APPENDIXES

These appendixes provide more detailed information on open shelf-life dating of food.

Appendixes A, B, and C provide technical background on the applicability of open dating of food. They summarize a report prepared for OTA by the Department of Food Science and Nutrition, University of Minnesota, under the direction of Dr. Theodore P. Labuza. These appendixes were prepared by Dr. Labuza and Linda Kreisman and were reviewed by the OTA panel on open shelf-life dating of food.

Appendix D is a summary of the status of open shelf-life dating regulations in selected foreign countries and international organizations. It is based on a paper prepared for OTA by Dr. Amihud Kramer.

Appendix E is a detailed bibliography on open shelf-life dating of food.

Appendix A

Application of Open Dating to Specific Foods

INTRODUCTION

This appendix contains a condensation of data on shelf life collected in contract OTA-C-78-001 for various food categories. In that contract. the specific modes of deterioration were analyzed, and shelf-life plots presented for each mode. The reader is referred to the specific data and literature references in that report.

In this review, the foods have been broadly classified into perishability categories, since many States have legislated open dating on a perishability basis. Three categories were chosen, based on normal processing, distribution, and handling conditions:

Perishable--foods of less than 30 days shelf life in which the major problem is high-temperature abuse.

Semiperishable--foods of greater than 30 days but less than 6 months' shelf life.

Long shelf-life foods-these are foods of greater than 6 months' shelf life. In some cases, they have been described as nonperishable foods. However, as noted in this report, all foods decay at some rate for certain environmental conditions.

It is noteworthy that this classification is not actually based on the food itself but is based on the food/process/package/storage conditions. Thus, a long shelf-life food like a canned food could deteriorate in less than 1 week if held at 40° to 50° C or in a few days if opened and held at room temperature. This point must be remembered when the regulatory aspects of shelf life are considered. It must also be noted that it is difficult to actually separate the semiperishable and long shelf-life foods.

PERISHABLE FOODS

Fluid Milk and Milk Products

Modes of deterioration. Fluid milk and fermented milk products such as buttermilk, yogurt, and cottage cheese deteriorate because of: 1) bacterial growth and 2) lipid reactions, including both autoxidation and enzymatic hydrolysis. The shelf life is usually from 7 to 14 days under refrigeration conditions.

Milk products are an ideal medium for growth of a number of psychrophilic bacteria. The optimum temperature for their growth is 20° to 30° C, but they also grow well, although more slowly, at refrigeration temperatures. Following pasteurization, it is generally only the more heat-resistant (thermoduric) bacteria, some of which can be psychrophiles, that remain. Their numbers should be quite low, and at low temperatures (0° to 10° C), the milk should have a fairly long shelf life. Thus, the best way to prevent spoilage is to prevent recontamination after pasteurization. Growth of psychrophiles in milk can lead to a variety of off-flavors and defects. Among these are bitter, fruity, rancid, stale, and putrid flavors, and ropiness in milk. One problem associated with establishing standards for acceptable levels of bacteria in milk is that different species produce different types and intensities of off-flavors and odors. The off-flavors may be detected at 10^4 colony forming units per milliliter (cfu/ml) of one species and not until 10^7 cfu/ml of another species, The temperature coefficients (Q_{10}'s)* for microbial growth in milk range from 3 to 30 and average around 6.

Enzymatic hydrolysis of triglycerides in milk can yield free fatty acids that cause rancid flavors even when present in very low concentrations. Lipase and other such enzymes are generally inactivated by pasteurization, but certain microbes can produce the enzymes as they grow. Oxidation of unsaturated fats and phospholipids can lead to a variety of off-flavors. Sunlight, fluorescent light, metal ions, excessive agitation as in homogenization, and a small amount of ascorbic acid and riboflavin favor or catalyze the oxidative reaction. Addition of antioxidants to milk is not allowed in the United States. Tocopherols are the only antioxidants known to be present naturally, although sulfhydryl groups produced during pasteurization also have antioxidant properties. The use of opaque- or colored-glass milk containers reduces the catalysis of autoxidation reactions. The Q_{10}'s for lipid reactions in milk are from 3 to 4, much lower than for microbial growth.

In milk conforming to current health standards, off-flavors and off-odors occur more quickly than do actual safety hazards or significant nutrient loss. These sensory quality defects should be used to set the end of shelf life.

Pack date. In pasteurized milk, the pack date is the date of pasteurization. Milk quality after pasteurization is highly dependent on sanitary handling, temperature control, and protection from light. Without a knowledge of these processing and distribution parameters, the pasteurization date is not very useful to the consumer. For example, milk unopened in the carton normally is expected to have a shelf life of 7 to 10 days at 6° C. If held at 0° C, it can last for 20 to 30 days with high quality, but the consumer usually does not know this.

Sell-by date. This dating system is currently used in several States for milk. Usually, the sell-by date is set as a certain number of days from processing (e.g., 10 days) for all pasteurized milk within a given State. This system has the advantage of forcing all processing and distribution systems to conform to a minimum standard. It, however, also has the disadvantage of discouraging higher quality practices and inhibiting introduction of new technology.

For example, ultra-high temperature (UHT) milk produced in Europe is milk pasteurized at very high temperatures, giving it a much longer shelf life (3 to 4 months) at room temperature. Since it would be classified as pasteurized milk, it might have to be labeled as a perishable food and thus there would be no technological advantage in producing it. A system of setting the shelf life separately for each batch of milk depending on initial quality and on quality of processing and distribution conditions would be more accurate and just. However, to do this would require further studies to develop time/temperature specifications on microbiological and esthetic milk qualities, which could be expensive. It would also require a flexibility within the dating system to adjust to changes in processing and distribution systems.

Best-if-used-by date. The high sensitivity of milk to sanitary treatment and temperature makes this date unsatisfactory. This is especially true if control of distribution is not undertaken. On the other hand, with good distribution control and knowledge of the initial quality parameter, one could theoretically place an end-of-shelf-life date on fluid milk.

Fresh “Bakery Products

Modes of deterioration. The various modes by which breads and cakes deteriorate include: 1) microbial growth, primarily visible mold growth on the surface of the product; 2) moisture loss causing hardening; 3) oxidative rancidity; 4) nutritional losses; and 5) staling.

The baking process is similar to pasteurization in that both enzymes and micro-organisms are destroyed by the heat. Thus, bread may be stored at room temperature in spite of its high water activity. By the time microbial growth begins to be a problem, the bread has usually been consumed or other modes of deterioration have already limited shelf life. Calcium propionate is often added to bread as a mold inhibitor to slow this process. Moisture loss can be kept to a minimum by use of moisture-proof packages, although it can be the limiting factor in cakes packaged in cardboard.

Staling usually occurs before either oxidative rancidity or significant nutritional losses. This is

*A measure of sensitivity of food to temperature is called the temperature coefficient (Q_{10}). See app. B, equation 8.

especially true of bread and usually true for cakes, in which rancidity can occasionally be a problem. Vitamin losses occur very slowly in bakery products. Loss of available lysine through nonenzymatic browning occurs more quickly but is not a significant problem, since bread is not a significant source of lysine in the diet.

Staling is by far the major mode of deterioration in fresh bakery products. Effects of staling include changes in taste and aroma, increased opacity of crumb, increased crumbliness, and increased hardness of crumb (with or without moisture loss). Many factors affect the rate and extent of staling, including the protein content of the flour used, pentosan content, and monoglyceride and diglyceride additives. Staling is one of the few degradative reactions in foods that proceeds faster at lower temperatures, having an inverse Q_{10} of 1.5 to 2.0. The shelf life of breads is usually considered to be about 2 days and that of cakes about 1 week.

Aside from the possibly toxic effects of consuming large amounts of moldy bread, there are little or no safety considerations in determining the shelf life of fresh bakery products. Most people, in fact, would reject moldy bread even when one colony forms. Nutrient loss is of minor consideration since it occurs much more slowly than sensory quality losses caused by staling.

Pack date. The pack date for bakery products would let the consumer know when the produce was made. This would be acceptable for bakery products, although not the most desirable type of open date. With a pack date on the product, the consumer may expect bread to be fresh when it is in fact very close to staleness. On the other hand, for cakes, with a shelf life of about 1 week, consumers may feel the product is too old when, in fact, there is considerable high-quality life left. The only way a pack date would be acceptable would be if people had an excellent knowledge of shelf life.

