulting of osmotic pressure promotes water loss, reducing water activity of the fruit and favoring its stability (Azeredo, H. M. C. de et al., 2005)

Fruit preservation by hurdle technology is based on combinations of low levels of various antimicrobial factors (hurdles) acting synergistically resulting in a shelf stable high moisture, fresh-like product. The objective of this work was to evaluate the stability of mango cubes obtained by combining the following hurdles: water activity reduction, pH reduction, and chemical preservation. *Tommy Atkins* mangoes, previously washed, sanitized and peeled, were cut into cubes of approximately 8 cm^3. The cubes were osmotically dehydrated under stirring (150 rpm) at 46°C in a sucrose solution at 65.5oBrix added with 2% citric acid and 0.2% potassium sorbate, during two hours. The product was drained, packed in low-density polyethylene bags, and stored at room temperature (about 25°C) during three months. The combination of hurdles on the final product (water activity, 0.96; pH, 3.99; potassium sorbate content, 396 mg/kg) was not effective to make it shelf stable, since the count of yeasts and molds increased. The cubes underwent pH reduction and color losses during storage. Furthermore, the acceptance of the product, as well as, the mango flavor intensity, decrease significantly with storage time (Azeredo, H. M. C. de et al. 2005).

Sankhla et al. (2012) conducted studies to preserve Sugarcane juice by following treatments viz. pasteurization at 80°C for 10 minutes + chemical treatments (KMS @ 150 ppm and citric acid @ 0.05%); pasteurization at 80°C for 10 minutes + chemical treatments (KMS @ 150 ppm and citric acid @ 0.05%) + sterilization at 80°C for 20 minutes. All the samples were packed in glass bottles, polyethylene Tetrapthelate (PET) bottles, and low-density polyethylene pouches (LDPE) and then irradiated at 0.25, 0.5, and 1.0 kGy and stored for 90 days at room and low temperature. Nonirradiated samples were taken as control. On treatment moisture content, ascorbic acid, viable bacterial count, and viable yeast and mold count were decreased significantly ($p > 0.05$) whereas no significant effect was observed on reducing and total sugars in cane juice. Among the three packaging material used glass and PET was found to be at par in increasing the shelf life of sugarcane juice in comparison to LDPE pouches. On storage, ascorbic acid and total sugars were decreased significantly ($p > 0.05$). Moisture content, viable bacterial count, and viable yeast mold count were increased on storage. Irradiation and packaging material statistically showed no significant differences on organoleptic properties of juice but storage showed changes in sensory scores. Among all the treatments pasteurization at 80°C for 10 minutes + chemical treatments (KMS @ 150 ppm and citric acid @ 0.05%) + sterilization at 80°C for 20 minutes was found to be best in maintain the shelf life of juice up to 60 days at room temperature and 90 days at low temperature with 1.0 kGy irradiation doses. Among glass bottles, PET bottles and LDPE pouches, glass and PET were found to be best in maintaining the quality of juice.

Mucchetti et al. (2008) studied effect of washing with a high pressure water spray on removal of *Listeria innocua* from Gorgonzola cheese rind. Contamination of Gorgonzola cheese surface by *Listeria* is a difficult problem to solve by only applying good manufacturing practices. Treating of the cheese rind at the end of ripening may be a tool to improve cheese safety. The aim of this study was to evaluate the effect of a high pressure water spray washing technology in reducing *Listeria* load from Gorgonzola cheese rind without using oxidizing agents. The surface of Gorgonzola cheese was contaminated (up to 10^7 cfu/g of scraped rind) with a mixture of four strains of *Listeria innocua*. The count of *Listeria* was made by scraping (2 mm depth) the rind of the cheese. The contaminated cheeses were then washed at different pressures, ranging from 1 to 5 MPa for one minute. The lower the pressure, the lower was the removal of *Listeria*. A reduction of up to 99.89% was achieved washing the cheese at 5 MPa, followed by rinsing at 1 MPa for one minute. Changing the inoculum size (10^2, 10^4, and 10^7 cfu/g), did not change the efficacy of *Listeria* removal, when the same water pressure was applied. The washing of Gorgonzola cheese with pressurized jet water, without adding any preservative to the water, can be considered a further important physical hurdle, in controlling pathogenic bacteria and improving cheese safety.

