HURDLE TECHNOLOGY

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Keywords: Food preservation, combined processes, hurdle effect, hurdle technology, basic aspects, microbial stability and safety, sensory quality, nutritional properties, total quality, minimally processed foods, healthful and functional foods, advanced food packaging, industrialized countries, developing countries, perspectives of food preservation.

Contents

Summary

Microbial stability and safety, as well as sensoric and nutritional quality of most foods, are based on a combination of several preservative methods (i.e., heating, chilling, drying, salting, curing, acidification, oxygen removal, and fermentation). For centuries, combined methods were applied empirically in food preservation. After the factors (F, t, a_w, pH, Eh, competitive flora, etc.) governing the traditional methods of food preservation were better understood, their interaction was studied. The preservative factors were called hurdles and their interactions the hurdle effect. The logical next step was to modify and optimize the hurdles in foods. This approach was called intelligent hurdle technology. Moreover, physiological aspects of micro-organisms (homeostasis, metabolic exhaustion, and stress reactions) were taken into consideration in order to improve the stability and safety of hurdle-technology foods. The ambitious goal for a gentle but more effective preservation of foods is now multitarget preservation (i.e., hitting simultaneously several essential targets within the microbial cells by hurdles taken from different target classes). This would lead to a synergistic effect of hurdles and could advance food preservation far beyond the state-of-the-art known today. More than 60 potential hurdles for the preservation of foods have been described and the number of useful hurdles is by no means complete. Even the most advanced food preservation methods (e.g., pulsed technologies) are more effective if applied in combination with traditional hurdles. Therefore, hurdle technology in the future will probably remain the cornerstone of food preservation. It is gratifying to learn that intelligent hurdle technology is equally applicable in industrialized and developing countries for the preservation of foods. Recent examples of its application are outlined in this contribution.

1. Introduction

For time immemorial, food preservation has been necessary to supply food between harvest peaks and in times of need. Several preservation methods, such as heating, chilling, freezing, drying, salting, sugar addition, acidification, fermentation, removal of oxygen, and addition of preservatives have emerged over the centuries from empirical observations. However, only in the last century have the principles behind these traditional food preservation methods been elucidated. Moreover, a quantitative approach has been introduced that expresses heating in F values, chilling in t values, drying in a_w values, acidity in pH values, removal of oxygen in Eh values, etc. The traditional food preservation methods, and therefore the underlying preservative factors, are often applied in combination.

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 factors (*hurdles*), and more recently on knowingly employed hurdle technology. Deliberate and intelligent application of hurdle technology allows a gentle, efficient preservation of foods, which is advancing world wide. Various expressions for the same concept in different languages are now used: Hürden-Technologie in German, hurdle technology in English, technologie des barrières in French, barjernaja technologija in Russian, technologia degli ostacoli in Italian, technologia de obstaculos in Spanish, shogai gijutsu in Japanese, and zanglangishu in Chinese. Therefore, hurdle technology is a contribution to global sustainable development.

Knowledge of the basic aspects related to hurdle technology (i.e., homeostasis, metabolic exhaustion, and stress reactions of micro-organisms) has also advanced in recent years. This has paved the way for the application of multitarget preservation of foods, which is the ambitious goal of the future in food preservation. In this contribution, the principles of hurdle technology, basic aspects, and advanced applications of hurdle technology in industrialized and developing countries are discussed, including food design based on hurdle technology. The conclusions section will summarize the state-of-the-art and will point out the perspectives of food preservation by hurdle technology.

2. Principles of Hurdle Technology

The most important hurdles commonly used in food preservation are temperature (high or low), water activity (a_w) (see *Colligative Properties*), acidity (pH), redox potential (Eh), preservatives (nitrite, sorbate, sulfite, etc.), and competitive micro-organisms (e.g., lactic acid bacteria). More than 60 potential hurdles for foods of animal or plant origin, which improve the microbial stability and/or the sensory quality of these products, have been already described, and the list of possible hurdles for food preservation is by no means complete. At present, physical, non-thermal processes (high hydrostatic pressure, oscillating magnetic fields, pulsed electric fields, light pulses, etc.) receive considerable attention (see *Nonthermal Processing*), since in combination with other conventional hurdles they are of potential use for the microbial stabilization of fresh-like food products, with little degeneration of nutritional and sensory properties. Another group of hurdles, of special interest in industrialized and developing countries at present, would be 'natural preservatives' (spices and their extracts, lysozyme, chitosan, pectine hydrolysate, etc.). In most countries, these 'green preservatives' are preferred because they are not synthetic chemicals, but in some developing countries, they are given preference, since spices are readily available and cheaper than imported chemicals.

