Open Shelf-Life Dating of Food

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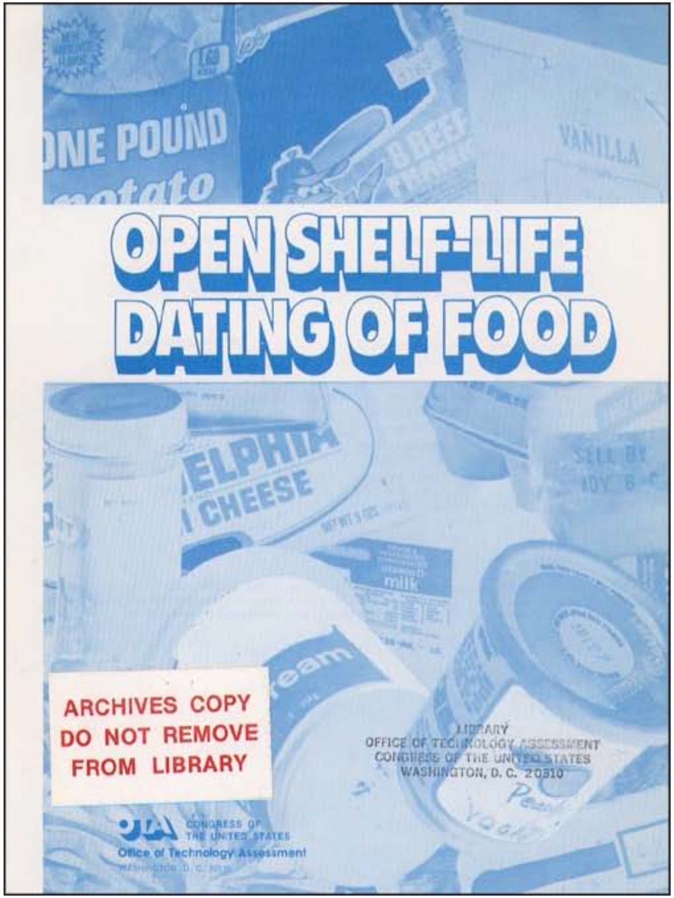

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Foreword

In this study OTA addressed the practicality of open shelf-life dating of food to disclose food freshness to the consumer. The assessment was undertaken at the request of the Senate Committee on Commerce, Science, and Transportation.

The Office of Technology Assessment formed a panel of consumer representatives, food retailers, processors, wholesalers, scientific experts, and State and Federal Government officials. Staffs of the Congressional Research Service, the U.S. Department of Agriculture, and the Food and Drug Administration provided background information to the assessment. Individual papers and reports were commissioned concerning the scientific basis for open dating of food and the critical issues involved. A nationwide mail survey was conducted to gain the consumer's perspective. In addition, reviews of the draft reports were provided by Federal agencies and officials, and a wide spectrum of interested individuals.

These wide-ranging contributions were vital to the shaping of the assessment and to developing congressional options. To all of these people OTA acknowledges a deep debt of gratitude; however, the report is an OTA staff synthesis and does not necessarily reflect the position or views of any particular individual.

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Contents

LIST OF TABLES

LIST OF FIGURES

Chapter I

Executive Summary

In their concern over the freshness **of food, consumers have increasingly advocated open shelf-life dating—the use of dates on a can or package of food that gives the consumer some idea of when a product was packed or should be sold or used. Although such a step appears simple and sensible at first glance, it entails many scientific and financial uncertainties and involves some complex choices.**

The Senate Committee on Commerce, Science, and Transportation asked OTA to assess the feasibility of open shelf-life dating of food and to provide Congress with the necessary information to adequately address this area of food labeling.

This assessment analyzes: consumers' perspectives on open-date labeling; benefits and costs; alternative systems and techniques; alternative criteria and scientific tests to establish open dates; enforcement mechanisms and liability related to open-date labeling; and options available to Congress.

CONSUMER CONCERNS

Ever since the vast majority of Americans became urbanized, consumers have had no sure way of knowing how fresh their food really is. Since they did not grow it themselves or personally know such factors as its age or storage condition, they have had to rely on assurances that wholesalers and retailers were abiding by some system that would eliminate food that was no longer fresh. Fresh food refers to food in which the quality has been unchanged from its initial state. Even under ideal conditions some foods lose their freshness within 2 or 3 days of being packed, while other foods may remain fresh for over a year,

Recent studies have shown that, indeed, consumers are concerned over whether or not the food they purchase is fresh. A U.S. Department of Agriculture (USDA) consumer survey in 1971 showed that 20 percent had complaints about food product freshness; a Nielson survey in 1973 turned up 50 percent with such complaints. A 1978 survey further supported this concern by noting that of all the problems on the minds of consumers when they shop for food, making sure that food in supermarkets is fresh heads the list. [1]

Facts that lend support to such concerns are scarce, however. There are no nationwide statistics on the amount of food sold that is not fresh, although there have been some individual State studies that indicate there is a problem.

