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Paper Title: The Principles of the Food Processing & Preservation

Module No. : 27

Module Title: Hurdle Technology

27.0 Hurdle technology

Hurdle technology (also called combined methods, combined processes, combination reservation, combination techniques or barrier technology) was developed several years ago as a new concept for the production of safe, stable, nutritious, tasty and economical foods. It advocates the intelligent use of combinations of different preservation factors or techniques (hurdles) in order to achieve multi-target, mild but reliable preservation effects in foods. Attractive applications have been identified in many food areas. Hurdle technology also advocates the deliberate combination of existing and novel preservation techniques in order to establish a series of preservative factors (hurdles) that any microorganisms present should not be able to overcome.

27.1 History and definition

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. 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, a high solids content (reduced water activity) and high acidity. In vegetable fermentation, the desired product quality and microbial stability are achieved by a combination of factors such as salt, acidification, and so forth.

In recent years, the concept of combining several factors has been developed by Leistner (1995) and others into the ó*hurdle effect*ô. From an understanding of the hurdle effect, hurdle technology has been derived, which has the goal not just to understand why a certain food is safe and stable, but to improve the quality of the food by an optimization and intelligent modification of the hurdles present. It employs the intelligent combination of different hurdles or preservation techniques to achieve multi-target, mild but reliable preservation effects. Hurdle technology has arisen in response to a number of developments;

(i) Consumer demands for healthier foods that retain their original nutritional properties
(ii) The shift to ready-to-eat and convenience foods which require little further processing by consumers
(iii) Consumer preference for more ónaturalô food which require less processing and fewer chemical preservatives.

Hurdle technology provides a framework for combining a number of milder preservation techniques to achieve an enhanced level of product safety and stability. Some of the most important hurdles used and examples of hurdles for food preservation are as follows (Table 1 & 2):

Table 1. Most important hurdles for food preservation

Symbol	Parameter	Application
F	High temperature	Heating
T	Low temperature	Chilling, freezing
aw	Reduced water activity	Drying, curing, conserving
pH	Increased acidity	Acid addition or formation

Eh	Reduced redox potential	Removal of oxygen or addition of ascorbate
Pres.	Preservatives	Sorbate, sulfite, nitrite
c.f.	Competitive flora	Microbial fermentations

Table 2: Examples of hurdles used to preserve foods

Type of hurdle	Examples
Physical hurdles	Aseptic packaging, electromagnetic energy (microwave, radio frequency, pulsed magnetic fields, high electric fields), high temperatures (blanching, pasteurization, sterilization, evaporation, extrusion, baking, frying), ionic radiation, low temperature (chilling freezing), modified atmospheres, packaging films (including active packaging, edible coatings), photodynamic inactivation, ultra-high pressures, ultrasonication, ultraviolet radiation
Physico-chemical hurdles	Carbon dioxide, ethanol, lactic acid, lactoperoxidase, low pH, low redox potential, low water activity, Maillard reaction products, organic acids, oxygen, ozone, phenols, phosphates, salt, smoking, sodium nitrite/nitrate, sodium or potassium sulphite, spices and herbs, surface treatment agents
Microbially derived hurdles	Antibiotics, bacteriocins, competitive flora, protective cultures

27.2 Mechanism

Microorganisms react homeostatically to stress factors. When their environment is disturbed by a stress factor, they usually react in ways that maintain some key element of their physiology constant. Microorganisms undergo many important homeostatic reactions (Table 3). Preservative factors functioning as hurdles can disturb one or more of the homeostasis mechanisms, thereby preventing microorganisms from multiplying and causing them to remain inactive or even die. Therefore, food preservation is achieved by disturbing the homeostasis of microorganisms. The best way to do this is to deliberately disturb several homeostasis mechanisms simultaneously thus a combination of multiple hurdles (hurdle technology) could increase the effectiveness of food preservation.

The success of hurdle technology depends on ensuring metabolic exhaustion. Most stress reactions of microorganisms are active processes, and this often involves the expenditure of energy, e.g. to transport protons across the cell membrane, to maintain high cytoplasmic concentrations of ósmoregulatoryô or ócompatibleô solutes. Restriction of the availability of energy is then a sensible target to pursue. This probably forms the basis of many the successful, empirically derived, mild combination preservation procedures exemplified by hurdle technology. As an example, if a food can be preserved by lowering the pH, then it is sensible also to include a weak acid preservative which will amplify the effect of the protons or to allow a milder, higher pH to be employed. It is sensible if proton export is made more difficult by the additional requirement that cells be forced to regulate osmotic strength. Then, if the food can be enclosed in oxygen-free vacuum or modified atmosphere packaging, facultative anaerobes will be further energy-restricted at a time when the various stress and homeostatic reactions are demanding more energy if growth is to proceed. However, environmental stresses can provide varying results because some bacteria may become more resistant or even more virulent under stresses through stress reactions such as synthesis of protective stress shock proteins.

It has been reported that synthesis of protective stress shock proteins is induced by several stresses including heat, pH, aw, ethanol, oxidative compounds, and starvation. And, although each stress has a different spectrum of antimicrobial action, those stress reactions might have a non-specific effect, since due to a particular stress, microorganisms become also more tolerant to other stresses i.e. ócross-toleranceô. For instance, acid-shock or acid-adapted cells became tolerant to a range of other environmental stresses in several pathogenic bacteria including *E. coli* O157:H7, *S. typhimurium*, and *L. monocytogenes*. Conversely, the heat shock response that follows mild heating can result in cells becoming more acid tolerant. Therefore, the various stress responses of microorganisms might hamper food preservation and could turn out to be problematic for the application of hurdle technology when hurdles are used consecutively. However, the use of different stresses at the same time (combination treatment) may also prevent the synthesis of those protective proteins because simultaneous exposure to different stresses will require energy-consuming synthesis of several or at least much more protective stress shock proteins which in turn may cause the microorganisms to become metabolically exhausted. This antimicrobial action of combining hurdles is known as ómulti-target preservationô introduced by Leistner (1995).

