ELSEVIER
International Journal of Food Microbiology 55 (2000) 181–186
INTERNATIONAL JOURNAL OF Food Microbiology
www.elsevier.nl/locate/ijfoodmicro

Review

Basic aspects of food preservation by hurdle technology

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Abstract

Hurdle technology is used in industrialized as well as in developing countries for the gentle but effective preservation of foods. Previously hurdle technology, i.e., a combination of preservation methods, 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 (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 behaviour of microorganisms in foods, i.e. their homeostasis, metabolic exhaustion, stress reactions, are taken into account, and the novel concept of multitarget food preservation emerged. In the present contribution a brief introduction is given on the potential hurdles for foods, the hurdle effect, and the hurdle technology. However, emphasis is placed on the homeostasis, metabolic exhaustion, and stress reactions of microorganisms related to hurdle technology, and the prospects of the future goal of a multitarget preservation of foods.

Keywords: Food preservation; Hurdle technology; Homeostasis; Metabolic exhaustion; Stress reactions; Multitarget preservation

1. Introduction

The microbial safety and stability as well as the sensory and nutritional quality of most foods is based on an application of combined preservative factors (called hurdles). This is true for traditional foods with inherent empirical hurdles as well as for novel products for which the hurdles are intelligently selected and then intentionally applied (Leistner, 1995a).

1.1. Hurdles in foods

The most important hurdles used in food preservation are temperature (high or low), water activity (a_w), acidity (pH), redox potential (Eh), preservatives (e.g., nitrite, sorbate, sulfite), and competitive microorganisms (e.g., lactic acid bacteria). However, more than 60 potential hurdles for foods, which improve the stability and/or quality of the products, have been already described, and the list of possible hurdles for food preservation is by no means complete (Leistner, 1999a). Some hurdles (e.g., Maillard reaction products) will influence the safety and the quality of foods, because they have antimicrobial properties and at the same time improve the flavour of the products. The same hurdle could have a

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0168-1605/00/$ – see front matter
PII: S0168-1605(00)00161-6

positive or a negative effect on foods, depending on its intensity. For instance, chilling to an unsuitable 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 as 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, considering safety as well as quality, and thus the total quality of a food (Leistner, 1994a).

For each stable and safe food a certain set of hurdles is inherent, which differs in quality and intensity depending on the particular product, but 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 should not be able to overcome ('leap over') the hurdles present during the storage of a product, otherwise the food will spoil or even cause food poisoning. This situation is illustrated by the hurdle effect, first introduced by Leistner (1978), which is of fundamental importance for the preservation of intermediate-moisture foods (Leistner and Rödel, 1976) as well as high-moisture foods (Leistner et al., 1981).

2. Hurdle technology

From an understanding of the hurdle effect, the hurdle technology has been derived (Leistner, 1985), which means that hurdles are deliberately combined to improve the microbial stability and the sensory quality of foods as well as their nutritional and economic properties. Thus, hurdle technology aims to improve the total quality of foods by application of an intelligent mix of hurdles. Over the years the insight into the hurdle effect has been broadened and the application of hurdle technology was extended (Leistner and Gorris, 1994).

In *industrialized countries* the hurdle technology approach is currently of most interest for minimally processed foods which are mildly heated or fermented (Leistner, 2000), and for underpinning the microbial stability and safety of foods coming from future lines, e.g., healthful foods with less fat and/or salt (Leistner, 1997) or advanced hurdle-technology foods requiring only minimal packaging (Kentaro Ono, Snow Brand Tokyo, Japan, personal communication, 1996; Leistner, 1996). For refrigerated foods chill temperatures are the major and sometimes the only hurdle. However, if exposed to temperature abuse during distribution of the foods, this hurdle breaks down, and spoilage or food poisoning could happen. Therefore, additional hurdles should be incorporated as safeguards into chilled foods, using an approach called 'invisible technology' (Leistner, 1999a).

In *developing countries* the application of hurdle technology for foods that remain stable, safe, and tasty if stored without refrigeration is of paramount importance, and has made impressive strides, especially in Latin America with the development of novel minimally processed, high-moisture fruit products. However, much interest in intentional hurdle technology is also emerging for meat products in China as well as for dairy products in India. There is a general trend in developing countries to move gradually away from intermediate-moisture foods, because they are often too salty or too sweet and have a less appealing texture and appearance than high-moisture foods, and this goal could be achieved by the application of intelligent hurdle technology. The progress made in the use of advanced hurdle technology in Latin America, China, India, and Africa has recently been reviewed by Leistner (1999b).