[1] Skelly Yankelovich, and White, Inc., "A Study of Consumers' Attitudes and Behaviors Towards Eating at Home and Out of Home," Woman's Day, Family Food Study, 1978.

For example, a study of 25 supermarkets in Minnesota showed that all of those stores had some outdated food on their shelves.[2] Another study in that State found that 44 percent of the baby formula being sold was over age and that since 64 percent of the store managers could not read a coded date, they could not rotate the stock.[3] These findings led the State to adopt mandatory open shelf-life dating for some foods.

Open shelf-life dating means the use of legible terms such as a day, month, and year as an indication of when the food was packaged or by when it should be sold or used. Such dating is considered by most people to be a measure of food freshness. It does inform the buyer about the time lapse between packaging and purchase or use and, to the extent that such time lapse is synonymous with quality loss, of the quality or freshness as well. However, such a time lapse is not necessarily the only factor leading to quality loss—i.e., deviation from freshness. Therefore, an open date is not an absolute assurance of freshness—but it can be an indication.

Dating of food is far from being a new concept—in fact, it started back in the early 1930's. However, the dates have usually been in coded form, based on a color-keyed or number/letter system. The codes were originally designed to aid in controlling food inventories and to assist in any product recalls, such as for contaminated foods.

Consumers complain that since they cannot interpret the codes, they cannot tell whether or not the food they are buying is fresh. Indeed, sometimes employees at both the retail and wholesale level cannot read the codes either and thus are unable to use them as a means of keeping stocks in-date.

All indications are that consumers do want dates they can understand. For example, in 1977 the New York Consumer Protection Board published a report translating food manufacturers' freshness codes. The Board received over 100,000 requests for copies of the report.

Currently, no Federal policy exists on open dating. There is wide variation among the 21 States and the District of Columbia that have some form of mandatory open dating. For example, different States require different products to be dated, require different dates for the same products, and the same dates can have different interpretations. In addition, none of the States seem to have done "before and after" studies of open dating.

Even where not required by State law, some manufacturers have chosen to voluntarily open date their products. However, since there are no industry guidelines, there is no uniform system.

The result is often consumer confusion. For example, a survey conducted for OTA shows that three out of four consumers can correctly identify the type of date on milk. But only one in four knows the type of date on breakfast cereal, and only one in three knows the type of date on ground beef. Of course, milk is more often open dated than are breakfast cereal and ground beef.

To further complicate matters, there is no scientific body of knowledge to accurately determine dates for various products, no consensus on which type of date or dates—"pack" (when food was processed or packaged for retail sale), "sell by" (the last date a food product should be sold), "best-if-used-by" (the date after which food is no longer at its most acceptable level of quality), or a combination of these—to use for which product, or even which products to date at all, and no real guidelines as to how to display the date.

What appears at first to be a simple task of converting code to open dates readily becomes complex with many unanswered questions.

Even though no action has been taken at the Federal level, there has been and contin-

[2]Minnesota Public Interest Research Group, "Survey of Minnesota Food Stores, 1972, " testimony before the Minnesota State Senate on Open Dating Legislation.

[3]Keith Ford, Minnesota Office of Consumer Services, testimony before the Minnesota State Senate Hearings on Open Dating Legislation, 1972.

ues to be much congressional and executive agency interest in open dating. Bills have been introduced in the U.S. Congress on food labeling that would require open dating. However, only the Senate has approved such legislation,

In 1978, joint hearings were conducted by the Food and Drug Administration, USDA, and the Federal Trade Commission on food labeling issues. Over 9,000 written responses were received, 5,000 of which were from consumers. Preliminary results of the consumer responses indicate that consumers do want some form of open dating,

BACKGROUND

State Practices

Some form of open-date labeling is required in 40 percent of the States, including the District of Columbia (table 1). But more revealing than the number of States that have open dating are the food products covered and the type of date used.

Perishable foods, such as fluid milk, are the most common food products open dated. In 21 States with some form of mandatory open dating, 12—or 60 percent—have laws limiting coverage to fluid milk and/or milk products. *

Open-dating laws or regulations in seven States and the District of Columbia apply to a broader class of food products. One State, Massachusetts, includes both perishables and nonperishables, or long shelf-life foods.