Sell-by date. A sell-by date sets a limit on the acceptable amount of staling of bakery products sold at full price in the marketplace without making a judgment of the amount of staleness the consumer would personally tolerate when actually eating the product. Sell-by dates are presently required in several States. Bakeries in these States have found that consumers do tend to pick the freshest product, but this presents no real problem since deliveries are made every day or every other day. They also have experienced no trouble in selling the average products at reduced prices since they are still edible and have lost no nutritional quality.

Best-if-used-by date. This date tells consumers that for maximum freshness they should use the product by that date without fear that if they do not, they must throw it away. This date would also be beneficial for the bakeries. They could sell the products past that date at a reduced price and therefore would not have to dispose of the product as could be the case with a use-by date.

For fresh bakery products, either the sell-by or best-if-used-by date would be suitable.

Fresh Meat

Modes of deterioration. There are essentially two modes of spoilage for fresh meat products: bacterial growth and loss of appropriate color.

Consumers relate the characteristic red color of fresh meat with quality and freshness. This red color occurs when red oxymyoglobin is formed because of the oxidation of purplish myoglobin. Exposure to air and light causes the color change of oxymyoglobin, generally within 24 hours, although packaging under a low oxygen atmosphere can delay the reaction. The color change is also extremely temperature-dependent as reflected in a high Q_{10}, of 20 to 35. It should be realized that although the color may change, the food still has high flavor quality and nutritional value. With some meat such as pork the use of a color index is not possible because of its initial color.

Bacterial spoilage is caused mainly by psychotrophs and, with the exception of ground beef, is primarily a surface problem yielding slime, off-colors, and off-odors. The shelf life of fresh meat is generally 3 to 4 days at refrigerated temperature, considerably longer than that for brown-color development. The critical factors to guard against microbial spoilage are: 1) maintenance of proper temperature, since the Q_{10}'s are relatively high (3 to 8), and 2) maintenance of proper sanitation to keep the original bacterial load low. At 5° C, ground beef with an original load of 10^5 cells/g has 2 more days of shelf life than that with an original load of 10^7 cells/g.

The package atmosphere can also drastically affect shelf life. A carbon dioxide (CO_2) atmosphere will lower the pH of the meat surface and retard growth, increasing shelf life by several weeks without any significant nutritional losses. It should be noted that the history of the animal prior to slaughter can also affect shelf life.

Proteolytic psychotropic bacteria grow more quickly in fresh meat at proper storage conditions than do pathogenic bacteria. Thus, the production of slime, off-flavors, and off-odors is rapid enough to occur before the possible development of safety hazards of pathogenic growth. Using color change as a sensory-quality criterion also means that sensory changes occur sooner than any safety hazards or significant nutrient loss. However, these color changes can cause rejection of the meat while it still has high flavor quality.

Fresh meat that is cut and prepared in the retail store, is not frozen at any time during its storage life, and is not packaged in any container or wrapping prior to sale could be exempted from open dating. The quality of fresh meat described above can be determined by sight, touch, and smell before purchase is made, In addition, there would be problems in physically placing a date on individual items, and the cost of such a program would be prohibitive.

For fresh meat that is packaged and/or frozen at some time during its storage life, an open date is more meaningful because consumers have more difficulty determining the quality of the product. An open date would be of more use to consumers under these conditions and would be more feasible placed on the package as opposed to the individual item.

Pack date. Almost all fresh meat is packaged by the retailer who deals directly with the public. This meat may have been slaughtered anywhere from 1 day to 2 weeks previously. Since carcasses of properly handled beef are essentially sterile internally, it is the packing procedure that initiates color and bacterial spoilage, Thus, the pack date is a good index in determining the shelf life. Since the shelf life of fresh meat is relatively short beyond the pack date, this date may be sufficient for consumer use and understanding, However, many people freeze meat at home, and the pack date does not give them any idea of the frozen product shelf life.

Sell-by date. The sell-by date may not be any more useful to the consumer than a pack date for fresh refrigerated meat because it does not tell the consumer the time at which quality changes were initiated. However, if the marketer has good quality control, it represents a better method than the pack date, as it might reduce wastage,

Best-if-used-by date. In the case of fresh meat, this date could be "for highest quality, use or freeze by____." This date might be most useful to the consumer. However, as evidenced by the Q_{10}'s of the deteriorative reactions, high temperature can result in very rapid deterioration of fresh meat. Thus, the potential for consumer abuse prior to the date may be too great for this date to be a practical alternative,

Poultry

Modes of deterioration. Discussion of the modes of deterioration of quality will be limited to those changes occurring after death that affect wholesomeness and fitness for food. These include: 1) microbial decay, 2) pathogen growth, 3) sensory quality changes, 4) chemical and enzymatic degradation affecting color and rancidity, and 5) physical decay.

Hundreds of different species of micro-organisms have been reported to grow in poultry meat and may or may not be pathogenic. In the United States, fowl foods once were the most frequent vehicle of dissemination in outbreaks of food-borne infections, and Salmonella were the most important organisms implicated in these outbreaks. However, according to the Center for Disease Control, poultry has become a minor vehicle for food poisoning in recent years because of better process controls.

Microbial growth during storage may or may not cause decay, depending on the type of organism (proteolytic or nonproteolytic). Slime formation occurs at a level of 10^8 to 10^9 organisms per square centimeter (cm^2) of surface, and sensory spoilage is detectable at 10^7 to 10^8 organisms per cm^2. Low temperature is the best prevention against microbial growth. Growth occurs only very slowly below – 12° C, and it is important that the temperature doesn't fluctuate above that, Since the Q_{10} for growth is about 3.

Flavor changes are affected by the sex and age of the animal, amount of fat, and surroundings of the carcass. They can be monitored by the degradation of inosinic acid into inosine and hyposanthine. Therefore, some chemical index of quality can be used.

Color change, weight loss, and rancidity development can be retarded by freezing, vacuum-packing, and use of low-oxygen permeable films. Careful handling of carcasses at low temperature slows the disappearance of adenosine triphosphate and postmortem glycolysis, Storage at high temperature leads to irreversible toughening. Careful handling also reduces bruising and loss of tissue water (syneresis),

The overall Q_{10} of deterioration of frozen poultry is about 20, which is very typical of frozen foods and meats in general. The Q_{10} for fresh poultry shelf life varies from 2 to 7, depending on the preprocessing and processing methods used.

The past frequency of foodborne infections that can be disseminated by poultry makes the question of safety relevant. This, however, cannot be prevented by an open date. From a consumer standpoint, nutrient loss and loss of sensory quality are the most important considerations in setting the open date.

Fresh poultry that is cut and prepared in the retail store, is not frozen at any time during its storage life, and is not packaged in any container or wrapping prior to sale could be exempted from open dating. The rationale for exemption is the same as discussed for fresh meat, However, for poultry that is packaged and/or frozen before sale, an open date is useful to the consumer.

Pack date. The pack date for most poultry is the date on which the product is slaughtered, cut up, and put into a package. With a product such as poultry that has a short shelf life, a pack date—if done at retail or in a process center—would be a useful date if it is close to the date of slaughter. However, temperature abuse would lead to an improper guess by the consumer as to the quality of the product beyond this date.

Sell-by date. The estimation of a sell-by date could be made by each producer, based on a knowledge of the exact processing conditions and the normal distribution conditions, including the retail store. The sell-by date would provide some help to the consumer, but the exact information regarding how long after the sell-by date the product could be used is missing. Coupled with a sell-by date, information on how long the product could be stored in the home—either frozen or refrigerated—would be most useful.

Best-if-used-by date. From the producers' standpoint, estimating a sell-by date is almost as difficult as estimating a use-by date, the only difference being the knowledge of temperature conditions under refrigeration and freezing in the consumer's home. Theoretically, a best-if-used-by date would be the most meaningful date for the consumer. However, based on presently available information on poultry shelf life, it would be difficult to estimate a general sell-by or best-if-used-by date. In addition, home storage temperature can vary by 6° and with a high Q_{10} this could affect shelf life. Determining these dates would require considerable money to collect the required information. In addition, different methods and more control for the grocery store display of products would have to be developed.

Fresh Fish

Modes of deterioration. The major mode of spoilage for fresh fish is bacterial decomposition on the surface of the fish. Factors affecting the keeping quality of fish are: 1) environment where caught (season, location, bacterial load of water), 2) fish species, and 3) handling conditions (temperature, sanitation). The same factors apply to shellfish, although since lobsters, clams, and crabs are sold alive, proper temperature—particularly prevention of any rapid change in temperature—is of paramount importance.

