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How to Reduce Food Degradation with Appropriate Processing, Transportation and Packaging

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INTRODUCTION

Situation

Food is obviously attractive for human beings, but is also desirable for animals, insects, birds and microorganisms. This results in food being lost in situations where food is available to these pests. Humans, animals and insects can eat foods in most forms. Microorganisms, however, are somewhat more restricted in the types of foods they can utilize, and we exploit these limitations in our processing and packaging systems.

Losses also occur as food is shipped and at every transfer point during shipment. Losses at each point may be small, but the total losses both decrease profitability and erode the food supply.

How to reduce losses

Food losses are reduced through a combination of processing and packaging. Any processing method would be ineffective unless the quality of the food is protected from outside influences such as moisture, oxygen, contamination or attack from insects and pests through appropriate packaging. The discussion below will therefore begin with a review of food degradation and the means by which degradation is either controlled or slowed.

Next, different distribution systems to bring food products from the producer to the consumer will be briefly described. Ambient, refrigerated and frozen distribution systems will be mentioned with their impact on processing and packaging requirements.

The final discussion will be a brief introduction of the packaging materials, with a synopsis of properties which protect food products.

Getting started

The review of food degradation, distribution systems and packaging materials will introduce the causes of food losses and potential solutions for their reduction. This information will allow the reader, to identify and quantify opportunities within their organization for reducing losses, and give them some initial ideas. Further information and details about products and the use of packaging materials is available through references presented at the end of this bulletin and through individual publications of the ITC PACkit series which highlight product and packaging attributes as well as guidelines for export by country. This combined information should supply the tools to reduce food losses and improve profitability.

1. FOOD DEGRADATION

Virtually all food products begin to degrade as soon as they enter the food chain. The only obvious exception is certain seeds which have been reported to have extended longevity. Fresh fruits and vegetables proceed to ripen and eventually decay through a process of senescence, which is the normal aging of the produce. They continue to be a living entity, and continue to respire (analogous to breathing) in that oxygen is consumed and carbon dioxide and water vapor are generated. This aging process continues until the product dies and starts to decay.

Bananas, for example, are typically harvested green, ripen to a yellow fruit, and finally over-ripen first to a speckled brown, then to primarily brown, and ultimately a black appearance. This ripening process is coded into the genetic make-up of the produce. It can be partially controlled by temperature, composition of the environment (controlled or modified atmosphere) and by scrubbing triggering agents, such as ethylene, which initiate the ripening of bananas and other fruits.

Animal tissue undergoes changes from the moment of slaughter. These changes are temperature and atmosphere dependant, and also are influenced by enzymes in the animal.

In addition to the actions within the biochemical system of fruits, vegetables, grains, and animal products, food losses are experienced through the actions of microorganisms, insects, birds, rodents and other animals. These actions are reduced through combinations of processing and packaging which stabilize the product, reducing access to the product, and reducing the ability of organisms to sense the presence of the food.

In addition to the biological degradation stated above, physical and chemical forces also degrade food. The physical forces are the shock, vibration and compression forces experienced by the food products during transportation and storage. Chemical changes include oxidation, thermally enhanced reactions, and reactions catalyzed by light. Moisture migration, either within (such as staling) or exchange with the environment (influx or drying) also affect food quality and keeping qualities.

Additional food losses result from spillage, wind and crushing during each transfer step in the distribution process. Theft also plays a part during distribution.

1.1 Senescence

Senescence will be influenced by picking agricultural commodities at an appropriate time. Once harvested, temperature and atmosphere influence products. Typically, cooler temperatures and reduced oxygen will promote longer life. However, different grains, fruits and vegetables can tolerate different temperatures and oxygen levels. Reduced oxygen slows down the respiration rate, but insufficient or lack of oxygen can kill the produce, similar to asphyxiation in humans. It is therefore important to define temperatures and oxygen levels which promote longer storage life. Dr. Adel Kader has compiled and published guidelines for optimal temperatures and atmospheres for many fruits and vegetables (Kader, 1980).

Fungicides and dips can also promote life extension of produce. This results because of both the elimination of the microorganisms which may directly attack the products, and by eliminating the atmospheric changes which result from the growth of the microorganisms. For example, a reduced oxygen atmosphere will promote extended storage life of fruits as long as the fruits may still respire. Lower oxygen content in the storage facility lowers the respiration rate and slows the senescence process. However, if oxygen falls below a critical value, as mentioned above, the fruit dies from lack of oxygen. Growth of a facultative microorganism (one that can grow in oxygen and then become anaerobic in a low oxygen setting) may use the available oxygen and drop it below the critical concentration.

Many reactions are catalyzed by light. Control of light, therefore, may influence storage life.

Finally, genetics play a vital role. Plant breeding and genetic modification has, and will continue to influence the senescence and keeping qualities of products.