Roedel and Scheuer (2007) investigated a model system to assess hurdle technology in relation to growth of microorganisms in meat products. Effects of various combinations of temperature (17–27°C in 1°C steps), a_w (0.990, 0.985, and 0.980) and $NaNO_2$ (0, 200, or 400 mg/L) were investigated on growth of *Escherichia coli*, at an initial inoculum level of 1×10^3 or 1×10^6 cfu/mL. Results show that effects of these three hurdle factors occur via highly complex interactions. Patterns of microbial growth varied widely. In no case was the hypothesis of a simple additive effect between different hurdle factors correct. The need to consider quantitative aspects of the hurdle technology concept is stressed. These results are considered in relation to predictive microbiology.

Studies were carried by Ilondu and Iloh (2007) out on the inhibition of 3 fungi isolated from a sorrel drink (zobo) using aqueous extracts of *Zingiber officinale* (ginger) and *Piper guineense* (West African black pepper) and heat as hurdles. The isolated fungi were *Aspergillus flavus*, *A. niger*, and an unidentified yeast. The spice extracts reduced fungal growth. As the spice concentration was increased, there was a decrease in fungal biomass in the beverage when compared with the control. A combination of both spice extracts at different ratios also reduced fungal growth. When the fungi were challenged at 100°C for different periods of times (minutes), growth reduction also occurred. The further combination of heat treatment with the combined spice treatment inhibited growth markedly.

Jafari and Emam-Djomeh (2007). Carried out the present study with the objective to reduce nitrite content in hot dogs using hurdle technology without sacrificing product safety and quality. In the present study, the water activity of the hot dog was adjusted to 0.95 by the addition of humectants. Although the pH at the hot dog was adjusted with Glocono-delta-lacton to 5.4, the product had ($p > 0.05$) the least acceptance on account of the organoleptic changes (sour taste). Moreover, the temperature of 80 ± 1°C for an hour with the aim of achieving an internal temperature of 75°C was applied. Subsequently, the temperature of the hot dog samples reduced to around 5–6°C within 40–45 minutes, and afterwards the sausages were kept at chilled temperature (>3°C but ≤10°C) throughout their shelf life. There was a decrease in total aerobic counts in hurdle treated hot dogs (with 50 ppm nitrite), compared to the control (with 120 ppm nitrite), whereas *Clostridium perfringens* counts and *Clostridium botulinum* detection were the same ($p < 0.05$) in both hurdle treated and control samples. The obtained results of present study clearly showed that both hurdle treated sample and control had the same ($p < 0.05$) overall acceptability and sensory attributes.

Yigit and Korikluoglu (2007) investigated the efficacy of hurdle technology in preventing growth of common spoilage fungi (*Alternaria alternata*, *Aspergillus niger*, *Fusarium semitectum*, and *Penicillium roqueforti*) in naturally fermented black olives. The factors studied included a combination of different concn. of potassium sorbate (100–1000 mg/L), a range of pH values (4.5, 5, 5.5, 6, and 6.5) and different NaCl concn. (0, 3.5, 5, 7.5, and 10%). Results showed that *A. alternata* was the most sensitive fungus and *P. roqueforti* the most resistant to all hurdle factors. A combination of all three hurdles completely inhibited *A. alternata* and *F. semitectum* at the lowest inhibitory levels (100 mg/L potassium sorbate, 3.5% NaCl, pH 5). *A. niger* and *P. roqueforti* were completely inhibited at pH 5 by a combination of 300 mg/L potassium sorbate with 10% NaCl and 400 mg/L potassium sorbate with 7.5% NaCl, respectively. Potassium sorbate with 5–10% NaCl had a significant stimulatory effect on *P. roqueforti* and *A. niger* ($p < 0.05$). Results indicated that potassium sorbate and NaCl are suitable preservatives for the inhibition of fungi in fermented olives.

Cepero et al. (2006) investigated the effectiveness of the hurdle effect to increase the shelf life of fresh sausages. Two formulations were stored between 4 and 8°C at 93 ± 5% of RH under two different conditions (hung in bars and vacuum packaged). Variants were studied for their physicochemical and sensory properties and microbiological quality; they were analyzed weekly by an acceptance-refusal test, pH measures, and microbiological technique. Sensory analysis was considered as a refusal approach. Results indicated that it was possible to increase the shelf-life of the Cuban fresh sausage from 4 to 32 days using the following hurdle technology: vacuum packaging to decrease the oxidation-reduction potential, potassium sorbate as a preservative and low temp. (between 4 and 8°C) during storage.

