Production of Safe Foods: Global Strategies

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Abstract

There is a worldwide demand for high-quality foods that are both fresh tasting and nutritious, which has created considerable interest and investment in the development of new or improved post-harvest storage and food-processing techniques. Competition for markets, which results from more liberalized trade requires a much greater emphasis on efficient and effective post-harvest handling, processing and distribution to access markets further afield. Consumers are demanding fresher and safer products, around the globe. This has created incentives to use improved post-harvest storage methods, as well as new and emerging, non-thermal technologies to produce safe foods. The challenges of free trade will require smaller commercial operations to seek strategic new linkages in order to survive. The food industry is a profession which will continue to ensure sustainable and nourishing safe, high quality food to meet market demands.

Keywords: Safe foods, high-quality foods, fresh foods, food loss prevention, food processing techniques, improved post-harvest, nutritious, hurdle technologies.

Introduction

There is a worldwide demand for high-quality foods that are both fresh tasting and nutritious, which has created considerable interest and investment in the development of new or improved post-harvest storage and food-processing techniques. Competition for markets, which results from more liberalized trade requires a much greater emphasis on efficient and effective post-harvest handling, processing and distribution to access markets further afield. Traditional food-processing technologies such as freezing and canning are no longer leading consumer demands. Although these methods contributed to improved food availability and safety in the past, conventional heating and cooling reduce many quality attributes of foods. Consumers are demanding fresher and safer products, around the globe. This has created incentives to use improved post-harvest storage methods, as well as new and emerging, non-thermal technologies to produce safe foods.

Factors leading to post-harvest food losses in developing countries include inefficient harvesting and handling methods, poor processing techniques, inadequate methods and storage and distribution and poor home preparation of foods. Losses are not calculated simply as weight or volume losses, but as quality losses as well.

The actual causes of volume and quality losses can be grouped into two main categories, the primary and secondary causes of post-harvest losses.

Primary Causes

The primary causes of loss are those that directly affect the food. They may be classified into the following sub-groups:

Biological: The direct consumption of food by insects, rodents or birds; aside from material losses, levels of contamination by excreta, hair, webbing and odors can be so high that the food is condemned for human consumption.
**Microbiological:** The damage of stored food by fungi and bacteria; microorganisms can damage goods to the point where they become unacceptable because of rotting or other defects, such as aflatoxin, produced by moulds or unhealthy bacterial growth.

**Chemical:** Many of the natural chemical constituents present in foods can react, causing loss of color, flavor, texture and nutritional value; examples include the reactions that cause browning in dried fruits.

**Biochemical Reactions:** A large number of natural enzyme-activated reactions can occur in foods during storage, giving rise to off-flavors, discoloration and softening.

**Physiological:** Natural respiratory losses occur in all organisms, account for a significant level of weight loss, and can also generate damaging heat; changes during maturation, such as ripening, wilting and sprouting, increase the susceptibility of the product to mechanical damage or infection by pathogens; a reduction in nutrient level, such as vitamin C, and lower consumer acceptability can also accompany these changes.

Of the above primary causes, the biological, microbiological, physiological and mechanical factors are responsible for the majority of the losses in perishable crops. (Hicks 1983).

**Secondary Causes**

While primary causes do the actual damage, the secondary causes are those that encourage the conditions which result in the primary cause of loss. They are usually the result of inadequate training, inadequate or non-existent storage structures, unsuitable technologies and ineffective quality control.

**Magnitude of Losses**

Post-harvest losses are difficult to determine accurately. Depending upon the year and the country, it is possible to find individual cases with losses ranging anywhere from near zero up to 100%. This high variability depends on a number of conditions.

Staple foods such as cereal grains can be stored in good condition for several years, whereas perishable foods such as fruits and vegetables spoil quickly, unless given particular treatment such as controlled-atmosphere storage, canning, freezing or irradiation. Horticultural crops suffer from higher losses than cereals.