1.2 Insect/Rodent Control

The initial step in controlling insects is to monitor the quality of the incoming materials. If fruits, for example, are placed in a storage facility with insects, larvae and/or eggs already present, control will be harder to maintain. Storage and handling also influence keeping quality and storage life. Bruised fruit, for example, release enzymes which promote further break down of the fruit. Temperature and atmospheric composition influence which insects may survive and how fast they can grow.

Good manufacturing practices apply to the warehouse environment. Firstly there must be a barrier to the entry of insects, birds and rodents. Secondly, some form of detection is desirable to allow timely action to control infestation at early stages. Finally, appropriate elimination of the pest will eliminate further damage.

It deserves mention that packaging can prevent access and prevent contamination or recontamination of products. A warehouse which provides sufficient barrier to entry allows open bin storage. Appropriate packaging can render safe storage in facilities with considerably less protection.
An interesting form of "packaging" protection resulted from a study at Michigan State University which found that a particular beetle required 24 hours to penetrate the hull of a bean before having access to the food. The package was a jute sack which contained the beans but which offered little resistance to insects. Rotating the bags every 12 hours dislodged the beetle which resulted on it starting to gnaw at another hull. When no food was found after 24 hours, the beetle stopped and starved, which drastically reduced the infestation by eliminating live beetles and reducing procreation. This example illustrates that additional procedures may help reduce losses once the cause of loss has been identified.

1.3 Choices for Microbial Safety

Microbial safety is achieved through one or a combination of five options:

- prevent growth
- prevent contamination
- eliminate microorganisms and spores
- eliminate dangerous microorganisms
- prevent growth of dangerous microorganisms

Each of these options will be discussed.

1.3.1 Prevent microbial growth

Microorganisms are ubiquitous. They can be transferred to food products through the soil, handling, tools or through the atmosphere. It is therefore prudent to preserve foods by preventing microbial growth. Some of these methods date back to prehistoric times, such as drying and salting, and were developed long before the existence of microorganisms was known, but observations that food quality was preserved led to their adoption. Moisture, acidity (pH), and temperature control as well as chemical preservation and removal of nutrients will be discussed.

a) *Eliminate access to water*
Primitive societies found that drying or salting food items would extend the use of those products. Microorganisms require moisture to grow, and elimination of moisture through drying or restriction to a moisture source by binding the existing water with sugar, salt, or freezing will suppress growth. Preserves, jams and jellies are excellent examples in which sugar and pectin bind moisture to discourage growth of molds, yeasts and bacteria.

Any processing procedure requires packaging protection to maintain the protected form of the food product. Dried foods will tend to absorb moisture if exposed to relative humidity which is greater than the water activity of the food. Water activity (Aw) is defined as the relative humidity (R.H.) above a food product divided by the saturated vapor pressure of water at the same temperature. Therefore, Aw is equivalent to a decimal form of R.H., i.e. R.H. from 0 to 100% is equivalent to 0.0 to 1.0 Aw. The practical application of these concepts is that any food exposed to a R.H. higher than the equivalent food Aw will tend to absorb moisture from the atmosphere; any food exposed to a lower R.H. than the equivalent Aw will tend to lose moisture to the atmosphere. Packaging will reduce the moisture transfer in proportion to the packaging material water vapor transmission rate (WVTR) which is a measure of the barrier properties of the packaging material. Glass and metal provide virtually absolute barrier to moisture (and oxygen), and therefore are commonly used to preserve food products. Plastic materials have measurable transmission rates and provide partial barrier to moisture migration. Matching barrier properties to product protection requirements will define the shelf life for the food product in that package under defined environmental conditions. This concept will be expanded in the packaging section.

b) *pH control*
Another form of growth control is adjustment of the acidity of a product which is measured by pH (technically power of the hydronium ion which is released by acids). High acid (which have low pH) foods prevent the growth of microorganisms, so high acid foods require less processing protection than low acid foods to prevent microbial growth. Additional protection may be achieved by adding food grade acids (such as citric acid or others) to foods to lower the pH. As mentioned with drying, packaging protection helps maintain the pH by preventing influx of moisture which will dilute the product and raise the pH.

A common method of food preservation which employs pH reduction is pickling, in which acetic acid (vinegar) is used to lower the pH and preserve vegetables.

c) *Temperature control*

Most microorganisms grow slower at lower temperatures, and temperature control is therefore a common method for food preservation. Refrigerated temperatures slow microbial growth and are therefore used for products which contain microorganisms. Colder temperatures also slow other degradation reactions such as oxidation. Oxidation reactions can alter the colors of foods, destroy vitamins and cause lipids to become rancid (resulting in an off-taste). Control of dangerous microorganisms will be discussed shortly, but many products cannot be easily processed to remove all microorganisms and spores. For example, the amount of heat processing required to sterilize dairy products will alter the organoleptic (taste and texture) properties of the products. Therefore, minimal processing is performed, and shelf life is extended through refrigerated temperature control.

