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HURDLE TECHNOLOGY: PRINCIPLES AND RECENT APPLICATIONS IN FOODS

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Abstracts: The application of hurdle technology in food preservation is progressing. The technology is becoming more acceptable among researchers in the field of food preservation due to its effectiveness at mild levels. The effects of conventional preservation techniques are minimized by hurdle technology through a smart combination of preservatives at less severe levels. Considerable advancement in the application of hurdle technology is realized in both developed and developing nations. Nutritional and sensory qualities were protected through the smart use of combined preservation. The safety and stability of foods were ensured using this technology, and many perishable foods are now ambient stable. This article reviewed the principles of hurdle technology and reported the recent applications of the technology in the preservation of foods from plant and animal origins.
Keywords: *Hurdle technology, food spoilage, food preservation, microorganisms.*

INTRODUCTION

Most raw foods are perishable, they are subjected to preservation to maintain their qualities, control pathogens and reduce their spoilage potentials during storage, transportation and marketing (Pinto et al., 2012). Quality deterioration is observed in food after harvesting, slaughter or manufacture, the rate of deterioration varies according to food composition, handling method and properties of the storage condition. Degradation of quality can occur at any of the many activities taking place between farm and consumers' tables. Changes in the qualities are triggered by several causes which include physical, chemical, biochemical and microbial. Quality deterioration by physical factors includes damage caused by cutting and bruises in perishable foods such as fruits, vegetables and tubers during handling, and losing or gaining of water through the vapor-permeable package in processed and packaged foods. Examples of quality degradation by chemical reaction include oxidation of fatty foods which causes rancidity, oxidative degradation of vitamin C, nonenzymic browning and color degradation by oxidation. Biochemical reactions that can lead to quality degradation include a browning reaction initiated by polyphenol oxidase (naturally occurring enzyme in plant foods), destruction of lipid by lipolysis (a biochemical process catalyzed by lipases) and enzymic browning. Causes of food spoilage are usually classified into (i) intrinsic factors (related to chemical and physical properties of the food itself (ii) processing factors (treatments deliberately applied to food) (iii) extrinsic factors (these are external factors and are properties of the immediate food environment (iv) implicit factors (depends on nature of microorganism and how it interacts with environment) and (v) net effects factors (the combination of many factors with are difficult to predict) (Skovgaard, 2004).

Food qualities can be disturbed by the growth of spoilage microorganisms and food safety is threatened by the presence of pathogenic microorganisms that can cause food infection and food intoxication (Skovgaard, 2004). The foodborne threat makes food safety important not only for a public health concern but also for its roles production economy and marketplace. Menace related to foodborne can disrupt the market and cause extensive economic losses along the food chain (Khan et al., 2017). Microorganisms account for more than 70 % of food spoilage, ensuring safety and stability of foods depends on the right choice of food preservation methods that will ensure microbial and chemical safety and maintain nutritional and sensory qualities (Abdullahi et al., 2016b)

The traditional methods of slowing or eliminating microorganisms in food are achieved through the use of extreme temperatures, drying, removal of oxygen, lowering pH, restriction of available nutrients and use of chemical preservatives (Khan et al., 2017). The number of these conventional techniques that were proven to solve food quality and safety-related problems was also reported to affect food qualities through the destruction of essential nutrients and the slashing of organoleptic qualities (Khan et al., 2017). To minimize the negative effects of traditional preservation methods it's imperative to use two or more hurdles in combination. Each of these hurdles will subject the microorganism to a hostile situation so that no growth will occur in the food (Pal et al., 2017). Hurdle technology is the best way to preserve food safety at the optimum processing condition (Devi and Babar, 2018). The aim of combining different preservation methods or techniques is to preserve the quality and safety of food during an extended storage period (Skovgaard, 2004).

The increasing demand for fresh, qualitative, microbiologically safe and stable foods stimulated the use of hurdle technology in food preservation (Ghrairi et al., 2012; Guerrero et al., 2017). An important current trend adopted by hurdle technology ensures the delivery of foods that are not heavily preserved through the combination of many preservative techniques at lower levels. This approach ensured higher quality foods that are more natural, contain fewer additives, received simple treatments and are nutritionally healthier than foods preserved through conventional methods. Consumer demand for foods with fewer changes in nutrients and sensory qualities also promoted hurdle technology in recent years (Pal et al., 2017).