**Modern Post-harvest Technologies**

Chemical and physical post-harvest technologies are mainly used to reduce decay, physiological irregularities and to delay normal senescence metabolism.

**Physico-chemical Post-harvest Treatments to Control Spoilage**

Conventional post-harvest treatments by dipping, drenching or spraying are effective, but can be significantly influenced by the commodity and variety of spoilage organisms such as moulds. Naturally, commodities differ in their resistance to moulds as measured by the effectiveness of various anti-fungal compounds, as well as the effects of their specific morphologies (calcium content, waxy layers of the skin, etc.).

In addition to conventional chemicals such as benzimidazoles, thiazoles, phenols and sulfur, natural plant extracts are gaining increased attention and application. Products such as thymol, cinnamaldehyde, salicylaldehyde and chitosan or a mixture of extracts are currently being evaluated and others are already being marketed.

For some commodities, hot water treatment at 55°C for 2-7 min., or 42°C for 30-60 min., reduces disease appearance. Temperature-time regimes are commodity-specific and operate within narrow margins. The combination of irradiation and heat treatment is also being currently investigated.

**Post-harvest Cooling**

The competitive need to market products of higher quality and to extend shelf life to allow trade in more distant markets requires rapid cooling after harvest, especially for
berries and small fruits. All delays in the application of cooling will shorten shelf life. In addition to conventional cooling rooms, pre-cooling using vacuum and high velocity forced-air systems is also available. In developing countries, storage techniques are generally limited to mechanical cooling, forced air cooling or storage in naturally cool caves. These technologies can be complemented or optimized by proper ventilation or simple modified atmosphere systems. To preserve fruit and vegetables in developing countries, research on solar drying, lactic acid fermentation, fresh packing of fruit with added natural juice, containing high ascorbic acid levels and low pH, or even natural anti-browning agents, such as grapefruit or avocado seeds, is being encouraged.

In developed countries, fairly sophisticated storage techniques exist. Because of the rapidly increasing markets for horticultural products, requirements for compressor capacity have substantially increased. New, non-ozone depleting refrigerants are increasingly employed and a far greater use of modified or controlled atmospheres, ultra-low oxygen environments and ethylene rooms is now evident.

Fresh pack and minimally processed products are developing very quickly. Because of the nutritional and quality changes that result from traditional processing, a significant amount of research has been carried out to develop new methods of treating foods. Some of them are already commercial, while others still require fine-tuning to make them competitive with technologies currently being used. Although the destruction or inhibition of unwanted spoilage and disease organisms is the common goal of these technologies, the resultant end-products can be divided into two types. The first of these products is heat-processed and does not resemble natural, raw products in any way. The major advance is in the way the thermal treatment is carried out. The second type of process seeks to destroy or eliminate unwanted microorganisms without significantly changing the basic character of the food, so that the consumer can utilize it as a ‘fresh’ product, without the fear of food-borne disease.

**New and Emerging Food Technologies**

The most promising among these emerging technologies are food irradiation and high-pressure processing, followed by pulsed-electric fields and pulsed light applications. Although it is beyond the scope of this paper to cover these technologies in detail, a brief review of their applications in food processing is in order (Hicks 1998).

**Food Irradiation**

Food irradiation is a century-old process where foods are exposed to a highly penetrating form of energy – gamma rays or high-energy electrons. Because these forms of energy can fairly evenly penetrate solid foods, gamma rays and high-energy electrons can uniformly inactivate the DNA of unwanted microorganisms without changing the basic nature of the food itself. Fresh irradiated foods with exceptional hygienic and eating qualities are very similar to fresh, untreated foods, except for the label and, in some cases, an improved appearance and shelf life.

Food irradiation can be used on most fruits and vegetables, as well as meat, poultry, fish, shellfish and seafood, spices, potatoes, grains and a host of other commodities. Depending upon the food product and treatment in question, the cost of food irradiation varies between 1-10c/kg. Considering the benefits it provides to the practical and hygienic qualities of foods, this is a very reasonable price to pay for the benefits it brings to consumers. The use of irradiation as a quarantine treatment is well established and it is anticipated to have more widespread commercial use in future (IAEA 1991).