The critical values of many preservative factors for the death, survival, or growth of micro-organisms in foods have been determined in recent decades and are now the basis of food preservation. However, the critical value of a particular parameter changes if additional preservative factors are present in the food. For instance, it is well known that the heat resistance of bacteria increases at low a_w and decreases at low pH or in the presence of preservatives, whereas low Eh increases the inhibition of micro-organisms due to reduced a_w. The simultaneous effect of different preservative factors (hurdles) could be additive or even synergistic. In food preservation, the combined effect of preservative factors must be taken into account, which is illustrated by the hurdle effect.

2.1. Hurdle Effect

For every microbiologically stable and safe food, a certain set of hurdles is inherent, which differs in quality and intensity, depending on the particular product. In any case, the hurdles must keep the 'normal' population of micro-organisms in the food under control. The micro-organisms present ('at the start') in a food should not be able to overcome (i.e., 'leap over') the hurdles inherent in this food. This is illustrated by the so-called hurdle effect, which is of fundamental importance for the preservation of foods, since the hurdles in a stable product control microbial spoilage and food poisoning as well as desired fermentation processes.

Some examples will facilitate the understanding of the hurdle effect, presented in Figure 1. Example 1 represents a food containing six hurdles: high temperature during processing (F value), low temperature during storage (t value), water activity (a_w), acidity (pH), redox potential (Eh), and preservatives (pres.). The micro-organisms present cannot overcome these hurdles, and thus the food is microbiologically stable and safe. However, example 1 is only a theoretical case, because all of the hurdles are of the same height (i.e., intensity), and this rarely occurs. A more likely situation is presented in example 2, since the microbial stability of this product is based on hurdles of different intensity.

In this particular product, the main hurdles are a_w and preservatives, whereas other less important hurdles are storage temperature, pH, and redox potential. These five hurdles are sufficient to inhibit the usual types and numbers of micro-organisms associated with such a product. If only a few micro-organisms are present (‘at the start’), a few or low number of hurdles will be sufficient for the stability of the product (example 3).

The super clean or aseptic packaging of perishable foods is based on this principle. On the other hand, as in example 4, if due to bad hygienic conditions, too many undesirable micro-organisms are initially present, even the usual hurdles inherent to a product may be unable to prevent spoilage or food poisoning. Example 5 is a food rich in nutrients and vitamins, which could foster the growth of micro-organisms (called the booster or trampoline effect), and thus the hurdles in such a product must be enhanced, or otherwise be overcome.