Hurdle Technology

Hurdle technology is a multiple-barrier technology that employed multiple preservative measures, that are strategically applied, to efficiently control the growth of microorganisms in food (Yuan, 2003). It is an important area of food microbiology which described the potentials of multiple preservation approach that act synergistically to inhibit microorganisms in foods (Duffy et al., 2003). The concept of hurdle technology involves the optimization of preservation techniques that ensure safe products with greater sensory and nutritional quality at lower costs (Augusto et al., 2018). Combining hurdle technologies has great potential in improving safety, stability, as well as freshness by minimizing destructive processing and preservation methods (Juneja, 2003). The approach to hurdle technology involves combining traditional and novel technologies to control microbial growth in food (Ravishankar and Maks, 2007). A combination of inhibitor factors or additives at a minimal level limit pathogenic growth by providing cumulative stress that makes microbial survival difficult (Novak, 2003). For an ideal synergistic action, the antimicrobial should have different mechanisms of action (Davidson and Zivanovic, 2003), so that different factors can work synergistically by hitting different targets (e.g. cell membrane, DNA, enzyme systems, pH, a_w, Eh) in the microorganisms (Rehal et al., 2017). Combined factors destroy microorganisms by disturbing one or more homeostasis mechanism within the cell, this prevents multiplication and make the microorganism inactive (Guerrero et al., 2017).

Control of spoilage and pathogenic microorganisms remains a serious challenge to the food industry despite many preservation techniques available. Anticipations of more natural foods by consumers that prefer fresh-like foods make the challenge, even more, greater (Leistner and Gorris, 1995). There is a need for developing mild preservation methods that will meet the needs of producers and consumers through the provision of fresh-like foods that are safe, stable, nutritious and palatable. Combine the use of anti-microbial at lower concentrations disturbed microbial activities than the use of single anti-microbial at higher concentrations (Abdullahi et al., 2016a). Adverse effects of conventional food processing on nutrients, texture and acceptability could be minimized or eliminated by hurdle technology. Smart combinations of different hurdles ensure microbial safety, minimize energy consumption, reduce emissions, increase profit and affordability and increase overall quality (Khan et al., 2017)

In addition to preservation effects, hurdles used in food can improve acceptability (Abdullahi et al., 2016b) and nutritional values of foods. Moawad et al. (2017) reported an increase in sensory qualities of tilapia fillets, a similar finding was also reported by Abdullahi et al. (2016a) in *Kilishi* (a Nigerian dried meat product). Hurdles involve Maillard reaction products, and nitrite used in curing of meat can improve flavor (Padhan, 2018). Nisin assists in maintain sensory characteristics of chicken sausage when used in combination with textured soy protein and lactic acid (Rindhe et al., 2017). Eke et al. (2013) reported an increase in protein efficiency ratio (PER) in *Danbun Nama* (Nigerian fried shredded beef) treated with citric acid.

Principles of Hurdle Technology

Conventional food preservation methods such as heating, chilling, freezing, freeze-drying, drying, curing, salting, sugar-addition, acidification, fermentation, smoking or oxygen removal are used in making food safe and stable (Leistner, 1992). The microbial safety, stability and sensory attributes of many processed foods including traditionally processed depend on the combined effects of many hurdles (Leistner, 2000). Different hurdles were combined smartly at lower levels to develop preservation measures that are mild but very reliable (Leistner and Gorris, 1995). Hurdles apply barriers (hurdles) such as heat, a_w, irradiation, chemical, pH, competitive flora, etc. simultaneously to contaminating microorganisms (Leistner, 2000). These barriers act synergistically and induce injuries that are more severe than that of a single barrier. The microorganisms required certain efforts to overcome each of the hurdles. More efforts will be required by microorganisms to overcome the hurdles when they are many (Leistner and Gorris, 1995).

The most important factors used in the hurdle technology are the intrinsic factors (a_w, pH, Eh, and chemicals) the extrinsic factors (temperature of storage and gas atmosphere), and the processing factors (heating, drying, fermentation) (Hamad, 2012). Novel physical factors such as hydrostatic pressure, pulsed electric fields, ultrasound, ozone, pulsed light, and ultraviolet light, among others, are now used to replace the deleterious processes such as thermal processing (Guerrero et al., 2017). This technology plays an important role in the production of various ready-to-eat and ready-to-cook stable products (Tripathi et al., 2011).

Understanding microbial cell physiology and growth requirements play an important role in choosing the right hurdle combination that will cause injuries and death (Wordon et al., 2012). Food preservation methods are more concerned about the physiology and behavior of microorganisms in foods viz. stress response, homeostasis and metabolic difficulties. The novelty of the multi-target food preservation approach based on a clear understanding of the physiology and behavior of contaminating microorganisms (Leistner, 2000)

Hurdle Applications in Food Preservation

Application of hurdle technology is progressing globally; the technology is used in developed countries to improve stability, safety and quality of foods. Hurdle technology is proved to be more useful in developing countries for the creation of novel foods that are minimally processed and ambient stable. It also plays important roles through modification and improvement of traditional food to produce intermediate moisture foods which are stable and also possess better sensory qualities. To apply preservative factors sensibly, concerning their quality and intensity, it is essential to know their effects and limits to inhibit or inactivate relevant microorganisms and their side effects on the sensory and nutritional quality of the food (Shelef and Seiter, 2005).