**High Pressure Processing**

Another method which is designed to maintain foods in their raw, natural state and only destroy the contaminating organisms is high-pressure processing. When organisms are placed under conditions of very high pressure, their proteins will be denatured, resulting in the
loss of enzymatic and biological activity. The organisms lose their viability and perish. This is more easily accomplished with vegetative bacteria than with spores, which require much higher pressures.

Other studies showed that high-pressure processing is beneficial in extending the shelf life of processed fruits. These early studies demonstrated that the application of high pressure had effects similar to the use of high temperature on proteins and microbial population in foods, but, unlike thermal treatments, maintains the fresh character of the original products.

Modern high-pressure treatment subjects food materials to pressure as high as 9,000 atmospheres applied uniformly throughout the food, independent of its mass. This method is currently applied to fruit products such as jams and juices, particularly in Japan. Raw materials are placed in chambers under very high pressure for 10-60 min. prior to opening the release valve. Both the equipment and the process are costly and, as a result, the major commercial limitation to this method is economic rather than technical. As a commercial process, high-pressure treatment can significantly increase the cost of foods. This has limited the wider adoption of this process and will probably continue to do so for some time to come. Examples are shown in Table 1.

Table 1. Some examples of products processed using high-pressure technology and changes in quality attributes other than microbial changes*

<table>
<thead>
<tr>
<th>Product</th>
<th>Process and Quality Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avocado puree</td>
<td>Prevents discoloration. Inhibition of undesirable browning reactions in presence of low pH.</td>
</tr>
<tr>
<td>Banana puree</td>
<td>Prevents discoloration. Reduction in polyphenol oxidase activity when combined with blanching.</td>
</tr>
<tr>
<td>Black beans</td>
<td>Cooking. Higher water absorption and less cooking time.</td>
</tr>
<tr>
<td>Cheese</td>
<td>Precise control of rennet coagulation of milk.</td>
</tr>
<tr>
<td>Jam</td>
<td>Commercial Production (Meiji-ya, Japan). Improved retention of color and flavor of fresh fruit.</td>
</tr>
<tr>
<td>Meats</td>
<td>Thawing. Reduction in drip loss and less color change.</td>
</tr>
<tr>
<td>Meats, tenderized</td>
<td>Commercial production (Fuji Chiku and Mutterham, Japan). Improved retention of sensory characteristics.</td>
</tr>
<tr>
<td>Orange juice, fresh-squeezed</td>
<td>Preservation. Retention of color and cloud stability during storage.</td>
</tr>
<tr>
<td>Pink grapefruit juice, fresh-squeezed</td>
<td>Preservation. Retention of color and cloud stability during storage.</td>
</tr>
<tr>
<td>Pork sausage</td>
<td>Manufacturing. Moister, denser and more tender sausages with more retention of color than if heat-treated.</td>
</tr>
<tr>
<td>Potato</td>
<td>Freezing. Reduction in freezing time in potato cylinders.</td>
</tr>
<tr>
<td>Rice paste with herbs (Yomogimochi)</td>
<td>Commercial Production (Japan). More desirable sensory properties than if heat-treated.</td>
</tr>
<tr>
<td>Soy proteins</td>
<td>Manufacturing. Less firm but more elastic and extensible gels. Improved preservation of color and initial aroma.</td>
</tr>
<tr>
<td>Surimi</td>
<td>Control of enzyme activity. Enhanced activity of transglutaminase in Surimi with increased gel strength.</td>
</tr>
<tr>
<td>Surimi, Pacific Whiting</td>
<td>Gelation. Increased gel strength in Surimi.</td>
</tr>
<tr>
<td>Tofu</td>
<td>Freezing. Production of small-sized ice crystals.</td>
</tr>
<tr>
<td>Tomato juice</td>
<td>Juice production. Modification of physical and sensory characteristics deemed desirable.</td>
</tr>
<tr>
<td>Yoghurt</td>
<td>Storage. Reduced ‘syneresis’ or weeping.</td>
</tr>
</tbody>
</table>

