Annals. Food Science and Technology
2016

CRITICAL REVIEW ON PRINCIPLES AND APPLICATIONS OF HURDLE TECHNOLOGY IN FOOD PRESERVATION

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Abstract
When considering food stability the microbial, chemical and sensory qualities must taking into consideration. To achieve these, appropriate preservation measures must be taken to the level that the activities of microorganisms will be overcome. Microbial activities account for more than 70% of food spoilage. Presence of active microorganisms in food causes rapid spoilage by directly destroying the nutrients present or by secretion of enzymes that will trigger many chemical reactions that will interfere with the chemical and sensory qualities of the food. The microbial stability and safety of the most traditional and processed foods is based on a combination of several preservation factors (called hurdles), which the microorganisms present in food are unable to overcome. Hurdles use in food can be physical, physicochemical or microbiologically derived. The main objective of hurdle technology is food preservation, but in addition, many hurdles were reported to improve sensory attributes. Hurdles application in food depend on the nature and chemistry of the food, as well as the processing and storage conditions. Many findings revealed that combination of preservatives at lower concentrations discourage microbial activities more than single preservative at higher concentration. In this review general introduction of hurdle technology was given, also basis on food spoilage and preservation. Principles, application, advantages and effects of hurdles on food quality were also reviewed. Hurdles classification with examples was also stated. Special emphasis was given to contributions from other researchers on the application and effectiveness of hurdle technology in maintaining microbiological, chemical, sensory and physical qualities of processed foods.

Key words: Hudle, Technology, Microorganisms, Food, Spoilage,

Submitted: 13.09.2016 Reviewed: 28.10.2016 Accepted: 16.12.2016

1. Introduction

Hurdle technology is a process of rendering food to be free from spoilage and pathogenic microorganisms by the combination of one or more preservation methods. The spoilage and pathogenic microorganisms have to pass through these individual approaches called “hurdles” for maintaining their activity in food products (Subha, 2013). Hurdle application of different treatments offers synergistic advantage compared to separate using of the individual treatment (Bazhal *et. al.*, 2003).

The concept of hurdle technology was first introduced by Lothar Leistner in 1978. More recently out of the comprehension of the hurdle technology new concepts for food safety have emerged (Leistner, 1997). The microbial stability and safety of most foods is based on a combination of several factors (hurdles), which should not be overcome by the microorganisms present (Leistner, 1994). Hudles ensures microbial safety in food and maintained its nutritional and organoleptic parameters for consumer preference (Subha, 2013). Current research trends in food microbiology and food technology focus on mild, physical preservation techniques and the use of natural antimicrobial compounds (Leif, 1994), examples include; combining traditional inactivation, survival and growth-limiting factors at sub inhibitory levels with emerging novel non-thermal intervention food preservation techniques using bacteriolytic enzymes (lysozyme), lactic cultures and culture products (e.g., bacteriocins), ionizing radiation, high hydrostatic pressure, or pulsed electric field (PEF) (Juneja, 2003).

Combining inhibitory factors can result in a significant improvement in securing microbial safety and stability as well as the sensory and

nutritional quality of foods (Juneja, 2003). These include manipulation of factors such as temperature, water activity and acidity, as well as processes such as gas packaging and high pressure processing. The aim is to interfere with several different mechanisms within microorganisms simultaneously. This multi-targeted approach allows effective use of mild techniques. (IFIS, 2005).
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 show that the combination of preservation factors can have unexpected antimicrobial activity (Leistner, 2011). The combined use of several preservation methods, possibly physical and chemical, or a combination of different preservatives is an age-old practice. It has been commonly applied by the food industry to ensure food safety and stability (Lee, 2004).

2. Microbiological Food Spoilage

Food Spoilage is deterioration of quality parameters of food by chemical, physical or microbial means (IFIS, 2005). Contamination of the food supply with spoilage and pathogenic microorganisms continues to be a global problem despite the wide range of preservation methods employed (Juneja, 2003).
Microbial food spoilage occurs as a consequence of either microbial growth in a food or release of microbial extracellular and intracellular (following cell lysis) enzymes in the food environment. Some of the detectable parameters associated with spoilage of different types of foods are changes in color, odor, and texture; formation of slime; accumulation of gas (or foam); and accumulation of liquid (exudate, purge). Spoilage by microbial growth occurs much faster than spoilage by microbial extra- or intracellular enzymes in the absence of viable microbial cells (Bibek, 2005).
For microbial food spoilage to occur, several events need to take place in sequence. Microorganisms have to get into the food from one or more sources, the food environment (pH, a_w, O–R potential, nutrients, inhibitory agents) should favor growth of one or more types of these contaminating microorganisms, the food must be stored (or abused) at a temperature that enables one or more types to multiply, and finally, the food must be stored under conditions of growth for sufficient length of time for the multiplying microbial types to attain the high numbers necessary to cause the detectable changes in a food (Bibek, 2005). It is clear that the microbial safety of food can be granted when the overall processing, including the production of raw materials, distribution and handling by the consumers are taken into consideration. Therefore, the microbial quality assurance of foods is not only a matter of control, but also a careful design of the process chain (Hofstra *et. al.*, 1994).