Recent applications in Plant foods

A summary of recent findings on the hurdle technology applications in the preservation of plant foods is presented in Table 1. Beristaín-Bauza et al. (2018) reported that the combination of natural antimicrobial (vanillin and cinnamaldehyde) and low-temperature storage significantly reduced the growth of *Salmonella typhimurium* in coconut water. More severe treatment which involves a combination of 7-min UV-C treatment, the addition of natural antimicrobial (vanillin and cinnamaldehyde) and storage at 5 °C eliminate the growth of *Salmonella Typhimurium* during 30-day storage. The addition of sodium benzoate and potassium sorbate to blanched tamarillo fruit improves microbial stability and does not affect anthocyanins, antioxidant and phenolic content of tamarillo sweet product (Preciado-Iñiga et al., 2018). Inactivation of acid-adapted *Escherichia coli* O157:H7 from orange and apple juices during pasteurization was reported by Gabriel (2015), the organism showed log-linear inactivation pattern in a combined treatment include UV, heating at a lower temperature (45 to 50 °C) and addition of chemical additives (0.1 % sodium benzoate or potassium sorbate). Pasteurization at 70 °C for 10 min and the addition of 200 ppm potassium metabisulphite extend the shelf-life of Juice blend made from white radish and sugarcane by three months under refrigeration condition (Kaur et al., 2019). Cells of *Saccharomyces cerevisiae* destroyed at 55 to 60 °C when subjected to low frequency (20 kHz) ultrasound before heating. This unveils the potentials of disinfecting beverages contaminated with *Saccharomyces cerevisiae* using lower temperatures (Wordon et al., 2012).

Devi & Babar (2018) reported the efficacy of bacteriocins in extending the shelf life of fruits and vegetables when combining with modified atmosphere storage. Browning reaction and surface softening were prevented in fresh-cut apple dipped into ascorbic acid/calcium chloride solution before pectin coating and pulsed light treatments, the combined effect of the treatment lower the microbial load by 2 log circle during refrigeration storage for 14 days (Moreira et al., 2017). Combine the use of calcium oxide, fumaric acid and slightly acidic electrolyzed water improve the quality of fresh leafy vegetables by maintaining it is freshness and causes an increase in microbial reduction (Ngnitcho et al., 2017). Dipping potatoes into slightly acid electrolyzed water and exposure to ultrasound at 40 °C for 3 minutes cause satisfied synergic effects against *Bacillus cereus* and inhibit the growth of the organism under different storage temperatures between 5 to 35 °C (Luo et al., 2016). Combination of citric acid, gamma radiation and modified atmosphere packaging was employed by Gupta et al. (2012) to extend the shelf life of minimally processed French beans, dipping into 8.4 gL^{-1} citric acid solution, application of 0.7 kGy gamma irradiation and storage at modified atmosphere consist of 18% O_2 and 4% CO_2 extend the shelf life of the beans by one week. Vacuum packaging (using nylon) improved stability and safety of Thai curry paste supplemented with 10 % sodium chloride by lowering its water activity, moisture, aflatoxin, total viable count and mold count (Phoem et al., 2019). Spores of *Clostridium botulinum* were eliminated in steamed bread treated with glycerol to lower its water activity below 0.94. The self-life of the bread extended from 1 day to 7 days by combining salt and glycerol at 13 and 180 g/kg flour (Lombard et al., 2000).

Table 1: Recent Application of Hurdles in Preservation of Plant Foods

Hurdle combination	**Preservation effects**
7-min UV-C treatment+ natural antimicrobial (vanillin and cinnamaldehyde) + storage at 5 °C	*Salmonella Typhimurium* in coconut water during 30-day storage (Beristaín-Bauza et al., 2018)
Sodium benzoate + potassium sorbate + blanching	Improve microbial stability of tamarillo fruit sweet product (Preciado-Iñiga et al., 2018).
UV + heating (45 to 50 °C) + chemical additives (0.1 % sodium benzoate or potassium sorbate)	Inactivation of acid-adapted *Escherichia coli* O157:H7 from orange and apple juices (Gabriel, 2015)
Heating (70 °C for 10 min) + addition of 200 ppm potassium metabisulphite	Extend the shelf life of Juice blend made from white radish and sugarcane by three months under refrigeration condition (Kaur et al., 2019).
Ultrasound (20 kH) + Heating (at 55 to 60 °C)	Destroy cells of *Saccharomyces cerevisiae* (Wordon et al., 2012).
Bacteriocins + modified atmosphere storage	Extend the shelf life of fruits and vegetables (Devi & Babar, 2018)
Dipped into ascorbic acid/calcium chloride + pulse light treatments	Prevent browning reaction and surface softening in fresh-cut apple during 14 days of refrigeration storage (Moreira et al., 2017).
Calcium oxide + Fumaric acid + slightly acidic electrolyzed water	Improve the quality of fresh leafy vegetables by maintaining it is freshness (Ngnitcho et al., 2017).
Slightly acid electrolyzed water dipping + exposure to ultrasound at 40 °C for 3 minutes	Inhibit the growth of *Bacillus cereus* in potato (Luo et al., 2016)
Citric acid + gamma radiation + modified atmosphere packaging	Extend the shelf life of minimally processed French beans Gupta et al. (2012)
Vacuum packaging (using nylon) + 10 % NaCl	lower water activity, moisture, aflatoxin, total viable count and mold count in Thai curry paste (Phoem et al., 2019)
salt and glycerol at 13 and 180 g/kg flour + steaming	Destroy pores of *Clostridium botulinum* and extend shelf life of steamed bread from 1 to 7 days (Lombard et al., 2000)