Fresh fish is generally not prepackaged and is almost always packed and distributed in ice. Maintenance of surface temperatures below 2° C is of utmost importance. Shelf-life data show that a typical marine (saltwater) fish such as cod has a shelf life of approximately 14 days when stored on ice. The Q_{10} values of from 4 to 6 indicate the importance of keeping fish properly chilled, since a small change in temperature has a drastic effect on an already short shelf life. For example, raising the temperature to 10° C would reduce shelf life to less than 2 days. The Q_{10}'s of growth for typical spoilage bacteria closely resemble the actual sensory quality data. As with fresh meat and poultry, safety from pathogenic organisms cannot be guaranteed by open dating, it is only possible by proper sanitation and holding temperatures below 7° C.

The detrimental effects of psychotropic bacterial growth become evident in fresh fish much sooner than any nutrient loss or safety hazard occurs. Thus, sensory considerations are the limiting factors in determining shelf life.

Fresh fish that is prepared in the retail store, is not frozen at any time in its storage life, and is not packaged in any container or wrapping prior to sale could be exempted from open dating. The rationale for exemption is the same as discussed for fresh meat. However, for fresh fish that is packaged and/or frozen before sale, an open date is useful to the consumer.

Pack date. In the case of fresh fish, the pack date should be termed the "catch date. " The catch date marks the beginning of deterioration and must be known in order to set a sell-by or use-by date. However, even with proper temperature control and sanitary handling, the length of shelf life varies with each species of fish and also within species because of season, location, and bacterial load of the water. Therefore, the catch date is not technologically useful in setting a shelf life. From a retailer's and a consumer's standpoint, the pack date would be most meaningful, since one could easily determine if the fish were old. Even if it were already packaged, a consumer could then reject it based on experience with old fish. This is especially true since most consumers buy fresh fish on or close to the date of consumption.

Sell-by date. This date would have to be set by the fishing company with knowledge of the catch environment as well as of the species of fish and the catch date. Its validity would depend on controlled temperature and sanitary conditions during distribution and retailing, Since most fresh fish is handled directly by independent fishermen with no research resources, presently it would be technologically impossible to set realistic dates based on real data. The only thing that could be done would be to set some average values on the products which might in fact deceive the consumer, especially since abuse may easily occur.

Best-if-used-by date. This date would be no more useful than a sell-by date for the same reasons. Since most consumers buying fresh fish feel a need to buy it as close as possible to the actual time of use, a pack date is more meaningful. The extreme sensitivity of fresh fish to temperatures above **2°** to **4° C** and to unsanitary handling would make retailers very reluctant to initiate a use-by date,

Fresh Fruits and Vegetables

Modes of deterioration. The major modes of deterioration of fresh fruits and vegetables can be classified as: I) enzymatic and chemical reactions leading to nutrient loss as well as loss of sensory appeal, and 2) microbial decay resulting in loss of sensory appeal as well as possible health hazards if pathogenic organisms are present.

Some of the factors affecting the point of onset and the rates of these various reactions include the following:

1. Growing conditions—such as soil and water consumption, amount of sunlight, and temperatures—that have a direct effect on the chemical composition of fruits and vegetables.
2. The point in the maturation process at which the fruit or vegetable is harvested, since it determines the degree of maturity and the rate of maturity. This effect varies with the type of fruit or vegetable.
3. The temperature of harvesting and subsequent storage. The higher the temperature, the faster the reaction rates (Q_{10} of 2 to 3), but damage can also occur if held at too low a temperature (chill injury), which varies with each fruit and vegetable,
4. Any physical bruising or damage occurring during harvesting and transportation. Punctures and broken skin can allow entry and growth of micro-organisms; cell rupture allows mixing of enzymes and substrates with subsequent decay reactions.
5. The composition of the storage atmosphere. Addition or removal of ethylene can speed or slow ripening; the ratio of CO_2 to oxygen has a direct effect on the rate of respiration, and lack of humidity can cause wilting,
6. Sanitation conditions. Washing or disinfecting reduces microbial loads on the surface; fumigation lowers the extent of insect damage.

The combinations of these various factors influence shelf life so radically that it is extremely difficult to predict. From the standpoint of food safety, most pathogens (except for molds) do not grow on these products. The presence of mold is easy to identify visually and can serve as an index for rejection.

Vitamin C is a relatively unstable vitamin. It degrades more quickly than most nutrients, so its loss can be used as a standard in judging the end of shelf life for foods that are major sources of vitamin C. However, since consumers cannot measure vitamin loss, consumers judge fruits and vegetables by their market quality—appearance and firmness. Market quality has been found to have a direct relationship to nutritive quality, microbiological contamination, and/or insect contamination. Sensory quality is therefore the primary consideration of the type of open-dating system,

Fresh fruits and vegetables sold in bulk—not packaged—could be exempted from open dating. This is because the quality of fruits and vegetables sold in bulk can be determined by sight, touch, and smell before purchase is made. It would be very difficult to determine a meaningful shelf-life date because fruits and vegetables are subject to varying rates and types of deterioration, including physical deterioration as a function of consumer handling. There would also be problems in physically placing a date on individual items, and the cost of such a program would be prohibitive.

For packaged fresh fruits and vegetables, consumers have more difficulty in determining quality.

Pack date. In the case of fresh fruits and vegetables, the pack date would be the date of harvest. Most consumers in the United States would probably have little knowledge as to when a fruit or vegetable was harvested unless it was in the growing season from local markets. In addition, the great influence of the factors discussed above on shelf life would make this date inapplicable to fruits and vegetables that can have extended shelf lives if stored under ideal conditions. However, a harvest date would be of great help in the case of vegetables that usually are picked at the peak of quality and have a relatively rapid deterioration in quality. Sweet corn on the cob is an example, but even here, unless the corn is immediately chilled, it can lose 50 percent of its sweetness in several hours, and the date would be no indication of quality.

Sell-by date. A sell-by date would be extremely difficult to predict, implement, or enforce, especially for products with a short shelf life. In any case, consumer judgment by appearance and texture is more valid and is a built-in means of shelf-life assessment.

Best-if-used-by date. The conclusions for a sell-by date are also true for a best-if-used-by date, unless advances are made to have absolute control over distribution. If such control were possible, a sell-by or best-if-used-by date could be implemented.

SEMIPERISHABLE FOODS

As noted earlier, this category is given to foods that do not deteriorate very rapidly but, on the other hand, do not last for a long time under normal storage conditions. Perishable foods can be made semiperishable by better handling and by use of new technology such as controlled atmospheric storage. Long shelf-life foods, if abused, become semiperishable. Thus, the choice of putting foods into the semiperishable category is more subjective than objective.

Fried Snack Foods

Modes of deterioration. Common to all fried snack foods is fat added as a processing agent. All fats are subject to deterioration by oxidative and hydrolytic rancidity—the major mode of deterioration of all fried snack foods. The more unsaturated the fat, the more subject it is to rancidity.

A second mode of deterioration of dry-fried snack foods is moisture gain. Unacceptable loss of crispness occurs when moisture gain reaches a water availability (a_w) of 0.4 to 0.5. Hydrolytic rancidity (an enzyme reaction) can be inhibited by high-temperature denaturation of the natural lipase enzymes present in most foods, It also is inhibited by drying to below an a_w of 0.2 and at low temperature.

Oxidative rancidity has a Q_{10} of about 1.5 to 2.5. It can be controlled by protecting unsaturated fats from oxygen, metal ions, light, and high temperature, Addition of phenolic-type antioxidants is one of the most important means of preserving fats. Use of fresh oil in processing also is important since the presence of intermediate compounds produced accelerates the reaction.

The shelf life of fried snack foods can also be extended by packaging under an inert atmosphere. Potato chips in cellophane film coated with a moisture barrier have a shelf life of 4 to 6 weeks at 21° C. This can be extended to 6 months by packaging in a laminated container under nitrogen gas.

No microbiological safety hazards are presented by average fried snack foods since their water activity is low and they would lose crispness before microbes would grow. The end products of lipid oxidation have been shown to be toxic in animal studies. However, large amounts of extremely rancid fried foods would have to be consumed for a hazard to appear. Likewise, there is little nutrient loss because of lipid oxidation, since only a small portion of the fat oxidizes. Thus the primary consideration in determining the end of shelf life is sensory quality.