Chawla et al. (2006) prepared Safe and shelf-stable natural casing using a combination of hurdles viz. reduced water activity, packaging, and gamma irradiation. Washed lamb intestines were treated with common salt to reduce water activity to 0.80 ± 0.02, packed in polyethylene bags, and subjected to gamma-irradiation (5 and 10 kGy). Control nonirradiated samples had high total viable counts (10^6 CFU/g), aerobic spores (10^3 CFU/g), spores of sulphite reducing clostridia (10^3 CFU/g), potentially pathogenic bacteria such as staphylococci (10^4 CFU/g), and coliforms (10^2 CFU/g). Treatment with gamma radiation resulted in a dose-dependent reduction in counts of these microbes. A dose of 5 kGy was sufficient to reduce total viable counts by three log cycles; spore counts by two log cycles and completely eliminate staphylococci and coliforms. Samples subjected to a 10 kGy dose were devoid of any viable microbes. The reduced water activity of the product prevented growth of the microbes in natural casings during storage at room temperature. Sausages prepared using hurdle processed natural casing were examined for sensory and textural properties. It was observed that product acceptability and mechanical strength was not affected by radiation processing. Studies indicated that shelf-stable and safe natural casing could be prepared using a combination of hurdles.

Kanatt et al. (2006) developed a process for the preparation of shelf-stable, ready-to-eat (RTE) shrimps using a combination of hurdles. The hurdles employed to cooked marinated shrimps included reduced water activity (0.85 ± 0.02), packaging and γ-irradiation (2.5 kGy). Microbiological analysis revealed a dose-dependent reduction in total viable count and *Staphylococcus* species. In nonirradiated samples a visible mold growth was seen within 15 days of storage at ambient temperature (25 ± 3°C). No significant changes in textural properties and sensory qualities of the product were observed on radiation treatment. These RTE shrimps were microbiologically safe and sensorially acceptable even after two months of storage at ambient temperature.

Nakimbugwe et al. (2006) studied the effect of hen egg white lysozyme (HEWL) and bacteriophage lambda lysozyme (LaL) in combination with high pressure (HP) treatment on the inactivation of four gram-negative bacteria (*Escherichia coli* O157:H7, *Shigella flexneri*, *Yersinia enterocolitica* and *Salmonella* Typhimurium), in skim milk (pH 6.8; a_w 0.997) and in banana juice (pH 3.8; a_w 0.971). In the absence of lysozymes, *S. flexneri* was more sensitive to HP in milk than in banana juice, while the opposite was observed for the other three bacteria. In combination with HP treatment, LaL was more effective than HEWL on all bacteria in both milk and banana juice. Depending on the bacteria, inactivation levels in banana juice were increased from 0.4–2.7 log units by HP treatment alone to 3.6–6.5 log units in the presence of 224 U/mL LaL. Bacterial inactivation in milk was also enhanced by LaL but only by 0.5–2.1 log units. Under the experimental conditions used, LaL was more effective in banana juice than in milk, while the effectiveness of HEWL under the same conditions was not significantly affected by the food matrix. This effect could be ascribed to the low pH of the banana juice since LaL was also more effective on *E. coli* in buffer at pH 3.8 than at pH 6.8. Since neither LaL nor HEWL are enzymatically active at pH 3.8, we analyzed bacterial lysis after HP treatment in the presence of these enzymes, and found that inactivation proceeds through a nonlytic mechanism at pH 3.8 and a lytic mechanism at pH 6.8. Based on these results, LaL may offer interesting perspectives for use as an extra hurdle in high pressure food preservation.