Recent applications in Animal foods

The use of hurdles in the preservation of food from animal origin is summarized in Table 2. The use of hurdle technology in meat processing was reported by Degala et al. (2018), treatment of the meat with 1 % lemongrass oil and exposure to 200 uW UV-C per cm^2 for 2 minutes lower the population of *Escherichia coli* K12 below the detectable level. The synergistic effects of combining lemongrass oil and UV-C are far higher than those of individual treatment. Application of high-pressure processing (535-580 MPa) and 0.3 % Inbac™ (organic acids and nisin formula) successfully replaced antimicrobial properties of sodium chloride in cooked harm and frankfurters in an attempt to replace salt with Artisalt™ (O'Neill et al., 2018). The shelf life of chicken sausage extended to six days by lowering its water activity and pH using textured soy protein and lactic acid respectively (Rindhe et al., 2017). A safe shelf-stable casing for sausage making was developed by a combination of osmotic dehydration using salt, polyethylene packaging and 10 kGy gamma-irradiation dose (Chawla et al., 2006). The decrease in the growth rate of both aerobic and anaerobic organisms and complete elimination of *Staphylococcus aureus* was observed in standardized *keema* (highly perishable Indian traditional meat product) with adjusted pH 5.8 using lactic acid and adjusted water activity (0.88) using humectant (isolated soy protein) during 5 days ambient (35.2±12 °C) storage (Karthikeyan et al., 2000).

Wiernasz et al. (2017) screened lactic acid bacteria and studied their potentials in the production of bio preservatives which can be used in combination with chitosan coating and super chilling to improve the safety and stability of fish and other seafood. A combination of 0.5 % marjoram essential oil and 2 % sodium tripolyphosphate reduces microbiological proliferation, lipid oxidation, protein breakdown and sensorial changes in tilapia fillets stored under refrigeration (4±1 °C) (Moawad et al., 2017).

Microbial load and activities of alkaline phosphatase were significantly reduced in milk by mild heat treatment (50 °C) and exposure to pulse electric field (30 KV at 50 °C for 6 min), the treatments extended the shelf life of the milk by 22 days (Indumathi et al., 2018b). 'Cold' pasteurization of skimmed milk was achieved by combining microfiltration, pulsed electric field (42 kV/cm for 612 μs) and mild heat (49 °C) treatment, a combination of these treatments is more effective and has higher antimicrobial efficacy than conventional thermal processing. The synergic effects of these hurdles combination result in a 7.1 log reduction in the microbial population (Walkling-Ribeiro et al., 2011). Mild heat and PEF hurdles were effective in killing *E. coli* present in raw milk and the hurdle treatment was effective in reducing the microbial load by 5 log cycles (Indumathi et al., 2018a).

Table 2: Recent Application of Hurdles in the Preservation of Animal Foods

Hurdle combination	Preservation effects
1 % lemongrass oil + exposure to 200 uW UV per cm^2 for 2 minutes	Lower the population of *Escherichia coli* K12 below the detectable level in meat (Degala et al., 2018)
High-pressure processing (535-580 MPa) and 0.3 % Inbac™ (organic acids and nisin formula)	Replaced antimicrobial properties of sodium chloride in cooked harm and frankfurters in an attempt to replace salt with Artisalt™ (O'Neill et al., 2018).
Textured soy protein + Lactic acid	Extend the shelf life of chicken sausage to six days (Rindhe et al., 2017).
Osmotic dehydration using salt + polyethylene packaging + 10 kGy gamma-irradiation dose	Used to develop safe shelf-stable casing for sausage making (Chawla et al., 2006)
Isolated soy protein + lactic acid	Decrease the growth rate of both aerobic and anaerobic organisms and eliminate *Staphylococcus aureus* in standardized *keema* (Karthikeyan et al., 2000).
LAB bacteriocins + chitosan coating + super chilling	Improve the safety and stability of fish and other seafood (Wiernasz et al., 2017)
0.5 % marjoram essential oil + 2 % sodium tripolyphosphate	reduces microbiological proliferation, lipid oxidation, protein breakdown and sensorial changes in tilapia fillets stored under refrigeration (4±1 °C) (Moawad et al., 2017).
Heating (50 °C) + pulse electric field (30 KV at 50 °C for 6 min),	Extend the shelf life of the milk by 22 days (Indumathi et al., 2018b)
Microfiltration + pulse electric field (42 kV/cm for 612 μs) + heat (49 °C)	Ensure 'Cold' pasteurization in skimmed milk by reducing the microbial population by 7.1 log circle (Walkling-Ribeiro et al., 2011).
Heating (50 °C) + pulse electric field (30 KV at 50 °C for 6 min),	Destroy *E. coli* present in raw milk (Indumathi et al., 2018a)