Pack date. The pack date has the advantage over the other two types of open dates in that it could be most easily and cheaply implemented. However, the disadvantage of the consumer's lack of knowledge about shelf life is compounded in this case by the fact that processing conditions (temperature, moisture content, use of fresh oil, and antioxidants) and packaging effectiveness (type of moisture, light barrier, and headspace gas) are crucial in determining the length of shelf life. Since these factors are different for each product, shelf life must be determined individually for each product. Therefore, a pack date is not meaningful except to help in stock rotation.

Sell-by date. The sell-by date could be a meaningful date for fried snack foods if the date were based on meaningful data as to quality changes in relationship to the environmental and initial oil characteristics, Companies could, based on typical ingredients, develop tests to measure shelf life. However, a range would be needed, since distribution conditions could vary, The date would best be accompanied by some meaningful home-storage information such as "store in a cool, dry place" or "store away from home appliances and in a cupboard. "

Best-if-used-by date. This date for fried snack foods would be relevant under the same conditions as a sell-by date. It would probably be most relevant if accompanied by recommendations for home storage. Abuse conditions, however, could occur that would lead to loss of quality before the end of shelf life.

Cheese

Modes of deterioration. Modes of deterioration for cheese include: 1) undesirable microbial growth resulting in visible surface-mold colonies, slime, putrefaction, or gas formation; 2) moisture loss; 3) chemical reactions such as nonenzymatic browning, lipid oxidation; and 4) lactose crystallization, In properly packaged, unopened cheese, surface mold or slime formation and moisture loss should not occur.

In processed cheese, chemical reactions are the major deteriorative modes, while in natural cheese, both undesirable microbial growth and chemical reactions lead to deterioration.

The shelf life of processed cheese stored at 4° C is generally about 4 months to 1 to 2 years. Natural cheese stored at 0° to 2° C has a shelf life ranging from 4 to 12 months, The Q_{10} for lipid oxidation is low, about 2, whereas for nonenzymatic browning, it is about 5. The Q_{10} for microbial growth is generally 6 to 8, so that temperature abuse will generally lead to microbial activity causing the end of shelf life. It should be noted that some browning is desirable as it leads to flavor development, and thus some cheese improves in quality with aging.

Cheese is susceptible to pathogenic growth, notably Staphylococcus aureus. However, contamination with pathogenic organisms only occurs if poor sanitary conditions occur during processing. The organism cannot grow below 7° C. Pathogenic growth does not correlate to shelf life, however. Also, since nutrient loss occurs very slowly after the initial processing procedures, it does not determine shelf life. Sensory quality changes from undesirable microbial growth and chemical reactions, therefore, are the primary factors in determining the end of shelf life.

Pack date. Since most consumers do not have knowledge of the shelf lives of cheese (and they vary considerably), a pack date is not beneficial except: 1) to ensure rotation and 2) for those cheeses that improve in quality as they age.

Sell-by date. Since most consumers store cheese under refrigeration, a sell-by date could be a meaningful way of open dating some cheeses that have a relatively short shelf life (1 to 6 months). For cheese of longer shelf life, it is probably not as meaningful as a use-by date. Of course, this means that distribution temperatures must be adequately controlled.

Best-if-used-by date. For cheeses with a long shelf life that are kept under adequate refrigeration, a use-by date based on good laboratory data would be a meaningful method of dating. This would also facilitate stock rotation.

Ice Cream

Modes of deterioration. One primary mode of deterioration of ice cream is the development of a grainy texture caused by crystallization of lactose under fluctuating temperature conditions as a result of the automatic defrost cycles of most freezers, Flavor deterioration caused by fat oxidation and hydrolysis becomes important during long-term storage,

Sensory quality as measured by adverse texture is the limiting factor in determining shelf life. Safety hazards or nutrient losses are not of importance since these would occur only if the ice cream were thawed, and the product would then be texturally inedible.

Pack date. The pack date would be the easiest date to implement, but differences in temperature cycles in different distribution systems far outweigh the relevance of the pack date. It would help to facilitate turnover, however,

Sell-by date. This date could be determined with knowledge and control of the temperature-time conditions encountered in the distribution system. It would be the most useful date to the consumer, since most ice cream is consumed within a relatively short time after purchase.

Best-if-used-by date. Determining this date would be very difficult, given the uncertainty of temperature cycling after purchase from the market. It would therefore not serve a meaningful purpose.

LONG SHELF-LIFE FOODS

Some foods have been classified by various State governments as being nonperishable and thus not subject to open dating. In fact, some manufacturers suggest their products have an indefinite shelf life. As pointed out in this report, all foods deteriorate as a function of the environmental conditions. Open dating of foods with a long shelf life may be the most meaningful of any food perishability category because these foods may remain on the shelf for a fairly long time both before and after purchase. Some type of date would help to ensure proper rotation and give the consumer an index of when the food should be used,

Dehydrated Foods

Modes of deterioration. In general, the major modes of deterioration for dried foods include: 1) loss of nutrients, especially vitamins C, B_1, and lysine; 2) nonenzymatic browning; 3) lipid oxidation; 4) pigment degradation; and 5) moisture gain to a critical level that causes sogginess, To ensure against these problems, drying to a specific protective moisture value is critical along with a good water-impermeable pouch to prevent gain, The pouch should be vacuum-sealed or gas-flushed, and should be opaque.

For all dehydrated foods, the moisture content has a great effect on the rate of the deteriorative reactions and also on the sensitivity of the rates to an increase in temperature. For example, the rates of loss of water-soluble vitamins, nonenzymatic browning, and chlorophyll degradation increase with increased moisture content, Overdrying causes an increase in the rate of lipid oxidation and increases the loss of carotenoid pigments and fat-soluble vitamins. For some reactions, an increased moisture content increases the Q_{10}, while in other reactions, the Q_{10} is lowered. Protection from oxygen can slow oxidation reactions, but the cost of oxygen-excluding packaging must be balanced with the practicality of adding antioxidants.

A knowledge of the types of deteriorative reactions in each product, their rates, and how these rates change with temperature, moisture content, packaging, oxygen availability, and other processing parameters is necessary to determine the shelf life of any dehydrated food, Hence, shelf life must be determined separately for each individual product.

In general, the shelf lives of dehydrated vegetables at 210 C vary from as low as 2 or 3 months to as much as 12 or 15 months. Similarly, meat shelf life can vary from 1 to 6 months, and dried fruits from 1 month to 2 years, depending on the above conditions. The Q_{10} for these reactions ranges from 2 to over 10.

Safety hazards from microbes are generally not a consideration in determining the shelf lives of dehydrated foods if they are protected from moisture gain. The only microbial growth that can occur is that of xerophilic yeasts and molds that can grow at water activities from 0.6 to 0.7. This growth is generally slow and not of a pathogenic nature and would be easily recognized. Nutrient losses occur through lipid and vitamin oxidations and through loss of essential amino acids during nonenzymatic browning. These have a Q_{10} of from 2 to 6. Sensory quality losses occur through color losses ($Q_{10} = 2$), nonenzymatic browning leading to darkening and hardening ($Q_{10} = 4$ to 6), and lipid oxidation ($Q_{10} = 1.5$ to 2) resulting in rancidity. Thus both nutrient loss and sensory quality change must be considered, the shelf life being limited by whichever becomes unacceptable sooner, based on some standard set for the change in the specific reaction allowable.

Pack date. With respect to dehydrated foods, a myriad of reactions can occur that are a function of initial quality and processing conditions and that are influenced by temperature, moisture change, oxygen level, light, and package permeability. Since consumers are unaware of these factors, a pack date would seem useful only from the standpoint of stock rotation.

Sell-by date. To implement a sell-by date, a manufacturer must assess the major mode of deterioration of a particular product and gather information on the distribution system. From this, an average sell-by date could be instituted. If an estimated shelf life after the sell-by date were established for various environmental combinations of temperature and humidity in the home, the product could be offered for sale after the sell-by date at a reduced price. Although a sell-by date is a reasonable type of open dating for dehydrated foods, some type of system that would give estimated shelf life for the food beyond the date should be included. This information could, of course, depend on the area of the country.

Best-if-used-by date. The interaction of the effects of environmental conditions illustrated in the above discussion and the fact that significant but condition-variable shelf life is left after the date of sale could make this date inapplicable to dehydrated foods unless it was based on the product being sold and consumed in specific areas of the country.