3. Principles of Food Preservation

Food preservation is a process of maintaining the original quality or existing state of food by treatment(s) that will prevent its spoilage or deterioration (IFIS, 2005). It implies putting microorganisms in a hostile environment in order to cause their death (Oladapo *et al.*, 2014). One of the major advances in human history was the ability to preserve food. It was the prerequisite to man settling down in one place, instead of moving from place to place in the never ending hunt for fresh food. The earliest preservation technologies developed were drying, smoking, chilling and heating. Later on the art of controlling these technologies was developed. The work of Pasteur in the nineteenth century made it possible to understand the real mode of operation of preservation techniques such as heating, chilling and freezing, providing the basis for more systematic monitoring and control. The use of various compounds such as salt and spices to preserve foods was also used in ancient times (Peter and Leif, 2003).
Development of safe, shelf stable foods is necessary to reduce dependence on refrigeration during their storage and distribution (Sujatha, 2014).
Preservative agents are required to ensure that manufactured foods remain safe and unspoiled

(Brul and Coote, 1999). When food is to be stored for a prolonged period, use of preservatives is essential in order to maintain its quality and flavour. Their use prevents spoilage of foods due to the growth of bacteria and fungi. They also maintain the quality and consistency of the foods, along with its palatability and wholesomeness. Preservatives also maintain nutritional value, control appropriate pH and enhance flavour (Arora *et al.*, 2014). The disturbance of the homeostasis of microorganisms is the main mechanism of food preservation (Leistner, 2011). Traditional methods for acceptable preservation of foods include heating, chilling, freezing, drying, curing, salting, preserving with sugar, direct acidification, natural fermentation, modified atmosphere packaging and smoking (Juneja, 2003).

Chemical preservatives may be injurious when used at higher concentrations. Arora *et al.* (2014) reported that at higher concentration benzoates can trigger allergies such as skin rashes, asthma and can also causing brain damage. He also reported that sodium chloride when used in high amount in meats and fish can lead to high blood pressure, kidney failure, stroke and heart attack.

4. Hurdle Technology

4.1 Principles

For each stable and safe food a certain set of hurdles is inherent, which differs in quality and intensity depending on the particular product, however, in any case the hurdles must keep the "normal" population of microorganisms in this food under control. The microorganisms present ("at the start") in a food product should not be able to overcome ("jump over") the hurdles present, otherwise the food will spoil or even cause food-poisoning (Leistner, 1994). The most important hurdles commonly used in food preservation are temperature (high or low), water activity (a_w), acidity (pH), redox potential (Eh), preservatives (nitrite, nitrate, sorbate, sulfite etc) and competitive microorganisms (lactic acid bacteria) (Leistner, 2011).

The concept is that for a given food the bacteria should not be able to "jump over" all of the hurdles present, and so should be inhibited. If several hurdles are used simultaneously, a gentle preservation could be applied, which nevertheless secures stable and safe foods of high sensory and nutritional properties (FOA, 2006). The microbial stability and safety as well as the sensory and nutritional quality of most preserved foods are based on a combination of several empirically applied preservative hurdles (Leistner, 2011), which the microorganisms present in the food are unable to overcome. The physiological responses of microorganisms during food preservation such as homeostasis, metabolic exhaustion, and stress reaction are the basis for the application of hurdle technology. Use of combined hurdles could increase the disturbance of homeostasis and cause the metabolic exhaustion of microorganisms. Since different hurdles have different spectra of antimicrobial action, the combined hurdles could attack microorganisms in different ways and may increase synergistically the effectiveness of preservation ('multitarget preservation') (Leistner, 2011). The mechanisms by which the combination of factors, or hurdle concept, works is that; when two target microorganisms ***a*** and ***b*** can grow when preservation methods ***X, Y,*** or ***Z*** are used as individual hurdles. Then, if *X* and *Y* are combined, the growth of ***a*** is arrested, and when ***X, Y,*** and ***Z*** are used in combination, both microorganisms fail to grow (Bibek, 2005).

Hurdle effect is of fundamental importance for the preservation of food, since the hurdles in a stable product control microbial spoilage and food poisoning as well as control of fermentation (FOA, 2006). The hurdle concept illustrates only the well-known fact that complex interactions of preservative factors are significant for the microbial stability of foods. From an understanding of the hurdle effect, hurdle technology has been derived, which allows improvements in the safety and the quality as well as the economic properties of foods, by an intelligent combination of hurdles (Leistner, 1994).