Challenges and Future Prospects

One of the limiting factors for hurdle application in food preservation is changes in sensory attributes, particularly when the combination involves chemical hurdles. Adverse changes can occur and this can lead to total rejection of the food (Juneja, 2003; Athmaselvi et al., 2019). Challenges regarding even distribution of some hurdles in the food matrices, their influence on flavor and color, possible resistance of microorganisms to new hurdles, and destruction of some hurdles by processing conditions were reported by Søltoft-Jensen and Hansen (2005). Another important challenge is understanding the stress response behavior of the target microorganisms, some microorganisms developed defense mechanisms when they are under stress and they become more resistant when they recover. Understanding the interaction pattern of the combined hurdle is necessary, because some hurdles can neutralize the effect of others, and some when combine can affect the sensory qualities of the food. Process uniformity is another factor that ensures the effectiveness of combined treatment. Hurdle treatment, whether physical, chemical, biological or competitive flora must be applied in a manner that will rich the target microbial cells (Gomez, 2011).

The potentials of hurdle technology have been employed in many areas of food preservation, however, a deeper understanding of their combined actions will ensure safer and more qualitative products. New strategies may be developed from fundamental knowledge of hurdle technology when there is a better understanding concerning how individual and interactive factors destroy microorganisms in foods (Gomez, 2011). The future of food preservation will base on a smart combination of different antimicrobial factors that will guarantee microbiological safety and stability while keeping organoleptic qualities at a maximum (Lucke, 2003). The use of innovative preservation methods in combination with less intense treatments is fast gaining attention (Alexandre et al., 2012). Novel preservation techniques such as high-pressure processing are only reliable when used in combination with other hurdles such as low pH, low temperatures, mild heat, or the addition of antimicrobials (Neetoo, 2012). The effectiveness of preservatives with narrow activity spectra (e.g. bacteriocins) and those with moderate or low antibacterial effects can be improved when used in combination or used with other preservatives (Vignolo et al., 2012). Traditional antimicrobial together with novel preservation techniques will continue to be used in the production of minimally processed foods (Alakomi et al., 2002). Predictive microbiological modeling can be used to forecast how microbes behave under different hurdle combinations, this is an important approach that can be used to test how microbes would grow in new food recipes (Ngadi et al., 2012). As research into hurdle and novel preservation techniques continues, a torrent of an endless number of hurdle combinations specifically customized for precise purposes are expected (Ngadi et al., 2012)

CONCLUSION

The use of hurdle technology in food preservation changes the manner of food preservation in recent years. More natural foods are consumed now, and nutrients and organoleptic qualities suffer less. The safety of many foods was improved, and the storage life of many perishable foods was extended. Resistance microorganisms are suffering, and many can be eliminated by a smart combination of different preservatives. Many achievements are underway and many challenges related to microbial contamination in foods will become history shortly soon. Development of new preservation techniques using new hurdles and understanding their properties when combined with existing preservation techniques will open new areas of research. Future researches should be focused on the preservative effects of hurdles at the industrial scale to understand the effectiveness of the technology on a commercial scale.

REFERENCES

Abdullahi, N., Ariahu, C.C., Abu, J.O., 2016a. Critical review on principles and applications of hurdle. Ann. Food Sci. Technol. 17, 485–491.

Abdullahi, N., Ariahu, C.C., Abu, O.J., 2016b. Effect of chemical hurdles on sensory attributes of kilishi 1 1. Ann. Food Sci. Technol. 17, 452–457.