Nonfat Dry Milk

Modes of deterioration. Nonenzymatic browning, resulting in loss of protein nutritional value, and flavor deterioration are the major deterioration modes of nonfat dry milk, The Q_{10} of nonenzymatic browning varies from 2.3 to **3**, increasing as relative humidity rises, The Q_{10}'s for flavor deterioration range from 2 to 16, increasing with rising moisture content. The shelf life of nonfat dry milk under normal storage conditions is around 1 year.

Under normal storage conditions, safety is not a consideration in setting the shelf life of nonfat dry milk, unless it was previously contaminated. Nutrient loss should probably be the major consideration in shelf life. Studies have shown that flavor change occurs but is not as significant as nutrient loss.

Pack date. The pack date could be most easily implemented for dry milk on the date of manufacture. However, the dependence of shelf life on initial moisture content lessens the usefulness of the pack date without an industrywide standard for initial moisture, Lack of consumer knowledge of shelf life is always a disadvantage in using a pack date, especially for long shelf-life foods.

Sell-by date. The sell-by date could be determined given a basic knowledge of initial moisture content, package permeability, and temperature/humidity conditions of distribution, Generally, a sell-by date is not as useful to consumers as a use-by date since it does not define the amount of time left for home storage, but it conveys more information than a pack date. If average home storage times were indicated, the sell-by date would be useful,

Best-if-used-by date. Given the sensitivity to external relative humidity and thus moisture content of nonfat dry milk deteriorative reaction rates, this date may be difficult to determine. Moisture gain after the package is opened would vary greatly with humidity conditions and could be the determining factor in shortening shelf life. Obviously, moisture gain would not be a problem with a small package that is used rapidly, but would be a problem with slowly used packages. Therefore, shelf life should be a criterion of the sealed pouch and not include time after opening, A best-if-used-by date could be set if all the same information as in a sell-by date were known.

Breakfast Cereals

Modes of deterioration. The shelf life of most ready-to-eat dry breakfast cereals is **6** to **18** months at ambient temperatures assuming package integrity based on industry estimates. The modes of deterioration include: 1) moisture gain resulting in loss of crispness, 2) lipid oxidation resulting in rancidity, 3) vitamin degradation resulting in loss of nutritional value, and 4) breakage resulting in esthetic undesirability.

Proper packaging can keep the moisture gain below the critical value of 2 to 3 percent and can minimize breakage. Turnover of most cereals usually occurs before any significant vitamin loss, since vitamin degradation proceeds very slowly. Vitamin A loss, under dry conditions, is the most rapid, but is still small. Thiamin and riboflavin loss become important only if abused at high temperatures.

Lipid oxidation is the major mode of deterioration most often resulting in the end of shelf life because: I) cereals are dried to the monolayer moisture value or below inhibiting other modes of deterioration and 2) cereal grains have a high ratio of unsaturated fats that promotes oxidation. The Q_{10} of lipid oxidation in cereals is less than 2, As a consequence of this low Q_{10} the potential for temperature abuse with respect to flavor is also low. Antioxidants, added to the flakes by spraying or to the package liner, extend shelf life but do not affect the Q_{10}.

No safety hazards are presented by over-age cereals under normal conditions, and there is little nutrient loss at the point of detectable rancidity. Sensory quality is thus the primary consideration in limiting shelf life.

Pack date. The use of a pack date would be advantageous in that it would be little different from the present system. Coded pack dates are presently placed on most cereal package overwraps, if not on each individual container. The major change would be to an uncoded date. If a pack date is used, there is no necessity of setting criteria concerning the quality of the product or for analysis of the modes and rates of deterioration. Cost of implementing the use of a pack date would be minimal and yet the open date would better facilitate stock rotation than would the coded date.

A disadvantage, however, would be the possibility of consumers confusing the pack date with a sell-by or use-by date and thus believing all the products to be over-age. The obvious disadvantage of a pack date is the lack of any information about the expected length of the high-quality life of the cereal—a life that varies more among the different cereal types than many consumers would expect. Consumers also may expect a shorter life in general than is actually the case, which could result in unnecessary waste. The pack date does have a consumer advantage in that it in no way imposes manufacturers' judgment about the "staying power" of product quality. Consumers are left to make their own judgment.

Sell-by date. A sell-by date has the advantage of giving consumers some idea of how long to expect high quality. It would always be a future date in the market so that there would be little room for confusion, and it is easily policed by retailers and consumers alike. A sell-by date is not a final date for use, so it leaves open the possibility of the retailer selling the product after the date if the retailer clearly informs the consumer that the sell-by date is past. The Q_{10}'s of cereal deterioration are so low that temperature variations do not have an extreme effect on the rate of deterioration unless a cereal is held for long times at high temperatures. Therefore, the time at which deterioration may become noticeable to the consumer can be adequately predicted over a fairly broad temperature range.

The disadvantages of a sell-by date include the fact that consumers may not know how long they can expect to store the product at home before using it, especially if they do not know proper storage conditions. The other side of this disadvantage is that a sell-by date alone does not give consumers the date of manufacture, so they must rely on the manufacturer's judgment of shelf life. In addition, temperature is still an important factor, so the end of shelf life would have to be underestimated to allow for possible temperature abuse, possibly resulting in the waste of some product if turnover rates were slow enough.

Best-if-used-by date. This date could be advantageous because it gives the consumer the best idea of the actual length of high-quality life. Its use can be considered for cereals because of the low Q_{10}. However, it should be accompanied with recommendations for storage conditions, since long-time abuse of high temperature would invalidate the date,

The major disadvantage of a best-if-used-by date over a pack or sell-by date would be that it requires the most accurate knowledge of distribution conditions and deteriorative reaction rates under these conditions. It should not result in much product waste because the shelf life of cereals is long compared with the turnover time, but it could result in some consumer objection to the length of the manufacturer's estimate of shelf life, especially at the beginning of implementation.

Pasta

Modes of deterioration. The shelf life of pasta products with egg solids added is generally recognized to be 9 months to 3 years, and that of macaroni and spaghetti to be 2 to 4 years. The modes of deterioration include: 1) moisture gain or loss, 2) loss of carotene pigment in the egg solids, 3) absorption of flavors from the package, 4) "staling" probably caused by lipid oxidation, 5) loss of B vitamins, and 6) loss of protein quality in enriched products.

Little or no information is available in the U.S. literature concerning rates of pigment loss or flavor deterioration in pasta.

Pasta with a moisture content below 6 percent is too fragile, and above 13- to 16-percent moisture content, both mold growth and starch retrogradation, which cause toughness when cooked, occur. Moisture gain or loss has been found to have a Q_{10} of 2.6 to 4.9, much higher than that of lipid oxidation (1.5 to 2.0). The loss of protein quality has a Q_{10} of 4 to 6.

Loss of B vitamins occurs very slowly in opaque packages, but when exposed to light. 50 percent of the riboflavin and pyridoxine content can be lost in 19 and 62 days, respectively. This vitamin loss has not been adequately considered in shelf-life studies and is not reflected in the shelf lives given above. No Q_{10} data are available.

No microbiological safety hazards can occur with over-age pasta under normal conditions. There is some evidence that nutrient losses may occur primarily because of vitamin B degradation in nonopaque packages. More information is needed, however, before nutrient loss can be used to set shelf life. Loss of sensory quality caused by toughening or flavor change is at present the primary consideration in determining shelf life,

Because the Q_{10} of the sensory changes is low, the advantages and disadvantages of each type of open dating are very similar to those previously described in the section on breakfast cereals.

Pack date. A pack date would be most easily and cheaply implemented, since it would simply mean uncoding dates already used. It involves no judgment of quality criteria and is simply a factual date. The disadvantage of using it includes the possibility that distribution times of pasta products of 1 to 2 months may lead consumers to object to a perceived lack of freshness, Consumers would need a knowledge of the actual shelf life in order to adequately use a pack date.

Sell-by date. The low Q_{10} of most deteriorative reactions found for pasta products means that a date could be set that would be very representative of products distributed within a fairly broad temperature range, However, if the pasta were to serve as a protein source in the diet, the high Q_{10} for nonenzymatic browning could lead to further deterioration if the product were abused. Much more data is needed on actual distribution times, temperatures, and humidities, and on the deteriorative reaction rates under these conditions to be able to set a sell-by date. The length of time of acceptable quality remaining after the sell-by date would have to be standardized, and consumers would have to be informed of this and of proper storage conditions.