* Source: APO (2000)
**High Electric Field Pulse Treatment**

This process seeks to destroy unwanted bacterial cells without the application of heat, in order to have a product remain in its raw natural state but without viable contaminating organisms. Recently, a high electric field pulse treatment (HEFP) pilot unit integrated with an aseptic packaging machine for processing of fresh orange juice on a pilot scale has been described. It was concluded that the treatment inactivated 99.9% of microbial flora. Compared with heat pasteurization, the HEFP-treated orange juice retained more vitamin C and flavor.

Since the utilization of this technology for the treatment of food is still in the experimental stages, there are many unsolved problems. One problem is that the process is not particularly selective and intact cells of the food are also damaged. This may lead to changes in the texture of those foods, such as a loss of crispness in carrots, for instance. The fact that low levels of treatment may result in minor injury that is reversible, raises the question as to whether microbial cells will be able to develop resistance to increasing levels of treatment before irreversible damage is achieved. Another concern is that most bacterial spores are very resistant to this treatment. Since spores are a particular problem in natural plant products, the applicability of this technology to fruits and vegetables will be severely limited if this problem cannot be overcome through the employment of other combination treatments. At the present time, this process is not in commercial use, but it may one day become a reality.

Table 2. Examples of foods processed using pulsed-electric fields*

<table>
<thead>
<tr>
<th>Products</th>
<th>Process and Quality Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apple juice, fresh and reconstituted</td>
<td>Pasteurization. No change in solids concentration, pH and vitamin C. Loss of calcium, magnesium, sodium and potassium. No sensory differences between processed and untreated juices.</td>
</tr>
<tr>
<td>Commercial cheese sauce, reformulated</td>
<td>Preservation. Better flavor and appearance than comparable products.</td>
</tr>
<tr>
<td>Green pea soup</td>
<td>Cooking. No sensory difference after four weeks storage at 4°C.</td>
</tr>
<tr>
<td>Liquid whole egg</td>
<td>Pasteurization. Prevention of coagulation, superior quality.</td>
</tr>
<tr>
<td>Orange juice</td>
<td>Preservation at pilot-scale. Less than 6% flavor loss, negligible vitamin C and color change.</td>
</tr>
<tr>
<td>Orange juice, fresh</td>
<td>Pasteurization. Minimal loss of flavor, color and vitamin C.</td>
</tr>
<tr>
<td>Spaghetti sauce</td>
<td>Aseptic processing. Acceptable after two years and 26.6°C storage.</td>
</tr>
</tbody>
</table>

*Source: APO (2000)

**Ohmic Heating**

In order to improve the uniform transfer of heat to food products, attempts were made to carry out thermal treatment in scraped-surface heat exchangers, followed by aseptic packaging in aluminum cans. This worked well for uniform fluid products such as smooth puddings, but failed when larger particulate matter was incorporated, as it heated up more slowly than the surrounding fluid. The entire process has to be slowed down to ensure that the particules are properly treated. One solution is *ohmic* heating.

*Ohmic* heating itself is not a new concept. An electric current is passed through the food and the solid materials heat up as fast or even faster than the surrounding fluid. The electrical current heats up all the particulates quickly and efficiently so that the final temperatures required to kill or inhibit bacteria are achieved with far less total cooking. This results in products with improved quality. However, although the process is now commercial, the total volume of products treated in this manner is thought to be very small.

The two last methods to mention are pulsed light treatment and oscillating magnetic...
fields. Neither method has found commercial application in post-harvest horticulture so far, but may in the future.