Podolak et al. (2006) evaluated hydrodynamic pressure processing (HDP), a novel nonthermal technology that uses a small amount of explosive (100 g) to generate a supersonic-hydrodynamic shock wave in a water-filled steel container (54 L) for inactivation of *Escherichia coli* O157:H7 (EHEC) in ground beef. The ground beef was inoculated with a six strain cocktail of *E. coli* O157:H7 at three different concentrations (10^3, $l0^4$, and $l0^6$ cfu/g). The following strains of *E. coli* O157:H7 were used in the cocktail: 3027-93, 3055-93, C7927, 43888, C9490, and green fluorescent protein-expressing *E. coli* O157:H7 B6-914 (GFP EC). Inoculated ground beef was wrapped in polyethylene wrap, vacuum packaged into multi-layer barrier bags, heat shrunk and treated with HDP. The initial concentrations of EHEC were 1.29×10^3, 2.88×10^4, and $2.19 \times l0^6$ cfu/g. After HDP treatment, the EHEC populations were reduced ($p < 0.05$) to 9.12×10^2, 2.40×10^4, and $1.91 \times l0^6$ cfu/g, respectively. A similar trend was observed for GFP EC which was also enumerated from the cocktail. The GFP EC initial populations of $4.26 \times l0^2$ and $3.72 \times l0^3$ cfu/g were reduced to 3.47×10^2, and $3.09 \times l0^3$ cfu/g, respectively. Although the reduction in EHEC populations due to HDP treatment was statistically significant, the practicability of the reduction was marginal. Therefore, other hurdle parameters should be included along with the HDP treatment for more practical inactivation of EHEC in ground beef. Hydrodynamic pressure processing has been applied for many unique applications including braking of ice sheets. The authors have originally developed the method of utilizing shock waves caused by explosives for tenderization of meat and are now attempting to extend the process towards microbial inactivation. The data suggest that the treatment applied only slightly reduced the population of *E. coli* 0157:H7 tested and suggested to modify the process including the use of extended shock waves as well as the combination with antimicrobial agents.

Selma et al. (2006) investigated the efficacy of pulsed electric fields for *Listeria monocytogenes* inactivation and control in horchata. Although *Listeria monocytogenes* is readily destroyed by thermal treatment, the factor that makes it particularly difficult to control in nonpasteurized foods is its ability to grow at refrigeration temp. In heat-sensitive products, nonthermal technologies such as pulsed electric fields (PEF) as part of hurdle technology could minimize the presence of foodborne pathogens. The influence of PEF-treatment conditions, inoculum size, and substrate conditions on the inactivation and recovery of *L. monocytogenes* in a traditional low-acid, vegetable beverage (horchata) was investigated. The combined effect of PEF, low temp. (5°C) and low inoculum level contributed to slow down the recovery of sub-lethally injured cells. However, at 12 or 16°C, this elongation of the lag phases after PEF treatment observed for low inoculum levels of cells was not achieved. Therefore, to prevent the development of *L. monocytogenes* in low-acid products using PEF, it may be necessary to combine it with low refrigeration temp. during distribution and storage, as well as to achieve a very low initial contamination by pathogens in the raw ingredients.

Vibhakara et al. (2006) conducted studies on grated carrots for the development of a shelf-stable moist—preservation process based on infusion of additives using hurdle technology. Additives comprising 3.0% sodium chloride (to reduce water activity, a_w to 0.94), 0.9% citric acid (to reduce pH to below 4.5), 1.0% sodium citrate, and 0.2% sodium benzoate (as a antimicrobial agent) were followed by partial dehydration. The product was stored in flexible polymeric pouches. The physical, chemical, and pathological stability was monitored during storage at ambient temperatures (19–33°C). The partially dehydrated grated carrots (moisture 66.2%) were acceptable for more than six months at ambient temperature with the retention of the carotenoid up to 82.5%. the product was found to be microbiologically safe throughout the study.

Yano et al. (2006) examined the antimicrobial effects of spices and herbs from 18 plant species on a foodborne pathogen, *Vibrio parahaemolyticus*, with the use of combinations of temperatures and nutrient levels. Basil, clove, garlic, horseradish, marjoram, oregano, rosemary, and thyme exhibited antibacterial activities at incubation of 30°C, while with the exception of horseradish, the same spices and additional seven species exhibited the activities at 5°C. The lowest MIC (minimum inhibitory concentration) was 0.125% observed in clove and marjoram at 30°C in a nutrient rich medium. Lowering of incubation temperature produced little effect on the MICs except for turmeric. The decreasing of the MIC in turmeric appeared to be basically attributed to the sensitivity of the bacterium to coldness. In nutrient poor medium, the lowest was 0.001 and 0.00025% in marjoram at 30°C and at 5°C, respectively. The sensitivity to several spices and herbs was similar among different clinical serotypes including the emerging strain O3:K6. These results suggest that the spices and herbs can be practical for protecting seafood from the risk of contamination by *V. parahaemolyticus* and used in hurdle technology with low temperature.