The type of date used varies by State, but the majority either require or suggest a sell-by date, which is the last date a food product should be sold. Seventeen States and the District of Columbia fall into this category.

There is some variation among the States, however, in the requirement for sell-by dates —particularly for fluid milk and/or milk products. For example, the New Mexico law states that fluid milk and cream containers shall be labeled "with a legible sell-by date not to exceed 14 days including the date of packaging for pasteurized products and 5 days for raw products. " By contrast, the Maryland law requires all pasteurized milk products to have the term "sell by, " which is designated as a date "7 days after the day of pasteurization. "

In addition to the 21 States requiring some form of open dating, some food manufacturers voluntarily open date their products, Some use a pack date, others a sell-by date, and still others a use-by or best-if-used-by date. Some explicitly indicate that it is a sell-by or use-by date, while others only show a date.

Therefore, in some areas of the country, a portion of the food supply has some type of open date, while in other areas, food does not carry any date. Even among the States requiring open dating, the same date can have different interpretations. And in voluntary open dating by industry, there is no guidance as to: 1) which products to date, 2) which date to use, 3) how to display the date, and 4) how to scientifically determine the date. In sum, there is no uniform system.

Practices in Other Countries

In contrast, many other countries and international organizations have established requirements for dating of food products. For example, open dating, with or without code dating, is mandatory for prepackaged con-

*Perishable foods have a short shelf life, usually less than 30 days. Semiperishable foods have a shelf life of between 1 and 6 months. Nonperishable or long shelf-life foods have a shelf life of more than 6 months,

Table 1.--Summary of Open-Date Labeling Requirements by States, 1978

State/locale	Primary products	Form of open date	Effective since about
Alabama	Dairy	Sell-by	1975
California	Dairy	Sell-by	1973
Connecticut	Milk	Sell-by	1973
District of Columbia	Perishable products	Sell-by	1974
Florida	Dairy	Sell-by	1976
Georgia	Milk, eggs	Sell-by	1973
Maryland	Milk	Sell-by	1971
Massachusetts	Perishable & long shelf life	Sell-byor use-by	1979[b]
Michigan	Perishable products	Sell-by	1969
Minnesota	Perishable products with shelf life<90days	Sell-by or use-by	1973
Nebraska	Eggs	Pack	—
Nevada	Dairy	Sell-by	1973
New Hampshire	Cream	Use-by	1973
New Jersey	Dairy	Sell-by	—
New Mexico	Milk	Sell-by	1977
Ohio	Perishable products	Sell-by	1977
Oklahoma	Meat, eggs	Sell-by	
Oregon	Perishable products	Pack or sell-by	1975
Pennsylvania	Milk	Sell-by	1975
Virginia	Dairy & infant formula	Sell-by	1974
Washington	Dairy & others	Sell-by	1974
Wisconsin	Smoked fish	Pack	1971

[a]This regulation is presently being challenged in court.
[b]1979 for perishable foods; 1980 for frozen foods; and 1981 for remaining long shelf-life foods. These dates may change depending on the court's decision concerning the legality of the regulation.
SOURCE: OTA survey.

sumer food items expected to have a short shelf life in practically all developed countries—with the United States a notable exception. In the developing countries, the same trend applies, particularly for foods intended for export, except that open dating is not confined to short shelf-life items.

Some other countries have already moved from simply code dating to open dating for long-life products. For example, Japan, Venezuela, and Sweden, while allowing codes, require that the pack date also appear in an "open'' form.

The Codex Alimentarius Commission, the global organization for food-labeling standards, states a general preference for open dates but requires them only on infant's and children's foods. The European Economic Community recently adopted open dating for nearly all food products, with some exceptions. (See appendix D for a breakdown of open dating throughout the world.)

In view of these international developmerits, the lack of a U.S. policy on open dating could cause problems and lead to confusion in future food trade. Therefore, the issue of open dating has international as well as domestic implications.

FINDINGS AND CONCLUSIONS

Overall Findings

1. There is little evidence to support or to negate the contention that there is a direct relationship between open shelf-life dating and the actual freshness of food products when they are sold.

2. The pressure for open shelf-life dating comes from a consumer perception that such dating ensures food freshness and that industry should disclose its coded dates.