Freezing is an interesting phenomenon. The temperatures in a freezer are low and reduce both microbial growth and other reactions. Freezing also binds water and removes it for access to microbial growth, which is why it was mentioned in the section on drying and moisture binding. Freezing therefore achieves a high level of food protection by providing multiple barriers to microbial growth.

d) *Removal of nutrients*

To be complete, elimination of nutrients needed for microbial growth can control microbial growth. However, such removal also reduces the food value of the product. Certain snack foods, for example, achieve some level of stability because of a lack of nutrients for microbial growth.

e) *Chemical control (preservatives)*

A final method for controlling microbial growth is to incorporate preservatives into the food formulation. Benzoates, sorbates, nitrates, for example, have been used for this purpose. Additional preservatives also reduce other degradation reactions, such as oxidation and moisture transfer. Other additives add nutritional and functional advantages, but are not in the scope of this bulletin.

1.3.2 Prevent microbial contamination

Care must be taken to avoid microbial contamination. The degree of care will relate to both the food type and the type of processing and preservation methods chosen for the food items. In addition, prevention of contamination becomes critical after the preservation procedures have been completed, especially if the product itself will support microbial growth. History's largest outbreak of Salmonellosis, for example, occurred in a dairy plant through contamination after pasteurization. The milk was expected to be safe, but remained a fertile growth media which brought the contamination into a public health hazard.

a) *Good Manufacturing Practice*

Good Manufacturing Practice (GMP) suggests that food processing procedures be designed to minimize potential sources of contamination throughout the entire plant. Equipment must be designed to allow appropriate sanitation. This requires materials which can be sanitized as well as shapes which prevent places for microorganisms to thrive and/or "hide" from the sanitizing solutions. Sanitation must be performed with appropriate scheduling. The raw materials must be handled such that contamination and cross-contamination is minimized. Unprocessed and processed food MUST be segregated such that finished goods cannot be contaminated by goods in process (which was the source of Salmonella in the dairy incident mentioned above). Personnel policies need to be designed to eliminate potential contamination through clothing, jewelry, hair etc.

Many guidelines for GMP have been published and exist as law in many countries. It deserves mention that a cleaner manufacturing facility will produce more consistent and cleaner products. Less contamination and less rejects translates to both better health and improved profitability.

b) *HACCP*

Hazard Analysis and Critical Control Points (HACCP) defines points in a processing line which are critical to producing a safe product. This subject is equally appropriate in this section (preventing contamination) as the section on preventing growth. The key is to define the points, set the limits, analyze the process and maintain the process within acceptable levels. HACCP is also related to hurdles, in which multiple barriers to microbial growth are incorporated into the process design such that product remains safe even if some hurdles are breached.

The HACCP concept consists of seven principles as follows:

1. Hazard analysis - identify the specific hazards associated with the specific product. These include biological, chemical and physical properties which may cause the product to become unsafe for consumption. The analysis should include both the likelihood that an identified hazard will occur as well as the resulting severity if it does occur. The analysis should also identify preventative measures.
2. Identification of Critical Control Points (CCP's) - identify points, steps or procedures at which control can be applied to prevent or reduce potential safety hazards. Examples of CCP's include sanitation procedures, formulation standards, cooking, chilling, or processing steps, prevention of cross contamination, and employee and environmental hygiene.
3. Establish critical limits or preventive measures for each CCP - set critical limits or boundaries for each CCP. This may include time and temperature for processing, level of moisture, water activity, pH, level of a preservative etc.
4. Establish procedures to monitor CCP's - observations and measurements to quantify the CCP to assure that it remains within acceptable limits. The procedures call for record keeping which provides a manufacturing history. For steps which cannot be monitored continuously, monitoring must be sufficiently frequent to permit the manufacturer to determine that a process is in control, and have sufficient opportunity to take corrective action if the process begins to exceed limits.
5. Establishment of corrective actions when a critical limit is exceeded - The goal is to maintain each process step within acceptable limits. A corrective action plan must be developed to adjust the process which is not in compliance and provide for the disposition of product produced while the process was out of specified limits. Records are required to show the corrective action.
6. Establish effective record keeping systems - which list the hazards, CCP's, critical limits identified by the company, monitoring records and procedures for correction as well as records of corrections.
7. Establish procedures to verify that HACCP is working - which monitors the existing plan and includes periodic revalidation to assure product is performing as expected.

c) *Packaging*

A common theme in this bulletin is that packaging remains the final barrier to contamination of most food products. The greatest care in processing will not be beneficial if the food is packaged with an unsealed material. A discussion of packaging materials is in Section C.