3. Basic aspects

Food preservation implies putting microorganisms in a hostile environment, in order to inhibit their growth or shorten their survival or cause their death. The feasible responses of microorganisms to this hostile environment determine whether they may grow or die. More research is needed in view of these responses; however, recent advances have been made by considering the homeostasis, metabolic exhaustion, and stress reactions of microorganisms in relation to hurdle technology, as well as by introducing the novel concept of multitarget preservation for a gentle but most effective preservation of hurdle-technology foods (Leistner, 1995a,b).

3.1. Homeostasis

Homeostasis is the tendency to uniformity and stability in the internal status of organisms. For instance, the maintenance of a defined pH is a prerequisite and feature of living cells, and this applies to higher organisms as well as to microorganisms (Häussinger, 1988). Much is already known about homeostasis in higher organisms at the molecular, subcellular, cellular, and systemic levels in the fields of pharmacology and medicine (Häussinger, 1988). This knowledge should be transfered to microorganisms important for the poisoning and spoilage of foods. In food preservation the homeostasis of microorganisms is a key phenomenon which deserves much attention, because if the homeostasis of these microorganisms is disturbed by preservative factors (hurdles) in foods, they will not multiply, i.e. they remain in the lag-phase or even die, before homeostasis is repaired (re-established). Therefore, food preservation is achieved by disturbing the homeostasis of microorganisms in a food temporarily or permanently. Gould (1988, 1995) was the first to draw attention to the interference by the food with the homeostasis of the microorganisms present in this food, and more work in this direction is certainly warranted.

3.2. Metabolic exhaustion

Another phenomenon of practical importance is metabolic exhaustion of microorganisms, which could cause ‘autosterilization’ of a food. This was first observed in experiments with mildly heated (95°C core temperature) liver sausage adjusted to different water activities by the addition of salt and fat, and the product was inoculated with *Clostridium sporogenes* and stored at 37°C. Clostridial spores surviving the heat treatment vanished in the product during storage, if the products were stable (Leistner and Karan-Djurdjić, 1970). Later this behaviour of *Clostridium* and *Bacillus* spores was regularly observed during storage of shelf stable meat products (SSP), if these products were stored at ambient temperature (Leistner, 1994b). The most likely explanation is that bacterial spores which survive the heat treatment are able to germinate in these foods under less favourable conditions than those under which vegetative bacteria are able to multiply (Leistner, 1992). Thus, the spore counts in stable hurdle-technology foods actually decrease during storage of the products, especially in unrefrigerated foods. Also during studies in our laboratory with Chinese dried meat products the same behaviour of microorganisms was observed. If these meats were contaminated after processing with staphylococci, salmonellae or yeasts, the counts of these microorganisms on stable products decreased quite fast during unrefrigerated storage, especially on meats with a water activity close to the threshold for microbial growth. Latin American researchers (Alzamora et al., 1995; Tapia de Daza et al., 1996) observed the same phenomenon in studies with high-moisture fruit products, because the counts of a variety of bacteria, yeasts, and moulds which survived the mild heat treatment, decreased fast in the products during unrefrigerated storage, since the hurdles applied (pH, a_w, sorbate, sulfite) did not allow growth.

A general explanation for this surprising behaviour might be that vegetative microorganisms which cannot grow will die, and they die more quickly if the stability is close to the threshold for growth, storage temperature is elevated, antimicrobials are present, and the microorganisms are sublethally injured (Leistner, 1995a). Apparently, microorganisms in stable hurdle-technology foods strain every possible repair mechanisms for their homeostasis to overcome the hostile environment, by doing this they completely use up their energy and die, if they become metabolically exhausted. This leads to an autosterilization of such foods (Leistner, 1995b). Due to autosterilization hurdle-technology foods, which are microbiologically stable, become more safe during storage, especially at ambient temperatures. For example, salmonellae that survive the ripening process in fermented sausages will vanish more quickly if the products are stored at ambient temperature, and they will survive longer and possibly cause foodborne illness if the products are stored under refrigeration (Leistner, 1995a). It is also well known that salmonellae survive in mayonnaise at chill temperatures much better than at ambient temperatures. Unilever laboratories at Vlaardingen have confirmed metabolic exhaustion in water-in-oil emulsions (resembling margarine) inoculated with