Barwal et al. (2005) preserved Cauliflowers (var. Botrytis) using a low-cost and low-energy process (hurdle technology) involving different concentrations and combinations of salt (5, 10, and 15%), potassium metabisulfite (KMS; 0.2%) and citric acid (1.0%) after blanching. Physicochemical and sensory properties and microbiological qualities were recorded on the preparation day and subsequently after 15, 45, 90, and 180 days of storage. Preserved cauliflower after 90 and 180 days of storage was reconstituted in running water for half an hour and evaluated for the preparation of pickle and pakora. Cauliflower samples steeped in 10 and 15% salt solution containing 0.2% KMS were rated highest throughout the entire period of storage. Cost of production of steeped cauliflower in 10 and 15% salt solution (along with KMS 0.2% and citric acid 1.0%) was INR 4.03 and 4.15 per jar, respectively. Sensory profiles of steeped cauliflower after reconstitution and also on preparations of pickle and pakora, were ranked above acceptable by a panel of judges for various quality attributes.

Guynot et al. (2005) investigated use of hurdle technology to control fungal spoilage of intermediate-moisture bakery products. Effects of various concn. (0–0.3%) of weak acid preservatives (sodium benzoate, potassium sorbate and calcium propionate), pH (4.5–5.5), and a_w (0.80–0.90) were investigated on growth of three common spoilage fungi (*Penicillium corylophilum*, *Eurotium* spp. and *Aspergillus* spp.) on a fermented bakery product analogue. The most effective preservative at 0.3% and all a_w levels was potassium sorbate, whereas the same concn. of the other two preservatives was only effective at low a_w values. However, the antifungal activity of potassium sorbate was slightly lower at pH 5.5 than at other pH values; under these conditions a 0.3% concentration was only effective at an a_w of 0.80. Results suggested that potassium sorbate could be used to prevent xerophilic fungal spoilage of slightly acidic bakery products.

Jaesung and Kaletunc (2005) evaluated the effect of acid, ethanol, and NaCl on *E. coli* by the differential scanning calorimetry (DSC) method. Mild heating with antimicrobial agents is used to preserve the nutritional and textural properties of foods and extend their shelf life; an approach termed hurdle technology (bacteria chemically or physically treated before or during heat treatment have reduced thermal resistance). The design of optimum processing conditions for hurdle technology depends on understanding how chemicals cause irreversible changes to major cell components, resulting in cell death and injury. Influence of HCl, ethanol and NaCl on cellular components and inactivation of *E. coli* ATCC 14948 were evaluated using DSC; cell viability was assessed using plate counting. Thermal stability for ribosomal subunit denaturation and the total apparent enthalpy decreased with increasing ethanol, NaCl, and acid concn. A reduction of the ribosomal subunit denaturation peak was the primary contributor to the decrease in total apparent enthalpy. Thermograms indicated that even at concn. at which 1<0.4-log reduction of cell viability with a concomitant min. reduction of total apparent enthalpy occurred, a decrease in onset temp. of ribosomal transition was evident. Acid treatments at pH 3 induced by HCl and by 0.4 M acetic acid caused the DNA denaturation temp. in vivo to decrease. Application of chemical treatment prior to heat treatment noticeably reduced *E. coli* cell viability at all heat treatment temp. (60, 62.5, 65°C) compared to that of heat treatment alone, suggesting an increased sensitivity of bacteria to heat treatment. Results suggested that DSC in vivo can be used to assess the effectiveness of hurdles when thermal processing technologies with hurdles are designed.

Nasr et al. (2005) studied minimum inhibitory concentration and minimum bactericidal concentration of chemical and biological food preservatives in a resistant strain of *Bacillus cereus*, which was isolated from pizza cheese containing sodium citrate as a preservative. Results showed that *B. cereus* was resistant to permitted concentration of sodium benzoate, sorbic acid, sodium citrate, potassium sorbate, and acetic acid. Food preservatives are often used in mixtures, as a single preservative cannot preserve foods effectively. Combinations of preservatives used as hurdles which exerted synergistic effects against *B. cereus* included: citric and benzoic acids (0.187 and 0.006%); sorbic and propionic acids (0.0018 and 0.156%); propionic acid and potassium sorbate (0.019 and 0.019%); sodium benzoate and propionic acid (0.026 and 0.019%); citric acid and potassium sorbate (0.375 and 0.625%); and nisin and propionic acid (125 IU/mL and 0.156%).