Best-if-used-by date. This date gives consumers the best idea of the manufacturers' judgment of the shelf life of the product. However, it requires the most accurate knowledge of distribution conditions and deteriorative reactions.

Concentrated Juices

Modes of deterioration. Frozen and canned concentrated juices can deteriorate by: 1) nutrient loss, primarily vitamins C or A; 2) microbial growth, primarily caused by yeasts and molds; 3) loss of color and flavor; and 4) loss of turbidity or cloudiness through enzyme reactions.

Vitamin loss tends to be very slow in concentrated juices. Frozen concentrated citrus juices retain **90 to 97** percent of their vitamin C for 1 year at temperatures as high as 0° C. Canned pineapple, tomato, and carrot juice may be stored at 10° to 15° C with minimal loss of vitamins A and C for 2 years.

The low pH of juices prohibits microbial growth other than yeasts and molds. Microbial growth occurs in two cases: 1) if the frozen juices are abused by holding above freezing temperatures or 2) after the cans are opened. Color and flavor changes occur to the greatest extent in concentrated frozen juices, mainly because of heat treatments needed to inactivate enzymes. New methods of high-temperature, short-time (HTST) pasteurization and canning procedures, coupled with the addition of aroma concentrate, have made greater color and flavor retention possible. In nonpasteurized concentrated juices, loss of cloudiness and turbidity are the primary limits to shelf life, With inactivation of the enzyme pectin methylestenase by HTST pasteurization, however, cloud stability has been significantly increased.

The shelf life of frozen concentrated fruit juices of – 18° C varies from 18 to 30 months, depending on the type of fruit. The Q_{10}'s for sensory quality losses of frozen fruit juices vary from 2 to 8. The Q_{10}'s for vitamin loss are less than 2. Of concern is the long storage of bulk product from a bumper year for sale the next year.

Open-dating considerations for frozen juices are very similar to those for frozen fruits and vegetables, with the exception that vitamin deterioration does not occur before sensory quality defects. Safety hazards from pathogenic organisms should not be of concern because of the low pH of the product.

Pack date. Since the shelf life of different juices varies significantly, a pack date may not be meaningful to the consumer. Pack dates, however, would help in maintaining stock rotation but would create problems if the juice is packed from the previous year's bulk storage.

Sell-by date. The sell-by date for concentrated juices would be of advantage if distribution conditions were known and abuse—especially for frozen products—were prevented. Some allowance would have to be made for excess products produced in bumper crop years and held into a second year to ensure against quality loss. A sell-by date with information as to months of high quality left in frozen or canned home storage would be beneficial.

Best-if-used-by date. This would be the best form of dating if adequate knowledge of storage conditions could be obtained. However, abuse—especially in the home—could shorten shelf life significantly.

Frozen Fruits and Vegetables

Modes of deterioration. The mode leading to loss of quality and nutritional value during storage of frozen fruits and vegetables is very dependent on the type of product, its initial quality, and the freezing conditions. Microbiological growth and spoilage should not be a problem if the product is stored below the freezing point, In fact, the microbial population will gradually decline during subfreezing storage, However, abuse can lead to growth, but it should not be significant with respect to pathogens.

The types of changes that can cause loss of sensory quality and nutritive value during storage of frozen produce include: 1) pigment loss, 2) ascorbic acid oxidation, 3) off-flavor development caused by either lipid autoxidation or browning, 4) loss of the characteristic flavor notes, 5) weight loss, 6) package ice formation, and 7) cellular and structure breakdown (loss of final crispness). The effects of desiccation because of a highly permeable package can cause a loss of up to as much as one-fifth of the weight over a storage period of 1 year at – 18° C. This will result in evident changes in appearance but has little or no effect on palatability or loss of ascorbic acid or carotene. Under longer storage, surface dehydration can advance to a stage where objectionable color and textural changes, as well as a dry appearance, are developed.

The shelf life of frozen fruits and vegetables can vary from 6 months to 2 years, depending on the product and on the quality aspect measured. Also, the temperature coefficients of the quality losses vary from 2 to 40. Thus, deteriorative reactions with greater temperature sensitivities may dominate at higher temperatures and be insignificant at lower temperatures. The high sensitivity, however, indicates that good temperature control is necessary.

A hazard due to pathogens can occur from frozen fruits and vegetables only if the microbes are frozen with the initial product (a processing failure), survive the freezing, and then thawing occurs so that the pathogens can grow (a handling failure). These events are rare enough that they are not open-dating considerations.

However, nutritive value is another matter. Frozen fruits and vegetables are consumed for pleasure and as a major dietary source of vitamins and minerals. In some cases, vitamin content may fall below some accepted standard before sensory quality becomes inadequate. Therefore, if vitamin content is used as the primary open-dating consideration, provisions should be made for the continued sale of over-age frozen fruits and vegetables up to the point of actual unpalatability y.

Pack date. Because the shelf life of frozen fruits and vegetables varies from 6 months to 2 years, the pack date may be the easiest to implement. However, it would not tell the consumer anything about the shelf life of the product. The problem of seasonal packing and of overabundant crops in 1 year could be a very difficult problem, since it could lead to wasting good products.

An extensive education program, perhaps coupled with a system similar to the British "three-star" system, could make the sell-by date beneficial. Under the British three-star system, home storage life for different temperatures is defined on the package. Freezer units are rated on their ability to maintain certain temperatures (-6°, -12°, and -18° C), and based on the temperature, receive a one- (★), two- (★★), or three- (★★★) star rating. Product packages are labeled with recommended storage times (either from the pack date or after a sell-by date) for each of the star ratings. As with other foods, the pack date does facilitate stock rotation.

Sell-by date. The sell-by date could be implemented without a home freezer-rating system. The last date of sale could be determined with a knowledge of initial product quality distribution times and temperatures and rates of deteriorative reactions at these temperatures, However, collecting this data could be expensive.

A sell-by date, coupled with the home-storage system mentioned above, would be very beneficial and would eliminate the possible wastage problem from years of high crop production. This system would also facilitate rotation,

Best-if-used-by date. The high Q_{10} of some of the deteriorative reactions of frozen fruits and vegetables, together with the uncertainty of home-storage temperature conditions make implementation of a definite use- by date difficult. Also, a definite use-by date may be impractical, since surveys have shown that a major portion of frozen fruit and vegetable deterioration occurs with the end user. The optimum date would be a best-if-used-by date, since it is most appropriate for a food with long shelf life under controlled conditions and with some estimate of home storage.

Frozen Meats and Fish

Modes of deterioration. Lipid oxidation and protein denaturation are the major modes of deterioration in both frozen meats and frozen fish, However, they occur more rapidly in frozen fish because of the greater ratio of unsaturated to saturated fats and the higher percentage of myofribular proteins that become insoluble with storage. Tissue desiccation and myoglobin color changes also occur with extended frozen storage.

Antioxidants have not been successfully applied for increasing shelf life of frozen meat and fish. Glazing with various solutions of phosphates, sugars, monosodium glutamate (MSG), benzoic acid, and polyhydric and other alcohols, if allowed, can be used in place of the more expensive wrap-packaging. Effective packaging increases shelf life and overall product quality by protecting from excessive dehydration, denaturation, oxidative rancidity, and microbial recontamination.

At – 18° C, the shelf life of fish varies from 2 to 8 months, depending mainly on the species, with Q_{10}'s varying from 1.5 to 4,5. Frozen shellfish generally have a shelf life at – 8° C of 2 to 4 months, with the exception of 10 months for crab. Frozen beef, pork, veal, and lamb at - 18° C have shelf lives of about 6 to 12 months, 4 to 12 months, 4 to 14 months, and 6 to 16 months, respectively, with Q_{10}'s of about 2.

The biggest problem is abuse by holding just below the freezing point. Under those conditions, excessive deterioration could occur. A freeze-thaw indicator with the right melting point could indicate whether this has occurred.

Microbial deterioration with possible pathogenic growth is not a major mode of deterioration in frozen meats and fish, since freezing temperatures inhibit activity of most microbes. Safety hazards are therefore not a consideration in open dating unless the product is abused and stored above freezing. Even then, spoilage organisms usually grow faster than the pathogens.