Alakomi, H., Skytta, E., Helander, I. and Ahvenainen, R. 2002. The Hurdle Concept. In: Ohlsson, T. and Bengtsson, N. (eds). Minimal Processing Technologies in the Food Industry. CRS Press, Washington. P 191

Alexandre, E. M. C., Brandão, T. R. S., and Silva, C. L. M. 2012. Emerging Technologies to Improve the Safety and Quality of Fruits and Vegetables. In: McElhatton, A., Sobral, P. J. A. and Kristbergsson, K. Novel Technologies in Food Science: Their Impact on Products, Consumer Trends and the Environment. Springer Science+Business Media, LLC. P 267

Athmaselvi, K. A., Kumar, C. and Poojitha, P. 2019. Interventions of Ohmic Heating Technology in Foods. In: Meghwal, M. and Goyal, M. R. (eds). State-of-the-Art Technologies in Food Science Human Health, Emerging Issues, And Specialty Topics. Apple Academic Press Inc. Canada. P 322

Augusto, P. E. D., Soares, B. M. C. and Castanha, N. 2018. Conventional Technologies of Food Preservation. In: Barba, F. J., Sant'Ana, A. S., Orlien, V. and Koubaa, M. Innovative Technologies for Food Preservation: Inactivation of Spoilage and Pathogenic Microorganisms. Academic Press, London. P 19

Beristaín-Bauza, S., Martínez-Niño, A., Ramírez-González, A.P., Ávila-Sosa, R., Ruíz-Espinosa, H., Ruiz-López, I.I., Ochoa-Velasco, C.E., 2018. Inhibition of Salmonella Typhimurium growth in coconut (Cocos nucifera L.) water by hurdle technology. Food Control 92, 312–318. https://doi.org/10.1016/j.foodcont.2018.05.010

Chawla, S.P., Chander, R., Sharma, A., 2006. Safe and shelf-stable natural casing using hurdle technology. Food Control 17, 127–131. https://doi.org/10.1016/j.foodcont.2004.09.011

Davidson, P. M. and Zivanovic, S. 2003. The Use of Natural Antimicrobials. In: Zeuthen, P. and Bùgh-Sùrensen, L. (eds). Food Preservation Techniques. Woodhead Publishing Limited, Cambridge. P 23

Degala, H.L., Mahapatra, A.K., Demirci, A., Kannan, G., 2018. Evaluation of non-thermal hurdle technology for ultraviolet-light to inactivate Escherichia coli K12 on goat meat surfaces. Food Control 90, 113–120. https://doi.org/10.1016/j.foodcont.2018.02.042

Devi, N., Babar, S., 2018. Effective bio preservation of food using bacteriocins with hurdle technology. World J. Pharm. Res. 7, 1–10. https://doi.org/10.20959/wjpr20184-10781

Duffy, S., Chen, Y. and Schaffner, D. W. 2003. Quantitative Risk Assessment of Minimally Processed Foods. In: Novak, J. S., Sapers, G. M. and Juneja, V. K. (Eds). Microbial Safety of Minimally Processed Foods. CRC Press LLC. P 179.

Eke, M.O., Ariahu, C.C., Igyo, M.A., 2013. In-vivo quality assessment of dambu-nama treated with some hurdles. Int. J. Eng. Sci. 2, 27–31.

Gabriel, A.A., 2015. Combinations of selected physical and chemical hurdles to inactivate Escherichia coli O157: H7 in apple and orange juices. Food Control 50, 722–728. https://doi.org/10.1016/j.foodcont.2014.10.017

Ghrairi, T., Chaftar, N. and Hani, K. 2012. Bacteriocins: Recent Advances and Opportunities. In: Bhat R., Alias, A. K. and Paliyath, G. (eds). Progress in Food Preservation. Wiley-Blackwell Oxford. P 485

Gomez, P. L., Welti-Chanes, J. and Alzamora, S. M. 2011. Hurdle Technology in Fruit Processing. Annual Review of Food Science and Technology, 2:447–465

Guerrero, S. N., Ferrario, M., Schenk M. and Carrillo, M. G. 2017. Hurdle Technology Using Ultrasound for Food Preservation. In: Bermudez-Aguirre D. (ed). Ultrasound: Advances in Food Processing and Preservation. Academic Press. Pp 39-40. http://dx.doi.org/10.1016/B978-0-12-804581-7.00003-8

Gupta, S., Chatterjee, S., Vaishnav, J., Kumar, V., Variyar, P.S., Sharma, A., 2012. Hurdle technology for shelf stable minimally processed French beans (Phaseolus vulgaris): A response surface methodology approach. LWT - Food Sci. Technol. 48, 182–189. https://doi.org/10.1016/j.lwt.2012.03.010

Hamad, S. H. 2012. Factors Affecting the Growth of Microorganisms in Food. In: Bhat R., Alias, A. K. and Paliyath, G. (eds). Progress in Food Preservation. Wiley-Blackwell Oxford. P 425

Indumathi, A.S., Sujatha, G., Baskaran, D., Dhanalakshmi, B., Pandian, A.S.S., 2018a. Microbial inactivation in raw processed by hurdle technology. Int. J. Agric. Sci. 10, 6706–6708.