**Pulsed-light Treatment**

Pulsed-light treatment involves the use of high-intensity light for the purpose of killing microorganisms on the surface of food or packaging materials. This procedure, developed under the trade name PureBright, uses a light spectrum containing wavelengths all the way from ultraviolet to near-infrared. The light spectrum generated with this equipment is similar to that of the sunlight reaching the earth’s surface but the intensity of PureBright is 20,000 times higher. The intense flashes of light produced by the PureBright system are used to destroy microorganisms.

Results indicate that application of pulsed light can reduce up to nine logs of vegetative microorganisms and more than seven logs of bacterial spores on smooth, nonporous surfaces, such as those of packaging materials. When the surfaces are more complex and porous, such as in the case of food materials, then the microbial reduction is only two to three log cycles. The reported costs of equipment amortization, lamp replacement, electricity and maintenance indicate expenditures of only a few tenths of a cent per square foot of treated area.

**Oscillating Magnetic Fields**

There are mixed results in the inhibition of microorganisms when placed in oscillating magnetic fields (OMF). Some studies indicate that magnetic fields have an inhibitory effect on the microbial population, while others show no effect or, in some cases, even a stimulating effect. Mechanisms describing these observations are under scientific inquiry. In one study, foods with high electrical resistivity were subjected to one or more pulses of oscillating magnetic fields. It was observed that a single pulse of magnetic field generally decreased the microbial population by at least two orders of magnitude. The process involves little thermal energy input, thus avoiding thermal denaturation of food components during treatment. However, the method is still experimental and more research is needed to understand the changes in microbial population when treated with OMF (APO 2000).

**Minimally-processed Foods**

While the above methods were developed to kill the microorganisms present in food, many other methods, some of them thousands of years old, are employed to simply control their excessive growth. Since the minimum infective dose of pathogens is fairly high for many food-borne diseases, these methods have played a very important role in maintaining food safety over the centuries. Common examples of these methods are acidification (as in pickled vegetables), fermentation, the use of high concentrations of salt or sugar, freezing or cooling and drying. These methods continue to be very popular in the manufacture of traditional food products. In fact, this approach has been broadened into a new class of foods, described as *minimally-processed foods*.

In order to increase the eating quality of contemporary ready-to-eat processed foods, a battery of gentle post-harvest techniques has been combined into fully integrated treatments. The philosophy behind this approach is based upon the notion that each technique alone might not destroy microorganisms, but when employed together they are very effective. The concept of minimal processing theoretically involves the care of foods throughout the entire post-harvest system – from the far-gate all the way to the consumer. This minimal processing approach is also called *hurdle technology*, simply because a series of hurdles is placed in the way of the microorganisms’ growth and survival; e.g. combinations of weak acid treatments with modified atmosphere packaging, or mild heating with reduced water activity, or alternative doses of mild heating and chilling. Indeed, the preparation and marketing of fresh-bagged salad in modified atmosphere packs has been a commercial success.
The marketing concept for minimally-processed foods is based upon the perceived consumer desire for more natural, less processed, high quality home-made-style food preparations. Chilled ready-to-eat or ready-to-heat foods are a very rapidly growing segment of the market. Some of the best examples of this are the so-called sous-vide or vacuum-packed products. These products are prepared under very rigorous hygienic conditions, packed under vacuum and cooked at fairly low temperatures. The cooking profile is not based on the need to destroy bacteria, but rather upon the culinary requirements of the product. This latter factor has meant that the shelf life of sous-vide products is normally limited to between one and three weeks.

Other technologies applied to minimally-processed foods include the addition of anti-microbial agents such as enzymes and other natural compounds that inhibit the growth of bacteria or prevent oxidation. Again, they constitute one step in an integrated hurdle approach that must follow the product from the farm to the consumer. This technology is gaining ground in Europe and will likely follow suit in North America. Unfortunately, to employ a combination of less severe treatments in the hope that, together, they will ultimately accomplish the task of inhibiting undesirable organisms, may lead to other problems.