A synergist effect could work if the hurdle in a food hits different targets (e.g., cell membrane, DNA, enzyme systems, pH, a_w, Eh) within the microbial cell, and thus disturbs the homeostasis of the microorganisms present in several aspects. Therefore, employing different hurdles in the preservation of a particular food should be an advantage, because microbial stability could be achieved with a combination of gentle hurdles. In practical terms, this could mean that it is more effective to use different preservatives in small amounts in a food than only one preservative in large amounts, because different preservatives might hit different targets within the bacterial cell, and thus act synergistically (FOA, 2006).

Previously hurdle technology was used empirically without much knowledge of the governing principles. Since about 20 years the intelligent application of hurdle technology became more prevalent, because the principles of major preservative factors for foods and their interactions, became better known. Recently, the influence of food preservation methods on the physiology and behaviour 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 (Leistner, 2010).

The hurdle includes temperature, water activity, pH, redox potential, modified atmosphere, organic and inorganic preservatives etc. (FOA, 2006). The intensity of the hurdle is ascertained and controlled according to the type of spoilage microorganism(s) and regulated as per consumer safety and preference without sacrificing the quality and appearance of the final food product (Subha, 2013). The different parameters or factors that are used in combination include intrinsic factors (e.g., a_w, pH, Eh, and natural inhibitors), processing factors (e.g., heating, drying, fermentation, and preservatives), and extrinsic factors (e.g., temperature and aerobic or anaerobic environment). Competitive flora (e.g., lactic acid bacteria) and non-thermal processing methods can be added to them (Bibek, 2005)**.**

complex interactions of temperature, water activity, pH, and redox potential are significant for the microbial stability of foods. With respect to procedures that slow down or prevent the growth of microorganisms in foods (Leistner, 2007). Hurdles used in food preservation could provide varying results depending on bacterial stress reactions such as the synthesis of protective proteins. These stress reactions or cross-tolerance may not exist when combined hurdles are used (Lee, 2004). Proper combination of hurdles will lead to destruction of the microbes and can prevent their further growth. It also ensures microbial safety in food thereby maintaining its nutritional and organoleptic parameters for consumer preference (Subha, 2013).

4.2 Types of Hurdle

More than 60 potential hurdles for foods of plant and animal origin, which improve the microbial stability and/or the sensory quality of these products have already describe, and the list of possible hurdles for food preservation is by no means complete (Leistner, 2011).

At present, physical non-thermal processes (eg. Pulse electric field) received considerable attention. Another group of hurdles of special interest in industrialized and developing countries at present would be “natural preservatives (spices and their extracts, lysozyme, chitosan, pectin hydrolysate etc.). In most countries, these “green preservatives” are preferred because they are not synthetic chemicals, but in some developing countries, they given preference, since spices are readily available and cheaper than imported chemicals (Leistner, 2011).

1. Physical Hurdles.

Most hurdles under this heading are processes used in food manufacturing. When using processes intended to kill microorganisms, it is necessary to protect the food product against (microbial) recontamination after processing, this includes: heat processing, manipulation of storage temperatures, irradiation, electromagnetic energy, photodynamic inactivation, ultrahigh pressure processing, ultrasonication and packaging (Leif, 1994).

2. Physicochemical Hurdles

Hurdles categorised under this heading include water activity (a_w), pH, redox potential (Eh), salt (NaCl), nitrite ($NaNO_2$), carbon dioxide (CO_2), oxygen (O_2), ozone (O_3), organic acids, spices and herbs, sulphite or SO_2, smoking, ethanol, maillard reaction products (MRPs) and lysozyme (Leif, 1994).

3. Microbiologically Derived Hurdles

Hurdles under this class are; competitive flora, starter cultures, bacteriocins and antibiotics (Leif, 1994).