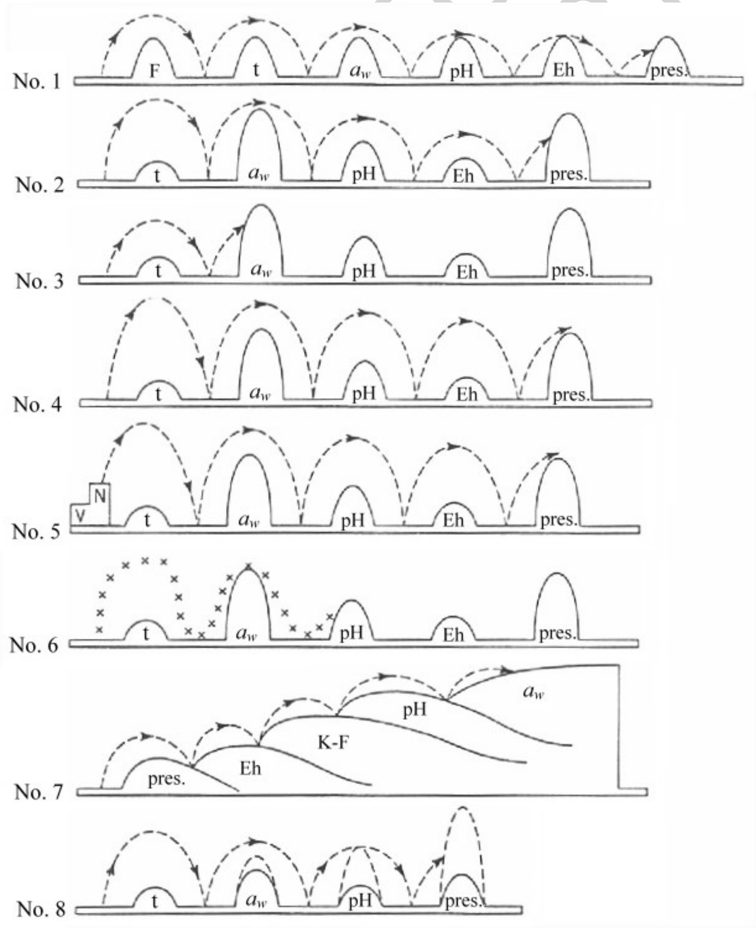

Figure 1. Eight examples of the hurdle effect that facilitate understanding of the application of hurdle technology in food preservation. See text for details. Symbols have

the following meaning: F, heating; t, chilling; a_w, water activity; pH, acidification; Eh, redox potential; pres., preservatives; K-F, competitive flora; V, vitamins; N, nutrients. [Source: Leistner L. (1992). Food preservation by combined methods. *Food Research International* **25**, 151-158.]

Example 6 illustrates the behavior of sub-lethally damaged organisms in food. For instance, if the bacterial spores in a food are damaged sub-lethally by heat, the vegetative cells derived from such spores will lack vitality; therefore, they will be inhibited by fewer or lower hurdles. In some foods, stability is achieved during processing by a sequence of hurdles, which are important in different stages of a fermentation or ripening process and lead to a stable final product.

A sequence of hurdles operates in fermented sausages (example 7), and probably in ripened cheeses or fermented vegetables. Finally, example 8 illustrates the possible synergistic effect of hurdles, which likely relates to a multitarget disturbance of the homeostasis of micro-organisms in foods.

2.2. Hurdle Technology

A better understanding of the impact and interaction of different preservative factors (hurdles) in foods is the basis for improvements in food preservation, because if the hurdles in a food are known and their interaction visualized, the microbial stability and safety of this food might be optimized by changing the intensity and quality of these hurdles. Understanding the hurdle effect is the key to understanding the effectiveness of traditional preservation methods for foods. The next step is the optimization of traditional foods, as well as the development of novel products by an intelligent combination of hurdles. Thus, from an understanding of the hurdle effect, hurdle technology has been derived, which means that hurdles can be deliberately combined in the preservation of traditional and novel foods. By using an intelligent mix of hurdles, it is possible to improve not only the microbial stability and safety, but also the sensory and nutritional quality of a food. Hurdle technology is increasingly used in industrialized and developing countries for the optimization of traditional foods and for making new products according to needs. For instance, when energy preservation is the goal, energy-consuming hurdles such as refrigeration and freezing (see *Food Freezing*) are replaced by other hurdles (a_w, pH, or Eh) that demand little energy, but still ensure a stable and safe food. Furthermore, if preservatives (e.g., nitrite in meats) are reduced or replaced, other hurdles (e.g., a_w, pH, refrigeration, or competitive micro-organisms) could be employed to stabilize the product. Recent examples related to the application of hurdle technology will be given in section 6 of this contribution.

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Biographical Sketch

Lothar Leistner has worked for 30 years as Director and Professor at the Federal Centre for Meat

Research of Germany, as well as for seven years at renowned research institutes in France and the USA. He has specialized in microbiology, technology, and the toxicology of food. Since retirement in 1992, he has concentrated on hurdle technology, which secures mild and effective preservation of foods, even without refrigeration. This innovative, sustainable approach is applicable to foods in industrialized as well as developing countries, and has attained enormous popularity. Leistner has been invited in the last decade to 50 different countries world wide, many times, for lectures and consultancies on hurdle technology. The first comprehensive book on hurdle technologies, *Hurdle Technologies: Combination Treatments for Food Stability, Safety and Quality* (ISBN 0-306-47263-5, 194 pages), was authored by Lothar Leistner and Grahame Gould, published in 2002 by Kluwer Academic / Plenum Publishers, New York.