Indumathi, A.S., Sujatha, G., Baskaran, D., Dhanalakshmi, B., Saravana Pandian, A.S., 2018b. Inactivation of Alkaline Phosphatase and Shelf Life Extension of Milk Processed by Hurdle Technology. Int. J. Curr. Microbiol. Appl. Sci. 7, 3278–3281. https://doi.org/10.20546/ijcmas.2018.707.381

Juneja, V. K. 2003. *Sous-Vide* Processed Foods: Safety Hazards and Control of Microbial Risks. In: Novak, J. S., Sapers, G. M. and Juneja, V. K. (Eds). Microbial Safety of Minimally Processed Foods.

CRC Press LLC. Pp 103,119.
Karthikeyan, J., Kumar, S., Anjaneyulu, A.S.R., Rao, K.H., 2000. Application of hurdle technology for the development of Caprine keema and its stability at ambient temperature. Meat Sci. 54, 9–15. https://doi.org/10.1016/S0309-1740(99)00053-4
Kaur, G., Kumar, V., Sangma, C., Kaur, J., Kaur, J., Suri, S., 2019. Preservation of spiced radish juice using hurdle technology. Int. Food Res. J. 26, 1095–1102.
Khan, I., Tango, C.N., Miskeen, S., Lee, B.H., Oh, D.H., 2017. Hurdle technology: A novel approach for enhanced food quality and safety – A review. Food Control 73, 1426–1444. https://doi.org/10.1016/j.foodcont.2016.11.010
Leistner, L., 1992. Food preservation by combined methods. Food Res. Int. 25, 151–158. https://doi.org/10.1016/0963-9969(92)90158-2
Leistner, L., 2000. Basic aspects of food preservation by hurdle technology. Int. J. Food Microbiol. 55, 181–186. https://doi.org/10.1016/S0168-1605(00)00161-6
Leistner, L., Gorris, L.G.M., 1995. Food preservation by hurdle technology. Trends Food Sci. Technol. 6, 41–46. https://doi.org/10.1016/S0924-2244(00)88941-4
Lombard, G.E., Weinert, I.A.G., Minnaar, A., Taylor, J.R.N., 2000. Preservation of South African steamed bread using hurdle technology. LWT - Food Sci. Technol. 33, 138–143. https://doi.org/10.1006/fstl.1999.0626
Lucke, F.-K. 2003. The Control of pH. In: Zeuthen, P. and Bùgh-Sùrensen, L. (eds). Food Preservation Techniques. Woodhead Publishing Limited, Cambridge. P 121
Luo, K., Kim, S.Y., Wang, J., Oh, D.H., 2016. A combined hurdle approach of slightly acidic electrolyzed water simultaneous with ultrasound to inactivate Bacillus cereus on potato. LWT - Food Sci. Technol. 73, 615–621. https://doi.org/10.1016/j.lwt.2016.04.016
Moawad, R.K., Mohamed, G.F., Hanna, El-Banna, A., Bareh, G.F., Mahmoud, K.F., 2017. Assessment of hurdle technology to preserve Nile tilapia fillets during refrigeration with the application of marjoram oil/polyphosphates dipping. Asian J. Sci. Res. 10, 116–127. https://doi.org/10.3923/ajsr.2017.116.127
Moreira, M.R., Álvarez, M. V., Martín-Belloso, O., Soliva-Fortuny, R., 2017. Effects of pulsed light treatments and pectin edible coatings on the quality of fresh-cut apples: a hurdle technology approach. J. Sci. Food Agric. 97, 261–268. https://doi.org/10.1002/jsfa.7723
Neetoo, H. and Chen, H. 2012. Application of High Hydrostatic Pressure Technology for Processing and Preservation of Foods. In: Bhat R., Alias, A. K. and Paliyath, G. (eds). Progress in Food Preservation. Wiley-Blackwell Oxford. P 255.
Ngadi, M. O., Latheef, M. B. and Kassama, L. 2012. Emerging technologies for microbial control in food processing. In: Boye, J. I. and Arcand, Y. (eds) Green Technologies in Food Production and Processing. Springer Science+Business Media, LLC. Pp 396-397
Ngnitcho, P.F.K., Khan, I., Tango, C.N., Hussain, M.S., Oh, D.H., 2017. Inactivation of bacterial pathogens on lettuce, sprouts, and spinach using hurdle technology. Innov. Food Sci. Emerg. Technol. 43, 68–76. https://doi.org/10.1016/j.ifset.2017.07.033
Novak J. S. 2003. Fate of *Clostridium perfringens* in Cook–Chill Foods. In: Novak, J. S., Sapers, G. M. and Juneja, V. K. (Eds). Microbial Safety of Minimally Processed Foods. CRC Press LLC. P 90.
O'Neill, C., Joseph, P.K., Malco, C.-R., 2018. High pressure processing as a hurdle technology for development of consumer- accepted, low-salt processed meat products with enhanced safety and shelf-life. University College Cork, Ireland.