4.3 Applications and Effects on Food Quality

Hurdle technology can be applied to wide categories of food which include; dairy products, fresh fruits and vegetables, fruits derived products, animal products (Aditya and Nida, 2015). The technology have a broad application in production Ready-to-Eat foods and production of edible coating. Some preservatives at high concentrations represent chemical hazards; a combination of chemical preservatives with other preservation methods is useful. Proper application of combined methods gives stable products, prevents the undesired side-effects of each individual treatment, saves energy and lowers the required concentration of added preservatives (Pokorn, 1994). Many researchers reported that combination of different hurdles at lower concentrations offer more resistance to microbial activities than individual hurdles used at higher concentrations. Different preservatives might hit different targets within the microbial cell and act synergistically (Sujatha, 2014). Example is the preservation of jams and jellies, for which high heat, low pH (of fruits), low a_w (sugar in fruits and added), and anaerobic packaging are used to reduce microbial numbers as well as the growth of survivors (Bibek, 2005)**.** Also in smoked products, for example, combination treatment includes heat, reduced moisture content and antimicrobial chemicals deposited from the smoke onto the surface of the food. Some smoked foods may also be dipped or soaked in brine or rubbed with salt before smoking, to impregnate the flesh with salt and thus add a further preservative mechanism. In jam and other fruit preserves, the combined factors are heat, high solids content (reduced water activity) and high acidity (Lee, 2004). Combination of thermal inactivation with other non-thermal hurdles takes a special place among different combined technologies (Bazhal *et al.*, 2003). Anurag *et al.*, (2013) reported that application of radiation to intermediate moisture products dried by infra-red, and use of 400 gauge polythene bag will provide effective retention to nutrient up to six months under ambient storage.

Abdullahi *et al.* (2016) reported that combination of 4% sucrose, 0.1% citric acid, 0.1% sodium benzoate and use of HDPE as packaging material eliminates the growth of *Salmonella spp.* and *Staphylococcus spp.* during ambient storage of *Kilishi* (West African traditional dried meat product. Eke *et al.*, (2013) reported that use of citric acid significantly increase the protein quality of *Dambu-Nama* and may as well increase the shelf-stability due to the reduction of the activity of micro-organisms. . Addition of both vinegar and sake was found to be an efficient means of improving the microbial stability of the sous vide packaged seasoned beef product stored at 8 and 20^0C. Combined addition of vinegar and sake may be considered as a possible alternative with minimal loss of organoleptic quality when longer storage is required like usual use conditions of sous vide packaging (Jae *et. al.*, 2006).

Addition of 3% Nacl and 0.3% citric acid on fresh coconut gratings extend it shelf life by one month under ambient conditions and by three months under refrigeration conditions (Gunathilake, 2006). Drastic growth inhibition of *Aspergillus flavus* and *A. niger* was reported by Ilondu and Iloh (2007) in *Zobo* (traditional sorrel drink) treated with spices and subjected to heating after production. Jose *et. al.* (2008) reported that addition of ascorbic acid, potassium sorbate, and sodium bisulphite into sugar syrup can retain the colour of fresh mango slice for a period of 30 days. Jyoti *et. al.*, (2013) reported that combination of salt (8%), Citric acid (300ppm), potassium

metabisulphite (300ppm) and sodium benzoate (300ppm) is the best hurdle treatment for low cost preservation of cauliflower. This treatment can extend the shelf life of cauliflower to 180 days when store at temperature between 30-37°C. The combination of hurdles osmotic dehydration, infrared drying, HDPE packaging and a radiation dose of 1 kGy were proved to be effective in extending the shelf life of pineapple slices up to 4 months under ambient storage (Sujatha, 2014).
On the other hand, hurdle could have a negative effect on foods, depending on its intensity. For instance, chilling to low temperature is detrimental to some foods of plant origin (chilling injury), whereas moderate chilling will be beneficial for their shelf life. Another example is the pH of fermented sausage which should be low enough to inhibit pathogenic bacteria, but not so low to impair taste. If the intensity of a particular hurdle in a food is too small it should be strengthened, if it is detrimental to the food quality it should be lowered. By this adjustment, hurdles in foods can be kept in the optimal range, using safety as well as quality, and thus the total quality a food (Leistner, 2000). Jae *et al.,* (2006) reported that addition of vinegar and sake lowered the hedonic scores of sous vide packaged seasoned beef.

4.4 Advantages of Hurdle technology over other preservation methods

1. The greatest advantage of hurdle technology is tendency to conquer the ability of microorganisms in developing resistance to conventional preservation methods because in combine technology different preservative acts synergistically by hitting different targets within the cell of the spoilage microorganism.
2. Hurdles are use at lower concentrations this prevent the undesired side effects, lower production cost and save energy
3. Another advantage is the opportunity of using natural preservatives in combination with synthetic preservatives, this also lower the risk associated with using synthetic preservatives at high concentration
4. Possibility of increasing shelf-stable foods; because food preserved by combined methods (hurdles) remains stable and safe even without refrigeration, and is high in sensory and nutritive value due to the gentle process applied (FOA, 2006).

Conclusion

Hurdle technology is an important approach that can be used to improve quality parameters during processing and storage of food. Smart application of hurdles improve sensory characteristics, chemical and microbiological qualities of food. More than 60 hurdles reported to be available, these can be use in different combinations and concentrations in wide range of foods. This versatility make the application of the technology possible in both modern and local food processing.

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