Vibhakara et al. (2005) investigated the ability of a combination preservation technique to stabilize spice-based high moisture (60–70%) knol–khol (kohlrabi) and cauliflower. The hurdle technique included 4% brine blanching with additives, treating with spices, packaging in polypropylene pouches, and irradiation. Several additives were used, including: 4% sodium chloride to keep a_w in the range 0.92–0.95; 0.5% citric acid to reduce pH $<$ 4.5; and potassium metabisulfite as an anti-browning agent. After packaging in polypropylene pouches products were subjected to 3, 5, and 8 kGy irradiation doses. Storage at ambient temp. (37°C) for up to four months indicated that the products were microbiologically stable while browning intensified at higher doses and the products became softer after four months. Before irradiation, commercial spices showed the presence of coliforms and *Aspergillus flavus* in the dried powder. Irradiation, in addition to acid and salt infusion treatments, reduced the microbial counts from an initial value of 10^4 to 10^1 cfu/g and *A. flavus* was absent. Irradiation at 5 kGy was useful as one of the preservative factors in stabilizing high moisture spice-based knol–khol and cauliflower products for four months at ambient temp.

Alexandre et al. (2004) investigated the preservation of the pulp of assai fruit (*Euterpe oleracea*; acai; a South American palm) through the application of hurdle technology. Preservation factors studied included: reduction of pH to approx. 3.5 by the addition of 0.5% w/w citric acid; thermal treatment (82.5°C for one minute); reduction of the a_w by the addition of sucrose (10, 25 and 40% w/w); and addition of potassium sorbate (0.075 and 0.15% w/w). A full factorial experimental design was used to generate product formulations that were then stored at 25°C in the absence of light for five months. Three formulations were discarded on the basis of sensory quality before three months of storage had elapsed. Pulp treated with 40% w/w sucrose, 40% w/w sucrose + 0.15% w/w potassium sorbate, and 25% w/w sucrose + 0.075% w/w potassium sorbate showed good overall acceptability with a shelf life of five months.

Gamlath et al. (2004) studied application of hurdle preservation techniques to extend the shelf life of minimally processed coconut gratings. Physicochemical and sensory changes in coconut gratings treated with different combinations of hurdles, including acidulants, humectants, preservatives, antioxidants, a mild heat treatment and packaging were evaluated. Results showed that it was possible to preserve the coconut gratings for four weeks in laminated polythene packages at 5°C in combination with 3% NaCl, 0.3% citric acid, 0.009% sodium citrate and 0.02% butylated hydroxyanisole.

Soliva-Fortuny et al. (2004) studied the effects of combined methods of preservation (e.g., control of storage temp., reduced pH or a_w, modified atmosphere and/or addition of preservatives) on microbiological quality of avocado puree during storage for four months at 4 or 22°C. Addition of sorbic acid had the most significant influence on microbiological stability during storage; 300 mg/kg sorbic acid was generally sufficient to control growth of yeasts and fungi that predominate the indigenous microflora of avocado. Purees could also be preserved for four months without the addition of the sorbic acid, by combining vacuum packaging and storage at 4°C. Reduction of a_w by addition of maltose gave a slightly more stable product. However, the amount of sugar required to achieve the required level of preservation was regarded as likely to have a negative impact on sensory properties.

Sun-Young Lee (2004) investigated the Microbial Safety of Pickled Fruits and Vegetables and Hurdle Technology. *E. coli* O157:H7 is a member of the enterohemorrhagic group of pathogenic *E. coli* that has emerged as a foodborne pathogen of major public health concern. *E. coli* O157:H7 is highly tolerant of acidic pH and outbreaks attributed to this bacterium have been in many acidic foods which have pH level with similar to those of pickled products. Therefore, pickled vegetables, although acidic, may not safe. In pickling vegetables, the combination of preservation factors (heat, acetic acid, and salt) will contribute to increase the microbial safety. Recently, the concept of combining preservative factors for food preservation was developed, called "hurdle technology." In hurdle technology, combination treatments are applied because it is expected that the use of combined preservative factors will have greater effectiveness at inactivating microorganisms than the use of any single factor. However, recent studies showed that the combination of preservation factors can have unexpected antimicrobial activity. Therefore, this article includes an overall review of the microbial safety of fruits and vegetables, preservative method including major preservative factors used in pickling technology, concept, and mechanism of hurdle technology and *E. coli* O157:H7.