Padhan, S., 2018. Hurdle Technology: A Review Article. Trends Biosci. 11, 3457–3462.
Pal, M., Shimelis, A., Mamo, W., Barot, A.M., Pinto, S. V, Prajapati, J.P., 2017. Hurdle Technology: A novel approach for Food Preservation. Beverage Food World 44, 20–23.
Phoem, A.N., Sankalee, S., Aryae, P., 2019. Evaluation of Hurdle Technology on Shelf Life Extension of Thai Red Curry Paste and Sour Curry Paste. Appl. Mech. Mater. 886, 92–97. https://doi.org/10.4028/www.scientific.net/amm.886.92
Pinto, V. F., Patriarca, A., and Pose, G. 2012. Plant Extracts as Natural Antifungals: Alternative Strategies for Mold Control in Foods. In: McElhatton, A., Sobral, P. J. A. and Kristbergsson, K. Novel Technologies in Food Science: Their Impact on Products, Consumer Trends and the Environment. Springer Science+Business Media, LLC. P 212
Preciado-Iñiga, G.E., Amador-Espejo, G.G., Bárcenas, M.E., 2018. Blanching and antimicrobial mixture (potassium sorbate–sodium benzoate) impact on the stability of a tamarillo (*Cyphomandra betacea*) sweet product preserved by hurdle technology. J. Food Sci. Technol. 55, 740–748. https://doi.org/10.1007/s13197-017-2985-x
Ravishankar, S. and Maks, N. 2007. Basic Food Microbiology. In: Tewari, G. and Juneja, V. K. Advances in Thermal and Non-Thermal Food Preservation. Blackwell Publishing. P 23
Rehal, J., Goswami, D., Rajput, H. and Mangde, H. M. 2017. Minimal Processing of Fruits and Vegetables. In: Meghwal M. and Goyal, M. R. (eds). Developing Technologies in Food Science: Status, Applications, and Challenges. Apple Academic Press Inc. Canada. P 130
Rindhe, S.N., Shinde, A.T., Jadhav, B.A., Kumbhar, V.H., 2017. Application of Hurdle Technology for Preservation of Chicken Sausages at Ambient Temperature (37±10c). Int. J. Pure Appl. Biosci. 5, 480–488. https://doi.org/10.18782/2320-7051.2989
Shelef, L.A., Seiter, J., 2005. Indirect and miscellaneous antimicrobials. In: Davidson, P.M., Sofos, J.N., Branen, A.L. (Eds.), Antimicrobials in Food, Third Edition. CRS Press, New York, pp. 573–598. https://doi.org/10.1201/9781420028737.ch17
Skovgaard, N., 2004. Hurdle Technologies. Combination Treatments for Food Stability, Safety and Quality. Food Engineering Series, First. ed, International Journal of Food Microbiology. Springer Science+Business Media, New York. https://doi.org/10.1016/s0168-1605(03)00370-2
Søltoft-Jensen, J. and Hansen, F. 2005. New Chemical and Biochemical Hurdles. Sun, D. W. (ed). Emerging Technologies in Food Processing. Academic Press, California. P 408
Tripathi, J., Gupta, S., Kumar, V., Chatterjee, S., Variyar, P. S. and Sharma A. 2011. Processing Food for Convenience: Challenges and Potentials. BARC Newsletter, 322.
Vignolo, G., Saavedra, L., Sesma, F., and Raya, R. Food Bioprotection: Lactic Acid Bacteria as Natural Preservatives. In: Bhat R., Alias, A. K. and Paliyath, G. (eds). Progress in Food Preservation. Wiley-Blackwell Oxford. P 468
Walkling-Ribeiro, M., Rodríguez-González, O., Jayaram, S., Griffiths, M.W., 2011. Microbial inactivation and shelf life comparison of "cold" hurdle processing with pulsed electric fields and microfiltration, and conventional thermal pasteurisation in skim milk. Int. J. Food Microbiol. 144, 379–386. https://doi.org/10.1016/j.ijfoodmicro.2010.10.023
Wiernasz, N., Cornet, J., Cardinal, M., Pilet, M.F., Passerini, D., Leroi, F., 2017. Lactic acid bacteria selection for biopreservation as a part of hurdle technology approach applied on seafood. Front. Mar. Sci. 4, 1–15. https://doi.org/10.3389/fmars.2017.00119
Wordon, B.A., Mortimer, B., McMaster, L.D., 2012. Comparative real-time analysis of Saccharomyces cerevisiae cell viability, injury and death induced by ultrasound (20kHz) and heat for the application of hurdle technology. Food Res. Int. 47, 134–139. https://doi.org/10.1016/j.foodres.2011.04.038
Yuan, J. T. C. 2003. Modified Atmosphere Packaging for Shelf-Life Extension. In: Novak, J. S., Sapers, G. M. and Juneja, V. K. (Eds). Microbial Safety of Minimally Processed Foods. CRC Press LLC. P 216.