1.3.3 Eliminate microorganisms and spores

Growth of microorganisms ceases to be a problem if no viable microorganisms or spores exist within a food product. Such processing allows a food product which would support growth to be shelf stable. The processing systems which will be discussed are thermal processing, pressure processing and irradiation.

a) *Thermal processing*

Nicholas Appert invented thermal processing in response to a challenge by Napoleon Bonapart to find a means to preserve food for troop movements. Food was placed in jars, which were capped and sealed, and processed in boiling water. This process was modified for metal packaging to result in canning. The key to success is to drive sufficient heat into the coldest locations of the package to kill all microorganisms and spores which are present in the product. The amount of heat will depend upon the geometry of the package, the properties of the product and the pH of the product. The larger the diameter of a cylindrical package, for example, the longer it takes to drive heat into the coldest locations, and the more processing time and/or higher heat required.

Food products conduct heat differently depending upon the characteristics of the food, particle size, and ability of the product to move (convection) within the package and thereby transfer heat. The pH is important because low acid foods can promote growth of a pathogenic organism, Clostridium botulinum, whose spores are heat resistant. High acid foods prevent botulinum growth and can therefore be safely processed at lower time/temperature conditions.

Processing times for thermal processing are calculated as the times necessary to kill microorganisms in the coldest point in the package. Long processing times can soften the texture of many foods. A thinner geometry in the package can provide shorter processing times and improved quality for food products, which is one reason for the development of the retort pouch. (Another reason was for military applications in which soldiers were injured when falling on cans which were in their pockets. Flatter pouches reduced these injuries.) The retort pouch is a flexible analogue of a can in which aluminum foil provides the barrier, polypropylene (inside layer) provides heat sealability, and an outer layer (usually polyester or nylon) provides strength for the package and protection for the foil. Since the pouch is wide and thin in comparison to a can, heat is driven into the pouch through the large faces, and needs to transfer only through a relatively short distance. Therefore, processing times are less and food quality can be substantially better than available with cans for certain products. This allowed for the development of foods which would not work well with cylindrical cans, such as meals consisting of meat and sauces which would lose definition with longer cooking times.

Certain food products can tolerate less thermal exposure and cannot be easily thermally processed. The canning or thermal processing described in the preceding paragraph (thermal processing is also common with glass packaging) basically takes an unsterile product, filled into an unsterile container (glass jar, metal can or laminated pouch) and sterilizes the packaged product. The retort pouch reduces cook time by offering a thinner geometry.

An alternative processing system is aseptic packaging in which a product is sterilized and filled into a sterile package in a sterile environment. The heat processing of an unpackaged product can be accomplished in thin tubes with a high temperature/short time (HTST) exposure sufficient to kill microorganisms without destroying the taste and/or texture of the food. Since the package is sterilized separately (such as by chemical means with exposure to hydrogen peroxide), the packaging material need not be required to be compatible with high temperature exposure. Therefore aseptic packaging is possible with a variety of packaging materials, such as paper/PE/foil/PE laminates used in aseptic cartons.

b) *Pressure processing*

High pressure has been shown to kill microorganisms and can therefore be used to preserve food products. This process requires substantially higher pressures than steam systems and is therefore practical only for companies with sufficient equipment and expertise to handle such conditions.

c) *Irradiation*

Irradiation utilizes high-energy gamma rays, which are supplied via electron beam or, more commonly, Cobalt 60, to kill microorganisms and spores. Since the Cobalt 60 is a radioactive source, safe operation requires a substantial facility to contain the radiation, typically with one or more metre thicknesses of concrete. The process is controversial, partially because many people believe that food products may become radioactive after treatment. This fear is not founded, however. Further concerns that products can be altered by exposure to gamma rays are more difficult to predict. Changes do occur in the food (as they do during the accepted thermal processing), but these changes have not been shown to be detrimental. It is possible to use lower levels of radiation to destroy insects, larvae and eggs (rapidly growing entities are specifically liable to radiation, which is the same reason it is justified for cancer treatment), which will be discussed below. Irradiation has been found to preserve foods, and is a technically sound alternative, but marketing of foods so preserved must address market concerns.

A common theme throughout this bulletin is the role of packaging to reduce food losses. Any processing used to preserve food items through elimination of viable microorganisms must include packaging to both hold the product during treatment, and prevent re-contamination after treatment. The processing is required to MAKE the food wholesome with time, packaging is required to KEEP the food wholesome with time.

1.3.4 Eliminate dangerous

It is sometimes impractical or impossible to eliminate all microorganisms from a product. Sufficient heat or treatment required to sterilize food could also destroy nutrients, flavor or texture. Techniques have been developed, therefore, to protect food products without sterilization. The resulting products often have a more limited shelf life, but exhibit higher quality than higher processing alternatives.

a) *Pasteurization*

Some food products are sensitive to heat and would not be acceptable after sufficient heat treatment to render them commercially sterile (i.e. contains no viable microorganisms). Pasteurization is a more gentle heat treatment (lower time/temperature exposure) which eliminates dangerous microorganisms, but allows more resistant, but not pathogenic organisms to survive. Such food products include dairy products which require refrigeration to extend their shelf life. It is important to mention that these foods are not sterile, and microorganisms can grow and change the characteristics of the food.