Jimenez-Villarreal et al. (2003) investigated effects of multiple antimicrobial treatments (hurdle technology) on the color stability of ground beef trimmings during simulated retail display. Trimmings were exposed to the following sequential treatments: 0.5% cetylpyridinium chloride + 10% trisodium phosphate (CT); 200 ppm chlorine dioxide + 0.5% cetylpyridinium chloride (CLC); 200 ppm chlorine dioxide + 10% trisodium phosphate (CLT); or 2% lactic acid + 0.5% cetylpyridinium chloride (LC). Trimmings were then minced, packaged and subjected to simulated retail display for 0–7 days at 2°C. CT-treated beef had significantly higher values for redness (a*) than control samples after 3 days ($p < 0.05$). Lightness values (L*) were higher than control values in CLC- and LC-treated beef ($p < 0.05$) and the vividness of LC- and CT-beef was similar to that of controls. Results suggested that the antimicrobial treatments used in this study have little adverse effect on the color of beef mince during retail display.

Plaza et al. (2003) investigated effects of combined hurdle treatments of high hydrostatic pressure and natural additives (citric acid and NaCl) on quality of tomato purees. Parameters investigated included color and viscosity, enzyme activity (polyphenoloxidase, peroxidase, and pectin methylesterase), total protein content, total microbial counts and counts of yeasts and other fungi. Response surface methodology was carried out according to a central composite face-centered design. Variable ranges used were: 50–400 MPa (pressure), 0–0.8% w/w (NaCl), and 0–2% w/w (citric acid); temp. and holding time of high pressure treatments were constant at 25°C and 15 minutes, respectively. Results showed that enzymic inactivation was significantly improved with these combined treatments at high values for pressure and additive concn. A highly significant reduction of 4 logarithmic units was observed for total microbial counts when pressure was increased to 400 MPa. It was concluded that combined hurdles may be effective in the manufacture of minimally processed tomato products with optimal sensory and microbiological characteristics.

Ziwei et al. (2003) explored combinations of different hurdles such as moderately high temp. (<55°C), antimicrobial compounds, and pulsed electric fields (PEF) to reduce naturally-occurring microorganisms in freshly-squeezed, unclarified apple juice. The microbial count decreased with an increase in pulse number and treatment temp. at constant field strength. Apple juice with yeast was treated without PEF to find the optimal treatment conditions. At field strength of 90 kV/cm, 40 pulses and 52°C, there was a 2.63 log reduction in microbial counts due to PEF alone. However, there was no significant difference ($p > 0.05$) in the reduction in microbial counts when the temp. was increased from 44 to 52°C in the absence of PEF. When PEF treatment was combined with added nisin (100 U/mL apple juice) or a mixture of nisin and lysozyme (27.5 U nisin/mL and 690 U lysozyme/mL), there was no further additive reduction in microbial counts with temperature treatments at temperature up to 46°C. Vitamin C levels in apple juice samples were not reduced as a result of these treatments.

Kanatt et al. (2002) investigated the feasibility of preparing ready-to-serve shelf-stable and microbiologically intermediate-moisture (IM) spiced mutton and spiced chicken products using a combination of hurdles (reduced moisture, vacum packaging, and irradiation). The a_w of the products was reduced to approx. 0.80, either by grilling or by hot-air drying. These IM products were then vacuum packaged and subjected to radiation processing at 0–10 kGy. Microbiological analyses revealed a radiation dose-dependent reduction in total viable counts and in numbers of *Staphylococcus* sp. IM meat products that did not undergo radiation treatment showed visible fungal growth within two months. The products subjected to irradiation at 10 kGy showed an absence of viable microorganisms, and also retained high sensory acceptability for up to nine months at ambient temp.

Santos et al. (2002) studied the formulation and processing conditions for production of a sausage stable at room temperature using hurdle technology. Raw materials (pork, fat, soybean derivatives, wheat flour, starch, water, salts, seasonings) were used to obtain a fine paste with small meat pieces in artificial impermeable casing with a guaranteed a_w of 0.95. Sausages were heated to 75 or 80°C at the center of the product and then stored at room temp. for up to three months. Fresh and stored sausages were analyzed for physicochemical and sensory properties and microbiological quality. Thermal treatment to a core temp. of 80°C in combination with use of the artificial casings guaranteed a shelf stable product with a shelf life of three months. Sensory properties, apart from color, remained unchanged throughout storage.