Nutrients in frozen meats are generally well preserved. Thiamin, riboflavin, and niacin have shown changes upon freezer storage, but no relationship between these changes and storage temperature have been seem The nutrient losses are insignificant and are not a good measure of shelf life in frozen meats and fish, Flavor deterioration caused by oxidation of fats is usually the primary limiter of shelf life.

Pack date. The date of packaging is useful in indicating production and facilitating stock rotation. However, since the shelf life is very species-dependent and consumers have little knowledge of shelf life, it is not a feasible system.

Sell-by date. A sell-by date for frozen meat and fish, using the same system as for frozen fruits and vegetables, would be of benefit to the consumer. The major problem would be abuse—especially holding just below the freezing point—which would deteriorate the product much sooner than expected.

Best-if-used-by date. As with frozen fruits and vegetables, the same information to set a sell-by date can be used to set a best-if-used-by date if adequate knowledge of home-storage conditions is available.

Frozen Convenience Foods

Modes of deterioration. Frozen convenience foods are precooked meat, vegetable, and pasta products packaged separately or in combination. Reheating in a tray is all that is usually necessary before consumption.

The predominant mode of deterioration of precooked frozen foods is lipid oxidation, causing rancidity in the meat portion of the product. However, the susceptibility of the product to lipid oxidation is strongly influenced by ingredients, processing, and packaging that go into making the product.

Changes in gravies and sauces (weeping and curdling) is the other major deteriorative mechanism. Note, however, that most of the literature on these convenience foods is more than 10 years old, and thus this may not necessarily be the major modes of deterioration of today's products (that is, few TV dinners or frozen precooked entree products list antioxidants as ingredients).

The shelf life of frozen precooked chicken, beef, and pork entrees with no sauce or gravy ranges from 6 to 12 months. With sauces and gravies acting as an oxygen barrier, the shelf life can be increased by over 400 percent. The Q_{10}'s range from 2 to 3.5 in the – 23° to – 29° C temperature range.

The shelf lives of the sauces and gravies are similar to those for meats, with a Q_{10} of up to 30.

In considering modes of deterioration, freezer storage at or below – 18° C has been assumed, although it is not always the case. At these temperatures, microbial growth is not a problem. Precooked frozen foods pose no real health hazard even if eaten when rancid—unless the product thaws out and is held at above 7° C, allowing pathogens to grow in the sauces. Adequate protection such as a freeze-thaw indicator would be needed to guarantee safety.

Nutrient losses may occur, but the great variety of ingredients, ingredient history, and packaging combinations that ultimately appear in the freezer case make generalizations difficult. Sensory quality changes are the most readily apparent and are the mode of deterioration most often reported in the literature. However, with the institution of open dating and further study into each product, it may be found that nutrient losses should actually be used as an indicating chemical factor to predict the end of shelf life of some frozen convenience foods,

Pack date. The great variation in ingredients, processing, and packaging of precooked frozen foods, resulting in a great variation in shelf lives, makes the pack date relatively useless to the consumer who cannot be cognizant of all variations. A legible pack date would aid in first-in, first-out stock rotation but may result in inappropriate purchasing patterns because of misconceptions about shelf lives.

Sell-by date. Given assurance of a temperature range of – 18° C or below in distribution conditions, this date could be determined by producers for each of their individual products. It would be especially useful to the consumer if coupled with label information concerning appropriate length of storage in different types of home freezers as discussed for other frozen foods. Even without this information, however, the sell-by date would be of more use to the consumer than would a pack date.

Best-if-used-by date. If the uncertainty of the frozen distribution system could be removed by assuring that some maximum time/temperature exposure would not be exceeded, a best-if-used-by date would seem to be most appropriate, as with other frozen foods.

Canned Fruits and Vegetables

Modes of deterioration. Components of canned fruits and vegetables deteriorate as a function of temperature in the following order: 1) flavor, 2) color, 3) texture, and 4) nutritive losses.

Changes in flavor in canned fruits and vegetables during storage can be caused by browning reactions, staling, and loss of flavor (flat taste). Browning reactions result in burned and bitter flavors, especially in fruits canned in syrups, and to some extent in sweet potatoes. Many vegetables get a "musty" taste, which could be described as "old. " Products high in starch become stale tasting as staling of the starch occurs. This reaction can be accompanied by yellowing. Changes in color during storage include fading of both chlorophyll and carotenoid pigments in red and green vegetables. Fruit and starchy vegetables generally turn dark, or brown, in color.

Changes in texture during storage include softening of some vegetables when stored at high temperatures. Extremely low temperatures can break down the texture of many vegetables, especially potatoes, beans, squash, greens, peas, and tomatoes. Other textural changes include a tendency towards lumping or clumping in beans and peas.

Loss of vitamins tends to occur more slowly than changes in flavor, color, and texture. Carotene and vitamin A are generally at least as stable as the overall quality of a given product. However, thiamin and ascorbic acid may or may not remain at acceptable levels, depending on the product, when compared with overall sensory quality.

Containers used for canned fruits and vegetables also deteriorate during storage. Corrosive products such as fruits tend to have shorter shelf lives than bland vegetables because of a more rapid deterioration of the can interior surface. Also, in rare cases, slight imperfections in the double seams of cans lead to a loss of vacuum during long-term storage. Storage at extremely low temperatures can lead to damage of can seams and subsequent loss of vacuum.

The shelf life of canned fruits and vegetables ranges from 1 to probably 3 years, depending on the product and on the quality aspect being measured. The Q_{10}'s of the deteriorative reactions are all quite low, from 1.5 to 2.5, indicating that the end of shelf life can be predicted over a fairly broad temperature range. Moisture gain or loss should not occur through the can wall, and oxidative reactions should be minimal,

A microbial hazard from *Clostridium botulinum* in canned fruits and vegetables is the result of processing failures and is not of importance in open dating, Most often, sensory quality defects occur more quickly than vitamin or other nutrient losses. However, thiamin and vitamin C losses do occur more quickly in some canned fruits and vegetables. It has been suggested that acceptable

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levels of these vitamins should be used as the shelf-life basis for canned foods that are significant sources of these vitamins in the list.

Pack date. According to the National Food Processors Association, the date of pack would be the easiest to implement but would not tell the consumer anything about the shelf life of the product. Canners who have seasonal packs would be in a difficult position because the date on the cans would seem old when the product is actually still well within the shelf life for the product. This would be especially true in years when an overabundant crop would force the canner to sell some product the following year. Since the canning industry usually figures that a 3-year shelf life for most fruits and vegetables is the norm, a 1-year delay would still result in a more-than-adequate shelf life for a given product. However, the consumer would have to be convinced of this fact. This would take much time, effort, and money. There is also. some chance for confusion among consumers who could mistake the pack date for a use-by date.

Sell-by date. This date is not really applicable to cans that are often stored in the home for some long period of time after being sold. However, if some system that indicates shelf life beyond the selling date were indicated, this would be feasible. It would not account for abuse, however.

Best-if-used-by date. This date could be useful to consumers because it would give an idea of the shelf life of the product if conditions of storage were known. This would also be useful for rotating stock at the grocery level. However, with all such dating, the actual end of shelf life would vary with processing, distribution, and home-storage conditions. Probably the most useful way to present this information would be to give label information of shelf life at several temperatures, but it is doubtful at the present time that there is sufficient good data for this format. However, since there is data for products at ambient conditions, a single date could be embossed on the can with an explanation of the storage temperature on which it is based, The canning industry could collect data on each product for each mode of deterioration, estimate time/temperature distributions, and then estimate the shelf life left at several home-storage conditions.

Coffee and Tea

Modes of deterioration. Staling is the major mode of deterioration of ground roast coffee. Increased humidity increases the rate of staling, Moisture can cause hydrolysis of the esters, acetals, and ketals in coffee aroma to compounds with less-pleasing aromas. Staling is thought to be caused by loss of flavor volatiles or by chemical changes in the volatile components caused by moisture and oxygen absorption. The aroma degeneration is defined as changing from flat to old to sharply rancid, with a cocoa odor in the advanced stages. Flavor concurrently changes from flat to bitter, old, and rancid. Unprotected ground roast coffee borders on unsalability in 1 to 2 weeks, depending on the relative humidity.