Trends in Trade

The world today is characterized by intensive traffic of people and goods. Modern air, sea and ground transportation bring the most distant places of the earth in close contact with one another. This situation is desirable and of great benefit to many. However, it also creates some dangers which did not previously exist. Among these is the movement of pests such as insects from country to country. To prevent or minimize this risk, countries have established quarantine measures supported by laws and regulations. This can create significant barriers to international trade and the free flow of plants and plant products.

Quarantine Measures

Because of the disastrous potential consequences of such pests, quarantine measures are enforced by law. Quarantine regulations prohibit the entrance of plants or plant products which might hide the unwanted pest from countries where it is known to exist. Inspections are carried out in the ports of entry with the objective of intercepting and destroying contaminated material. Exemption from such quarantine is granted only on assurance that agreed measures to disinfect the plant material have taken place. Such measures could consist of specific treatment of the material at the point of origin, in transit or at the port of entry.

Quarantine treatments generally fall into three categories:

1. Chemical Treatments: These are fumigants for pests that occur inside or on the surface of the plant or plant products. Non-chemical methods comprise the next two categories.

2. Physical Treatments: Temperatures treatments applied in various ways. High temperature treatments, such as double hot water dipping, are also used for mangoes and papayas, but fruit quality can suffer.

3. Ionizing Radiation: Numerous investigations on the use of ionizing radiation for the disinfection of fresh plant materials for quarantine purposes have been completed. Recent studies show that rather low dosages of ionizing radiation will control fruit fly problems. This makes the use of irradiation for quarantine treatment an excellent practical possibility.

Future of Irradiation in Post-harvest Technologies

Irradiation offers a broad scope as a quarantine treatment of fresh horticultural produce. The interest in using irradiation as a quarantine treatment of fresh and stored food products has increased recently because methyl bromide (MB), the most widely used fumigant to control insects in food and agricultural commodities, is being phased-out globally
under the international treaty for the regulation of ozone depleting substances (Montreal Protocol). The US Environmental Protection Agency has already issued a Final Rule to prohibit the production and consumption of MB by 31 December 2000, with no exemption (EPA 1993). Research data have demonstrated that irradiation could be used as a quarantine treatment instead of MB for a number of food and agricultural commodities.

There is some concern, however, at the new Codex Guidelines promulgated in July 1999, on the production of Organic Foods. These do not permit the use of irradiation. It is a subject that will hopefully be reconsidered in future. On the other hand, there is positive news in the lifting of the 10-year ban on irradiation in New Zealand and Australia.

There is no doubt that food irradiation has a strong future. Insect quarantine measures serve as only one example. There are several other applications for food irradiation in the reduction of post-harvest losses. Some other examples of the use of radiation to enhance the safety and quality of food are explained below.

♦ Control of Sprouting and Germination
♦ Shelf-life Extension of Perishable Foods
♦ Delaying Ripening and Aging of Fruits and Vegetables
♦ Destruction of Parasites

Under the present circumstances, irradiation will find practical uses only in advanced post-harvest systems where the distribution infrastructures are reliable and highly efficient. With the possible exception of plantation crops such as large scale roots and tubers, coffee, tea, and spices or seafood, food irradiation has very limited use at present in developing countries. The focus in these countries will continue to remain on improving of small-scale village storage and marketing systems to ensure minimum losses.

Summary

A good post-harvest system has many benefits. It reduces spoilage and will enhance the acceptability, utility and nutritional quality of foods. It leads to the establishment of entirely new industries that produce processed foods and provides a consistent year-round demand for indigenous crops. These include the latest new and emerging technologies such as food irradiation and high pressure processing, also improved on-farm storage, such as solar-refrigerated storage. This applies equally to treatments which extend shelf life using various chemical or natural compounds. The challenges of free trade will require smaller commercial operations to seek strategic new linkages in order to survive. This is a profession which will continue to ensure sustainable and nourishing safe, high quality food to meet market demands.

References

EPA. 1993. Final Rule to Prohibit Production and Consumption of Methyl Bromide. US Environmental Protection Agency, USA.