Jayaraj and Patil (2001) studied the effect of different hurdle processing steps [a_w (0.90, 0.94, 0.98), pH (4.7, 5.3, 5.9), heat treatment (*F*-values of 0.2, 0.5, 0.8) and potassium sorbate (0.0, 0.05, 0.10%)] on hardness and chewiness of fried paneer, immediately after processing as well as during storage, by response surface methodology (Hoke's design). The parameters studied markedly influenced hardness and chewiness during processing as well as during storage. Data were fitted to a second-order polynomial regression equation. Constants were calculated for the best fit polynomial equation for changes in hardness and chewiness of paneer with respect to effects of processing and storage. Using these equations, changes in hardness and chewiness as a function of the above parameters were predicted and were presented in the form of response surfaces. Decrease in a_w and pH increased hardness and chewiness, whereas heat treatment decreased them. Based on the predicted response surfaces, the minimal changes in hardness occurred at the following values: a_w 0.90–0.93 at pH 5.1–5.9; a_w 0.918–0.948 at *F*-value 0.37–0.79. Minimal changes in chewiness occurred at a_w 0.90–0.97 at pH 4.7–5.3; a_w 0.900–0.945 at *F*-value 0.20–0.35. A synergistic effect of these parameters was also observed. Results of this study were of significance in improving quality and extending shelf life of canned paneer and paneer-based products.

Vijayanand et al. (2001) preserved pineapple, mango, and papaya fruit chunks preserved by hurdle technology using the hurdles of pH, mild heat treatment preservatives, and packaging. Pineapple and mango fruit chunks, blanched in syrup at 85°C for five minutes, dipped in syrup containing 340 mg of potassium metabisulphite/kg and 413 mg sodium benzoate/kg for eight hours and packed in 150 gauge polypropylene pouches showed acceptable sensory and microbiological quality up to a period of 30 days at 27°C and 60 days at 2°C and had SO_2 content of 65–85 mg/kg and benzoic acid 150–200 mg/kg. Papaya chunks treated with increasing levels of preservatives up to 680 mg potassium metabisulphite/kg and 826 mg sodium benzoate/kg exhibited good storage stability for up to 90 days at 2°C and ambient temperature

Rao and Patil (1999) successfully developed ready to eat paneer curry using hurdle technology. The product was so formulated as to have a water activity of 0.95, pH 5.0, potassium sorbate 0.1% and processed at *F*-value of 0.8 in tins. The product kept well, at 30°C and had better quality than the heat sterilized (15.0 *F*-value) product stored under similar conditions.

Jayaraman et al. (1998) developed a simple process using hurdle technique to preserve tropical fruits like mango and pineapple. Combination of slight reduction in water activity (using sucrose syrup), lowering of pH (using citric acid), and mild heat treatment (in pack pasteurization) produced a high moisture product which remained acceptable for more than six months at ambient temperature.

Arya et al. (1998) prepared suji halwa and stored it for six months by adding 0.25% potassium sorbate, 0.5% calcium propionate, and 0.25% sodium benzoate and heating in hermetically sealed pouches at 95°C for two hours.

Lopez et al. (1995) investigated the storage stability of papaya slices preserved by hurdle technology by blanching for three minutes in saturated vapor, a_w reduction to 0.98 by osmotic concentration in syrup, adjusting pH using citric acid and addition of potassium sorbate and sodium sulphite. Slices showed good overall acceptability even after three months at 25°C.

Guerrero et al. (1994) developed banana puree having storage life of 120 days by adjusting water activity (a_w) to 0.97, pH to 3.4, adding 250 ppm of ascorbic acid, 100 ppm of potassium sorbate and 400 ppm of sodium bisulphite and applying a mild heat treatment.

Alzamora et al. (1993) observed that pineapple slices blanched in saturated vapor for two minutes cooled in water and immersed in a glucose syrup containing 150 mg/kg sodium bisulphite and 1000 mg/kg potassium sorbate were acceptable up to 120 days of storage.

Aguilera et al. (1992) reported that addition of 6% salt, and 0.2% sorbate at pH 5.7 when accompanied by heat treatment (10 minutes, 80°C) increased the shelf-life of minced pelagic fish to 15 days at 15°C compared with less than three days for original mince.

CONCLUSIONS

Hence, hurdle technology is used in industrialized as well as in developing countries for the gentle but effective preservation of foods by which a preservation parameter can be used at an optimum level in order to get a maximum lethality against micro-organisms by a combination of two or more such parameters so that the damage to the sensory parameters of the food is kept to the minimum.

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