Listeria innocua. In these products listeria vanished faster at ambient temperature (25°C) than under refrigeration (7°C), at pH 4.25 > pH 4.3 > pH 6.0, in fine emulsions more quickly than in coarse emulsions, under anaerobic conditions more quickly than under aerobic conditions. From these experiments it has been concluded that metabolic exhaustion is accelerated if more hurdles are present, and this might be caused by increasing energy demands to maintain internal homeostasis under stress conditions (P.F. ter Steeg, personal communication, 1995). Thus, it could be concluded that refrigeration is not always beneficial for the microbial safety and stability of foods. However, this is only true if the hurdles present in a food inhibit the growth of microorganisms also without refrigeration, if this is not the case then refrigeration is beneficial. Certainly, the survival of microorganisms in stable hurdle-technology foods is much shorter without refrigeration.

3.3. Stress reactions

Some bacteria become more resistant or even more virulent under stress, since they generate stress shock proteins. The synthesis of protective stress shock proteins is induced by heat, pH, a_w, ethanol, oxidative compounds, etc. as well as by starvation. Stress reactions might have a non-specific effect, since due to a particular stress microorganisms become also more tolerant to other stresses, i.e. they acquire a ‘cross-tolerance’. The various responses of microorganisms under stress might hamper food preservation and could turn out to be problematic for the application of hurdle technology. On the other hand, the activation of genes for the synthesis of stress shock proteins, which help organisms to cope with stress situations, should be more difficult if different stresses are received at the same time. 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. Therefore, multitarget preservation of foods could be the key to avoiding synthesis of stress shock proteins, which otherwise could jeopardize the microbial stability and safety of hurdle-technology foods (Leistner, 1995b).

3.4. Multitarget preservation

The concept of multitarget preservation of foods has been introduced recently by Leistner (1995a,b). Multitarget preservation of foods should be the ambitious goal for a gentle but most effective preservation of foods (Leistner, 1995b). It has been suspected for some time that different hurdles in a food might not have just an additive effect on microbial stability, but they could act synergistically (Leistner, 1978). 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, a_w, Eh) within the microbial cells and thus disturb the homeostasis of the microorganisms present in several respects. If so, the repair of homeostasis as well as the activation of stress shock proteins become more difficult (Leistner, 1995a). Therefore, employing simultaneously different hurdles in the preservation of a particular food should lead to optimal microbial stability. In practical terms, this could mean that it is more effective to employ different preservative factors (hurdles) of small intensity than one preservative factor of larger intensity, because different preservative factors might have a synergistic effect (Leistner, 1994a).

It is anticipated that the targets in microorganisms of different preservative factors for foods will be elucidated, and that hurdles could then be grouped in classes according to their targets. A mild and effective preservation of foods, i.e. a synergistic effect of hurdles, is likely if the preservation measures are based on intelligent selection and combination of hurdles taken from different target classes (Leistner, 1995a). This approach is probably not only valid for traditional food-preservation procedures, but as well for modern processes such as food irradiation, ultrahigh pressure, pulsed technologies (Barbosa-Cánovas et al., 1998). Food microbiologists could learn from pharmacologists, because the mechanisms of action of biocides have been studied extensively in the medical field. At least 12 classes of biocides are already known which have different targets, and sometimes more than one, within the microbial cell. Often the cell membrane is the primary target, becoming leaky and disrupting the organism, but biocides also impair the synthesis of enzymes, proteins, and DNA (Denyer and Hugo, 1991). Multidrug attack has proven successful in the medical field to fight bacterial infections (e.g., tuberculosis) as well as viral infections (e.g., AIDS), and thus a multitarget attack on microorganisms should also be a promising approach in food microbiology (Leistner, 1995b).

4. Conclusions

The physiological responses of microorganisms during food preservation (i.e., their homeostasis, metabolic exhaustion, and stress reactions) are the basis for the application of advanced hurdle technology. The disturbance of the homeostasis of microorganisms is the key phenomenon of food preservation. Microbial stress reactions may complicate food preservation, whereas the metabolic exhaustion of microorganisms present in stable hurdle-technology foods could foster food preservation. The novel and ambitious goal for an optimal food preservation is the multitarget preservation of foods, in which intelligently applied gentle hurdles will have a synergistic effect. After the targets of different preservative factors within the microbial cells have been elucidated, and this should become definitely a major research topic in the future, preservation of foods could progress far beyond the state-of-the-art of the hurdle technology approach as we know it today.

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