Table 3: Homeostatic responses to stress by microorganisms

Stress factor	**Homeostatic response**
Low levels of nutrients	Nutrient scavenging; oligotrophy; óstationary-phase responseô; generation of óviable non-culturableô forms
Lowered pH	Extrusion of protons across the cell membrane; maintenance of cytoplasmic pH; maintenance of transmembrane pH gradient
Lowered water activity	Osmoregulation; accumulation of ócompatible solutesô; avoidance of water loss; maintenance of membrane turgor
Lowered temperature for growth	óCold shockô response; changes in membrane lipids to maintain satisfactory fluidity
Raised temperature for growth	óHeat shockô response; membrane lipid changes
Raised levels of oxygen	Enzyme protection (catalase, peroxidase, superoxide dismutase) from H2O2 and oxygen-derived free radicals
Presence of biocides	Phenotypic adaptation; reduction in cell wall/membrane permeability
High hydrostatic pressure	Uncertain; possibly low spore water content
Ionizing radiation	Repair of single-strand breaks in DNA
High voltage electric discharge	Low electrical conductivity of the spore protoplast
Competition from other microorganisms	Formation of interacting communities; aggregates of cells showing some degree of symbiosis; biofilms

The concept of multi-target preservation increases the effectiveness of food preservation by using a combination of different hurdles which have different spectra of antimicrobial actions. It has been suspected for some time that combining different hurdles for good preservation might not have just an additive effect on microbial stability, but they could act synergistically. A synergistic effect could be achieved if the hurdles in a food hit, at the same time, different targets (e.g. cell membrane, DNA, enzyme systems, pH, aw, Eh) within the microbial cells and thus disturb the homeostasis of the microorganisms present in several respects. Thus repair of homeostasis as well as the activation of stress shock proteins becomes more difficult. Therefore, simultaneously employing different hurdles in the preservation of a particular food should lead to optimal microbial stability. In addition, no one preservative factor is active against all the spoilage microorganisms present in foods. Therefore attempts have been made to compensate for this deficiency by combining various preservative factors having different spectra of action. Since from this multitargeted approach, hurdle technology could be more effective than single targeting, it allows the use of individual hurdles of lower intensity for improving product quality as well as for food preservation.

27.3 Limitations

As described above, 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. However, although hurdles are applied simultaneously in combined form, there are three possible results whereby the action may be changed by combining two or more preservative factors:

(i) Addition or additive effect: The term additive effect denotes that the effects of the individual substances are simply added together.
(ii) Synergism or synergistic effect: Synergistic effect is the expression used when the inhibitory action of the combination is reached at a concentration lower than that of the constituent substances separately.
(iii) Antagonism or antagonistic effect: An antagonistic effect is the opposite of this latter, i.e. one where the mixture concentration required is higher than that of the individual constituents.

Among these results, first two are desirable results and the main reason the hurdle technology is employed for food preservation rather than one hurdle. Generally, it is accepted that the combination of hurdles has a higher inhibitory effect than any single hurdle. However, recently, some studies showed that combination treatments were less effective at reducing levels of microorganism than were single treatments. These effects of combining hurdles were antagonistic. In some cases, application of the hurdle concept for food preservation may inhibit outgrowth but induce prolonged survival of microorganisms in foods. The various responses of microorganisms under mild stress conditions of hurdle technology might hamper food preservation and could turn out to be problematic for the application of hurdle technology. However, no general statements can be made about the actions of any particular preservative method on other factors. Additionally, in many studies, any synergistic effects observed in laboratory tests were so weak as to have no significance for practical food preservation. It was mainly for commercial reasons that most combination products formerly marketed in large numbers were preferred to straight preservations.

Although some combinations of hurdles showed less or not significant effectiveness for killing microorganisms in foods, many promising hurdles have been identified so far. However, the application of the idea in the food industry has been largely restricted to the meat sector. Recent studies, however, emphasize a much wider potential application, e.g., in bakery products, fish, and dairy products, More specifically, the concept was introduced into mild processing of fruits and vegetables. However, there is only limited information available about the effect of combined hurdles in these types of foods. The vast majority of preserved foods that are consumed in different countries rely on combinations of preservative factors for their stability and microbiological safety. Therefore, it will be important to understanding the interactions of different hurdles in various foods to find types and intensity of that hurdles are needed for the desired microbial safety and stability of a particular food.

27.4 Conclusion

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, and more recently on knowing employed hurdle technology. 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. The disturbance of the homeostasis of microorganisms is the main mechanism of food preservation. And the 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 (ómultitarget preservationö). Although recently, there have been many studies that investigated the effect of combining hurdles in laboratory media and foods, the interactions of many hurdles are still not clear. Also, studies of hurdle technology have been restricted to specific foods such as meat and fruit products. A better understanding of the occurrence and interactions of different preservative factors (hurdles) in foods can form a powerful and logical basis for improvements in food preservation. If all the hurdles operating in a particular food are known, the microbial stability and safety of that food, and its quality, might be optimized by changing the intensity or the character of these hurdles.

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