Milk will sour, cheeses and sour cream, for example may develop surface mold. These changes, however, make the products less desirable, but not dangerous.

b) *Low dosage irradiation*
Irradiation was mentioned above as a means to sterilize food products. Low dosage irradiation can be used to de-infestate (kill some microorganisms, insects, larvae and eggs) within the products without using sufficient energy to sterilize. These low dosages will cause fewer changes in the products than dosages required for sterilization, so can be used for more sensitive products. Low dosage irradiation, for example, has been used to remove pests from spices without altering the properties of the spice.

1.3.5 Prevent growth of dangerous microorganisms

An important procedure for preserving food is to intentionally add safe microorganisms which will grow and compete with potentially dangerous microorganisms. This process has been used since ancient times in the form of fermentation used to prepare wines, cheese, yogurt and specialty products. In some cases, such as wines, the growth of the microorganisms creates a preservative (alcohol) for the product. In others, such as yogurt, the microorganism may remain viable, but are not harmful, and may even be beneficial to humans.

Fermentation has been utilized for animal and vegetable products and has been utilized by virtually every society in some form.

Packaging remains necessary to maintain the beneficial characteristics of the food products.

2. DISTRIBUTION SYSTEMS

The system in which products are shipped influences both their processing and packaging requirements. Ambient, refrigerated and frozen distribution systems will be briefly discussed.

2.1 Ambient Distribution

Ambient distribution describes standard transport with trucks, ships, carts, planes and animals. Therefore, ambient distribution is characterized by a lack of control for the transportation and storage of food products. Temperatures and relative humidity may be the environmental conditions for the region, and can even be considerably more abusive. Temperatures in a metal entity, such as a truck or warehouse, which is exposed to the sun can be considerably hotter than the ambient temperature outside of the entity. Such conditions will promote growth of microorganisms, so foods distributed in ambient conditions must be preserved to prevent such growth - either by eliminating any viable organisms or eliminating growth conditions. Therefore, ambient distribution is restricted to either shelf stable foods, or foods with a limited shelf life, such as fresh produce.

Shelf stable grains (sufficiently dried) or processed foods which are made shelf stable by procedures mentioned above are protected from microbial attack as long as the packaging systems remain intact. Breaches of packaging through physical abuse during transport (shock, vibration, crushing or tearing) or attack by rodents, birds or animals may cause unacceptable food losses. Such losses may be reduced by improved packaging, additional packaging, or elimination of potential hazards.

Improved packaging involves identifying a cause for food loss and modifying the package to reduce or eliminate that cause. For example, products which become unacceptable through oxidation or moisture gain will be improved with better oxygen or moisture barrier materials, respectively. (Losses could alternatively be reduced by distributing the products more rapidly through an improved distribution system.) Packages which are prone to puncture will benefit from a tougher (harder to puncture) material.

Transportation packaging can be designed to reduce losses. A stronger shipping case, for example, may eliminate crushing. Unitizing loads with use of stretch wrap may both prevent shifting of loads during transit and provide an additional barrier to pests. Containers used for shipping provide additional protection, but also require specialized handling.

2.2 Refrigerated Distribution

Refrigerated distribution brings a level of temperature control to the distribution system. Since the lowered temperatures help maintain food quality, the foods shipped via this system need not be shelf stable as mentioned for foods distributed through ambient systems. Temperatures must be controlled, however, or the products will rapidly degrade. This control must be maintained through the entire system.

Since refrigerated distribution requires a controlled environment, it typically reduces or eliminates insect or pest contamination, which provides additional reduction of food losses.

2.3 Frozen Distribution

Since temperature and water binding are the primary form of preservation in frozen distribution, temperature control is essential, at least with limiting exposure to above freezing temperatures. Temperature fluctuations will tend to pump moisture in and out of the product. This occurs because warmer temperatures can hold more moisture, such that small temperature increases will cause moisture to sublimate from the product into the package headspace. Subsequent drops in temperature will cause that moisture to condense and freeze onto the inside surface of the packaging, which is the surface on which temperatures first reduce. This transfer of moisture from the product to the package results in the phenomena termed "freezer burn" which is manifested as a discoloration and texture modification on the surface of food products.

The packaging solution to reduce freezer burn is to minimize the headspace within the package by supplying the tightest package possible. Reduced headspace reduces the moisture which can sublimate from the product and thereby reduces the effect.

Pest and insect contamination potential is drastically reduced in a frozen environment and the system required to maintain the frozen environment serves as a barrier to entry for such contamination.

Since the frozen state is critical to the food quality, it is imperative for the frozen state to be maintained, and important to have a recorder to verify the temperature conditions.

3. PACKAGING

Packaging is essential to protect food products between processing, distribution and consumption, and also serves to help market most products. This section will review the functions of packaging and briefly introduce the scope of packaging materials available. Emphasis will remain on those attributes of packaging materials which protect food products. Graphics potential, labeling and marketing attributes can be obtained through other sources, including references presented in this bulletin.