The shelf life of ground roast coffee packaged under vacuum in metal cans depends largely on the efficiency with which oxygen is removed, In order to ensure the greatest product stability, it is necessary to have no residual oxygen in the can. The difference between 27 “in” of mercury vacuum and 29 “in” is significant, Nine months’ shelf life is an acceptable industry average,

Instant coffee also loses flavor and stales during storage. Freeze-dried coffee has a longer shelf life than spray-dried coffee. This extended shelf life is largely because of the lower moisture content (2 percent) of the lyophilized coffee compared with 4.5-percent moisture content of the spray-dried.

In addition to flavor loss, instant coffee has the problem of caking because of moisture absorption when it is exposed to the atmosphere. Isotherms show that the moisture content of instant coffee rises rapidly when it is exposed to increasing relative humidities (RH). At 50-percent RH, instant coffee begins to agglomerate, and above 75-percent RH, it will turn into a liquid. The shelf life of unopened instant coffee varies from 18 to 36 months, depending on the type of package. The Q_{10}’s for coffee staling and moisture absorption are quite low, 1.5 to 2,0,

Tea is preserved by its low moisture content, which inhibits growth of micro-organisms. During storage, tea may undergo staling or lose some of its aroma. Sometimes foreign or incompatible odors may be absorbed, Moisture absorption results in caking of instant tea but occurs only if the jar is opened. Black leaf tea and packaged instant tea have a shelf life of about 18 months at 21° C, with a very low sensitivity to changes in temperature, Changes in humidity are more important considerations in the shelf life of tea, especially tea bags packaged in boxes.

No microbiological hazards are presented by over-age coffee or tea, They do not provide a significant source of nutrients in the diet, so nutrient loss is not a consideration. Loss of sensory qualities is the major open-dating consideration.

Pack date. The date of manufacture would not be advantageous to the consumer because it would not provide any information about the shelf life of the product. In fact, an open date of manufacture might result in considerable wastage, since the consumer might conclude that an older product is not as good as a newer one and would buy the product with the latest date on it. This conclusion would be particularly erroneous in the case of ground roast coffee, since the greatest consumption of shelf life occurs after the product is opened.

The date of manufacture also does not give any indication of the true age of the coffee or tea, since the green coffee beans or tea leaves could vary in age considerably from the time they were harvested until they were processed and packaged. The date would also not reflect any differences in shelf life caused by different processing procedures among manufacturers.

For example, two manufacturers of ground roast coffee may package on the same day and have the same date of manufacture. One manufacturer, however, evacuates the cans to 29 “in” of mercury and thereby rids the cans of essentially all of the oxygen. The second manufacturer evacuates the cans to 27 “in” of mercury and leaves a residual amount of oxygen. The coffee produced by the first manufacturer would be expected to have a longer shelf life than that of the second, yet this fact would not be reflected in the date of manufacture. The date of manufacture placed on a product with no explanation of what kind of date it was would also tend to confuse the consumer who might interpret it as an expiration date and assume that it was already beyond its predicted shelf life.

Many manufacturers use coded dates of manufacture, and this practice could be changed to an open date for coffee and tea. Open pack dating or coded dating would assist in stock rotation for the processor, distributor, transporter, and retailer to allow a “first-in, first-out” system. A coded date could also include other information such as the factory, shift, lot number, etc. to aid in inventory control and tracing of an item should a consumer complaint ever occur or a recall be necessary. The tracing of a consumer complaint would mean that the code must be placed on each package of food.

Sell-by date. Placing a sell-by date on coffee or tea products would be beneficial; however, the shelf life of these products is long, and abuse might make these dates meaningless. The only product for which a sell-by date would be applicable would be ground roast coffee packaged in bags, since the shelf life of this product is much shorter than that of coffee packaged in vacuum cans. Some manufacturers already place an open pull-date on this product for the benefit of the consumer and as an aid in stock rotation, but the practice of selling ground roast coffee in fold-top bags is usually localized and has become rather scarce.

Best-if-used-by or use-by date. The shelf life of coffee or tea mainly depends on the storage conditions such as temperature and relative humidity—especially after the product has been opened. Storage of instant coffee or tea mix, for example, with the lids open or loosely screwed on would result in moisture pickup and caking of the product. Storage of ground roast coffee in an unsealed container would result in faster staling.

A use-by date would also result in wastage not only because the consumer might reject the food in the grocery store because of the date but also because an expiration date would give the impression that the product should not be consumed for health reasons after a certain period of time when, in fact, no health hazard exists when aged coffee or tea is consumed. Food deterioration is also a gradual process, and rarely is a product good one day and bad the next. Shelf-life predictions for the same product can differ from one manufacturer to the next, since the end of shelf life is often a subjective decision, and a consumer may unjustly reject a product with a conservative shelf life in favor of the same product produced by a different manufacturer with a more liberal shelf-life prediction.

The same storage information collected by the manufacturer can be used to implement a best-if-used-by date based on minimal changes in flavor and odor during storage and does not have the disadvantages discussed above.

Spices, Sugar, and Salt

Modes of deterioration. Flavor, pungency, and color may be lost from spices by either physical or chemical routes, The active principles of most spices are organic compounds in the volatile oil fraction. Whole spices retain essential oils very well, as illustrated by the 5-year shelf life of whole cumin at room temperature. But loss of these volatiles can be a problem in ground spices. In ground spices, the temperatures during and immediately after grinding have been found to be important in retaining essential oils.

Color loss from capsicum spices (paprika and red peppers) is thought to be an oxidation reaction that may be induced by light, pro-oxidants, or coupled with other oxidation such as lipid oxidation. Increasing storage temperature and decreasing water activity seem to increase the rate of color loss as is true of lipid oxidation. In sweet red paprika, the color seems most stable at a_w 0.65. However, at this a_w, caking and browning become problems.

Pure sucrose is not susceptible to microbial or chemical deterioration, but sugar can become unacceptable to the consumer if contaminated by insects or rodent droppings. Excessive moisture gain leading to caking can also render the package unacceptable. However, these failures are indicative simply of poor storage or packaging failure. Under proper storage conditions, granulated sugar should be indefinitely shelf-stable.

Brown sugar, which is susceptible to moisture loss resulting in an extremely hard mass, is sealed in plastic or waxed bags for retail sale. Confectioners' sugar is susceptible to moisture gain resulting in caking, but anticaking agents such as cornstarch are added to combat this problem. The shelf life of confectioners' sugar is about 18 months at 21° C. The Q_{10} is about 2 for both brown and confectioners' sugar, based on moisture gain.

Table salt (NaCl) is not susceptible to microbial or chemical deterioration. However, pure salt is very hydroscopic and will absorb moisture from the surroundings above 75-percent RH. For this reason, anticaking agents are added to salt to ensure the free-flowing property. Stored in moisture-proof containers, salt will remain indefinitely stable.

Sensory quality (aroma, pungency, taste, and color) is the determining factor for shelf life of spices. Although some spices, notably paprika, are rich in vitamins, they are not consumed for their nutritive value. Spices imported from areas with poor sanitary facilities can have high loads of micro-organisms and be contaminated with aflatoxin via rodent or insect infestation or inclusion of extraneous plant material, Although contaminated spices can be sources of inoculum for foods, microbial contamination per se does not limit shelf life of spices because most spices are too dry to permit growth. Fumigation with ethylene oxide can be used to reduce the microbial load of spices.

Neither safety hazards nor nutrient loss occurs in sugar or salt, No sensory losses occur in salt or granulated sugar. Functional loss can occur in brown and confectioners' sugar because of moisture loss/gain, resulting in loss of free-flowingness.

Pack date. Very little published data are available on deterioration of spices. However, since wholesalers sell oleoresin, oils, and extracts to industrial users at certain specifications, it would be surprising if these wholesalers do not have data on storage stability of spice products.

Considering this lack of published data, however, a legible pack date would be of little or no value to consumers. Indeed, it is interesting to speculate whether or not the majority of consumers, with no standards for comparison, have any idea as to the strength of spices in terms of taste, pungency, or color. A pack date on sugar or salt would also be of little or no value,

Sell-by date. A sell-by date with no instructions for storage or to use within a specified time for best results is of little value in products such as spices, sugar, and salt that tend to be stored for long periods before use in the home.

Best-if-used-by date. A statement to the effect "for best flavor results, use before "___ would be the most useful method of open dating for consumers of ground spices. However, even with adequate data made available. the simple loss of pungency and color is a subjective judgment. A use-by date has no relevance for salt and granulated sugar with indefinite shelf life, Instructions on methods of reversing the hardening and caking of brown and confectioners' sugar would be more beneficial than would a best-if-used-by date.