3.1 Functions of Packaging

The functions of packaging are quite varied. They include the following (Soroka, 1999):

- contain
- protect & preserve
- distribute
- measure & dispense
- store
- communicate & display
- promote & differentiate
- motivate to buy
- meet regulations - both domestic and foreign

These functions include both technical and marketing functions, both of which are essential for international trade. A product which is presented to the ultimate consumer in an unacceptable form will obviously not promote sales. Similarly, a well-protected packaged product, which cannot convey information about the enclosed product, will be ineffective. Therefore, packaging must meet these multiple roles.

This bulletin concentrates on the protective functions. The primary package, i.e. the packaging component which is in direct contact with the product, provides the chemical protection. It restricts oxygen and moisture influx which could deteriorate the product, usually prevents microbial or insect contamination and may provide additional protection. Barrier properties of packaging materials limit transfer of odors both into and out of packages. The degree of barrier, however differs with the materials as described below.

Additional protection is supplied by transportation packaging. Corrugated shippers, wood crates and containers serve to contain products and often reduce effects of shock and vibration which occur during transfer and shipment. Transportation packaging also allows products to be stacked and thereby reduces crushing of products.

3.2 Packaging Materials

A wide variety of packaging materials exist which have many characteristics which protect food products. Virtually complete moisture, oxygen and other gas barrier is provided with glass and metal. Plastics provide barrier properties related to both their type and processing. The barrier properties both reduce degradation of the food products and slow odors leaving the product which could attract animals and insects. Hermetically sealed packages prevent or reduce potential contamination by animals, insects or microorganisms.

Transportation packaging, typically wood or corrugated, provides protection against the physical forces experienced by products during distribution.

The classes of packaging materials will be introduced below. Further information can be obtained through references suggested at the end of this bulletin as well as other ITC bulletins and publications in the PACkit series.

3.3.1 Glass

Glass appears as a vitreous "solid" but is really a fluid material. It flows very slowly, but this flow can be noticed in old windows which become thicker at the bottom. It has excellent barrier properties, being essentially impervious to oxygen, moisture and odors. It has good strength, and glass containers can be stacked because of this strength.

The primary ingredient used to make glass is sand, so this material is inexpensive. However, it is heavy, so transporting glass can be expensive. A packaging trend to substitute plastics for glass has resulted in part because of transportation costs associated with the weight of glass, partly because of hazards associated with breakage, and partly because of convenience features which can be incorporated into plastic containers, such as squeezability, dispensing, increased design criteria, etc.

Glass is sensitive to surface effects. It becomes more easily broken after the surface is scratched. To survive distribution without breakage, therefore, glass must be made thicker or have the surface protected. Glass has been successfully made thinner with applications of coatings to protect the surface, and with labels, including paper, polymers and foams, which also prevent scratching of the surface. Glass has also been able to be made thinner with technologies which promote even distribution of glass in containers such that impact forces are not concentrated to promote breakage. These developments provide lighter glass packages which continue to compete with plastics, especially in instances in which the higher barrier is required.

For more information on glass, please refer to PACkit Integrated Export Packaging Information Kit and references below.

3.3.2 Paper/Paperboard

Paper and paperboard are differentiated by the International Organization for Standardization (ISO) by basis weight. Paper is considered to be materials below 250 grams per square meter, and paperboard is materials over this weight. The U.S. equivalent for the metric value is 51#/1000 square feet, with paper being defined below this value and paperboard defined above it. These basis weight values translate to paper being below 300 micrometers (0.012 inches) with paperboard thicker than this value.

Paperboard is used to make corrugated, which consists of two or more liners separated by one or more corrugated mediums. This composite offers tremendous strength for a given weight of packaging material and has therefore become the favored material for transportation packaging, especially food packaging. Corrugated offers stacking strength in one direction (corrugations creating columns), but is moisture sensitive and loses strength in high humidity environments. If corrugated shipping containers are observed to lack sufficient strength for a given application, such as pallet stacking in a humid environment, the corrugated can be strengthened with heavier liners, increased walls, or moisture protective coatings.

For more information on paper and paperboard, please refer to PACkit Integrated Export Packaging Information Kit and references below.

3.3.3 Wood

The largest use of hardwoods worldwide, is for pallets. These serve to unitize loads such that they can be moved as a pallet quantity (with a suitable pallet truck or jack) rather than individual cases. Pallets reduce damage in two major ways. First they enable loads to be moved as units such that each shipper is handled less. Secondly, heavier loads are typically lifted shorter distances than lighter loads so pallet loads will experience less shock than a typical unpalletized load.

Reducing damage requires care in pallet usage. Broken stringers and extended nails on a pallet may promote damage to products; well-maintained and better quality pallets will reduce damage. The manner in which products are stacked on the pallet (pallet patterns) also have an impact. The ideal situation is products which are correctly sized for the pallet. Underhang (products which do not fill the pallet) allows products to shift during transit and promotes damage. Overhang (products extending past the pallet) allows products to be hit as the pallet is moved. Overhang also exhibits a portion of the shipper which is not supported by the pallet, which can lead to damage.

Wood is also used for individual and grouped product. Crates, boxes and barrels all may serve as primary packaging, such as crates for fresh produce, and/or transportation packaging (such as pallet boxes and crates). Crates (both wood and plastic) remain important for fresh produce distribution, and allow air circulation around the produce, which facilitates respiration and moisture removal, a product of respiration, and also offers strength to prevent crushing of the produce.

Wood is also used in some primary food packaging applications. One example is cork which remains active for closures of wine and champagne bottles. Polymer based alternatives also compete in this market.

For more information on wood packaging, please refer to PACkit Integrated Export Packaging Information Kit and references below.

3.3.4 Metal

Metal and glass are the only packaging materials which supply virtually perfect barrier to moisture and gases, including oxygen. The word virtually is used because all packaging containers of glass and metal require a closure which incorporates other materials, such as the polymeric sealing compounds used in cans. These compounds allow a very small amount of transfer.

Metal cans can tolerate both high temperatures and pressures which develop during retorting of food products. They have therefore become a common package choice for thermal processed foods. Since these foods are shelf stable, they require no refrigeration or freezing for keeping quality, and can experience a long shelf life under a variety of conditions. The strength of metal cans also protects products from crushing, which facilitates stacking in warehouses even if the transportation packaging, such as a corrugated shipper, were inadequate for the weight.

Metal is also used for other products, such as beverages. Both aluminum and steel cans are employed. In the case of carbonated beverages, the carbonation pressure adds rigidity to the cans. Aluminum, which is more expensive than steel, took advantage of this pressure by utilizing thin sheet which would not be strong enough for non carbonated beverages, and thereby reduced the packaging costs to compete against steel.

The major impact of thermal processing (canning) is that food products are made shelf stable. Food items deteriorate rapidly with time, and thermal processing drastically reduces the degradation. Therefore, the losses which may occur following a harvest season for which production cannot be distributed before the food becomes unacceptable may suggest an opportunity for a canning facility.

In addition to cans, metal is used for tubes, pails and drums. These uses serve both consumer and industrial, such as bulk food ingredient applications.

Another use of metal is foil, which supplies high barrier with very thin gauges. Pinholes increase with thinner gauges so thicker foils are utilized for critical applications. A curve of incidence of pinholes versus gauge indicates a dramatic increase below certain values (which move to thinner gauges as technology improves). Foils are therefore most cost effective at the thickness just above this point.

Unsupported foil is prone to puncture, especially in thin gauges and is rarely used for packaging. Therefore foils are typically laminated. Polymers tend to plug pinholes and provide strength and heat sealability. Paper is also often used to add strength. Seal strength and seal integrity is critical to maintain barrier properties. Seals and flexing can also fracture foils and reduce barrier properties. But foil laminates are an excellent means to produce high barrier flexible films.

Another form of metal which supplies a lesser degree of barrier is metal deposits onto films (sputtered) to form metalized structures. The barrier properties will be related to the amount of metal deposited and how contiguous the layer is deposited. Metalized films have found favor in many applications such as snacks and candy bars.

For more information on metal packaging, please refer to PACkit Integrated Export Packaging Information Kit and references below.

3.3.5 Plastics

As a relatively new packaging material, plastics have experienced the fastest growth. With a selection of different polymers (all plastics are polymers although not all polymers are plastics), plastics offer a variety of forms, properties, barrier and processing characteristics. Different plastics are available in rigid or flexible forms. In addition, plastics can be coextruded (melted and extruded at the same time) or laminated (combined after the base material is formed) with other plastics, paper, or foils to provide properties for almost any product.

In rigid and semi-rigid forms, plastics can be used as trays, bottles, boxes, tubs or single service packages. The properties required will suggest the polymer. Dairy products are typically packaged in HDPE (milk) or PP (items such as sour cream and cottage cheeses). Carbonated beverages require more gas barrier to maintain carbonation and typically employ polyethylene terephthalate (PET) bottles. Cooking oils perform well in polyvinylchloride (PVC). Products with very high sensitivity to oxygen, such as ketchup, require much better oxygen barriers and utilize a multi-layered structure which combines strength and barrier properties.

With the wide range of properties and costs of polymers, plastic packaging has tremendous potential to reduce food losses. The polymers can be used as single materials, laminated or coextruded with other polymers, laminated to foils or paper, and are available in film, semi-rigid and rigid forms.

For more information on plastic packaging (both rigid and flexible), please refer to PACkit Integrated Export Packaging Information Kit – Plastics and references below.

3.3.6 Other materials

Other materials are used for packaging. Walter Soroka (1999) suggests that any item historically used for packaging remains active in some location in the world. This includes animal organs, plant materials and products made from animal and plant sources. Animal skins and a processed form, such as leather, are widely used. An example of plant materials is jute (called burlap in the United States) which remains a major form of transportation packaging. Plastics, such as woven polypropylene have also competed in this use. Cellophane is a plastic which is made from cellulose and was a major and early plastic package, but has been largely replaced with other polymers.

Clay and ceramics remain useful for packaging applications, but weight concerns and freight costs have restricted these applications, especially with food products, primarily to specialty products, upscale products and local distributions.

For more information on glass, please refer to PACkit Integrated Export Packaging Information Kit –Glass and references below.

3.4 Choosing Primary Package

Primary packaging is the packaging which is in direct contact with the product and provides the principle protection against chemical degradation (moisture and oxygen) as well as reducing contamination through animals, insects and microorganisms.

A major step in defining primary packaging is specifying barrier protection. Oxygen sensitive products require more oxygen barrier than less sensitive products; hygroscopic dry products require more moisture protection, etc. If metal or glass is chosen, adequate barrier protection is expected, but plastics always allow some transmission of gases and moisture. Improved barrier protection is achieved by choosing polymers with higher barrier properties, using a thicker film of any particular material, or combining materials through lamination or coextrusion.

Product quality will relate to the availability of any degradation agent. Therefore oxygen sensitive products benefit by slowing oxygen influx into the package. Such products will also benefit from removal of the residual oxygen in the package, by techniques such as nitrogen flushing, nitrogen injection or use of oxygen absorbers.

It deserves mention that the desired shelf life impacts the barrier requirements. If a product can be sold more rapidly it can tolerate a lower barrier material. Conversely, long shelf life requirements increase barrier requirements.

Shelf life and barrier protection also relate to product size. For any package configuration, as the product package size increase, the barrier requirements actually decrease. This occurs because the volume increases more rapidly than the package area with increasing sized packages. The result is that more gas can traverse a larger package area, but is absorbed into more product such that the amount of oxygen per gram of product decreases. If a common packaging material is employed, the larger sizes will have a longer shelf life.

The reverse of sizing is also true. A smaller package for a given product will either have a shorter shelf life or require more barrier than the same package in a larger configuration. This principle is important when preparing smaller packages for marketing promotions.

Having defined the barrier requirements for a given desired shelf life of a specific product, the next step is to find packaging materials to supply the defined barrier. Absolute or extremely high barrier suggests glass, metal or foils. High or intermediate barrier requirements allow use of high or intermediate barrier polymers which may be used singly or combined in laminations or coextrusions. Barrier is proportional to thickness, so a thin layer of a high barrier material may supply equivalent barrier to a thicker layer of an intermediate barrier material. Cost-effectiveness is often obtained by appropriate composite structures.

3.5 Transportation Packaging

Packaging (both primary and transportation) is cost-effective when it adequately protects the products, allows it to be presented to the consumer in an attractive form, and does this at a reasonable cost. Cost effectiveness is not necessarily low-cost packaging. A package choice on the basis of cost which offers inadequate protection - to either chemical or physical attacks - will not be cost effective. Food losses will result. A presentation to the consumer of a crushed or damaged package, even with an intact product, will interfere with sales. However, if a company only tracks costs until product is shipped, such losses may be either not recorded or under-recorded. It is therefore prudent to follow products through the entire distribution chain and choose packaging which optimizes cost versus delivery.

Products are shipped through a variety of temperature and humidity conditions. A hot humid warehouse, for example, will tend to drive moisture into products. Corrugated shippers, often used for transportation packaging, weaken under such conditions and may collapse if designed for less severe conditions. Excessive damage of shippers in warehousing in this situation therefore suggests that either stronger corrugated board should be used or a moisture resistant coating should be considered. If the cost of the package improvement is less than the damage, profitability is enhanced.

Products are also exposed to shock, vibration, compression and movement during transportation. An evaluation of conditions and damage would suggest remedies to reduce losses. For example, with reference to the pallet discussion above, collapsing pallets suggest either stronger corrugated or possibly a column stack pallet pattern would improve delivery. In contrast, shippers falling off the top of the pallet suggest that an interlocking pallet pattern (which reduces swaying) or unitizing the load (with stretch wrap, banding, adhesive etc.) would help.

Transportation packaging also includes the labeling which identifies products to facilitate shipment and transfer. Clear and adequate identification can discourage accidental losses. Closures and means to unitize loads (part of transportation packaging) can serve to reduce losses by preventing cases from separating from the load or falling off pallets, and also discourages accidental or intended (theft) separation of loads.

As carried as a theme throughout this bulletin, profitability is enhanced through a choice of processing, packaging and distribution which provides for the best combination of delivery of acceptable product, minimal losses and reasonable package costs.

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PACkit Series, An integrated Export Packaging Information Kit available through the International Trade Centre. The Kit consists of modular profiles which present packaging information in four categories:

1) products and their packaging needs
2) different packaging materials
3) packaging profiles of exporting countries
4) packaging profiles of major target markets/importing countries

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