3. Deterioration in food quality is affected by environmental factors such as temperature, humidity, and light in relation to time. Ideally, dating information should reflect on these factors, but the technology to measure their influence inexpensively is in various stages of development and is not likely to be applicable in the near future,

4. Open dating is applicable for all food categories because all foods deteriorate. For most perishable and semiperishable foods the major modes of deterioration cause sensory quality loss such as color loss or off-flavor development, which can be easily recognized. For long shelf-life products, a major mode of deterioration is nutrient loss, such as vitamins A or C, which cannot be recognized by consumers. In addition, most long shelf-life foods are packaged such that it is not possible to examine contents for sensory quality loss before purchase.

5. Information gaps exist on: a) the amount of food sold nationally that is not fresh, b) the experience of States that have initiated open-dating programs, c) the scientific base to determine and monitor a freshness date, and d) the costs of open dating on a product-specific basis.

Specific Findings

Benefits

1. Open dating encourages better handling practices by wholesalers, retailers, and consumers by expediting the sale or use of food near the end of shelf life. This can result in a decrease of consumer complaints about buying spoiled or stale foods, Indeed, a USDA study found that such complaints decreased by 50 percent after the introduction of open dating.

2. Open dating can increase consumer confidence in the freshness of food purchased. In the same study, USDA found that the reduction in consumer complaints about spoiled or stale foods was reported for both open-dated and non-open-dated food in the same store. Apparently, because information was available for some foods, shoppers had more confidence in the freshness of all foods.

3. Better handling practices attributed to open dating could minimize nutrient loss. A processor could estimate the length of time the product would be in the distribution system and, given the environmental conditions, determine how these factors would affect the loss of unstable nutrients, such as vitamin C.

4. There is little or no benefit derived from open dating in terms of improved microbiological safety of foods. For foods in general, microbiological safety hazards are a result of processing failures, contamination after processing, and abuses in storage and handling. These factors are usually independent of the age of the product and have little relationship to an open date,

Costs

Very little research has been done to determine costs of open dating. These findings are based on the best estimates of academic and industry shelf-life experts and experience by industry and Government with nutrition labeling.

1. A major initial cost in adopting open dating is establishing a reliable date. Estimates are approximately $100,000 for each perishable and semiperishable food and $200,000 for each long shelf-life food (1979 dollars).
2. Major costs to wholesalers and retailers would be for employee time to inspect shelves for out-of-date stock and then dispose of such stock.
3. Enforcement costs for the Federal Government could vary from practically none to more than $500,000 per year, depending on the enforcement system and the extent to which the system were mandatory.
4. Based on nutrition-labeling experience, total costs of adopting open dating would be small on a per-dollar sales basis but nonetheless may add from 0.1 to 1 cent to the cost of each package of food. In 1975, the average cost of establishing nutrition information per dollar of sales was .004 cents, and the average continuing cost of nutrition labeling, which involves complex testing procedures and more information to be printed on the label than does open dating, was a minimal amount—especially once it was established. The same should be true for open-date labeling.

Open-Dating Techniques

There are many possibilities in converting codes to open dates. The date could be a pack date, sell-by date, best-if-used-by date, or a combination of these.

1. **A pack date** is the day, month, and year the food product was processed or packaged for retail sale. It is of minimal value to consumers in that it provides little information as to freshness or how long products should remain at acceptable quality. A pack date is, however, the easiest and least expensive for industry to implement.
2. **A sell-by date** is the last date a food product should be sold in order to allow a "reasonable" length of time for consumer use. This date is appropriate for perishable foods such as milk and dairy products because they have a short shelf life. It is the most useful date for wholesalers and retailers in their inventory control, since it states the last day of sale. However, it does not indicate to the consumer when foods should be used. Because it is currently being used on many perishable foods, it could easily be implemented by industry for products with a short shelf life.
3. **Best-if-used-by date** is the date after which food is no longer at its most acceptable level of quality. It is the preferred single date by consumers and provides the most useful information on quality. It is more appropriate for foods that have a long shelf life. It is, however, the most difficult for wholesalers and retailers to use in inventory management because they must subjectively determine allowances for home storage in order to determine the last day of sale.

   This date is presently used on some semiperishable and long shelf-life foods. However, the full implementation of this kind of date may require as much as a 2-year period to scientifically establish it for a given product at a cost of $200,000 per product.
4. **Combination dates** are preferred by consumers to single dates. They provide the most information, especially a sell-by and best-if-used-by combination. Combination dates, however, have all of the disadvantages of single dates.

Criteria in Establishing Open Dates

There are several criteria that can be used to establish sell-by and best-if-used-by dates including: sensory quality, nutrient loss, and degree of perishability,

1. **Sensory quality,** such as color, odor, and flavor, is the most discernible criteria for establishing sell-by and best-if-used-by dates. For some foods, sensory quality change may also be an indicator of nutrient quality. However, regulatory agencies would probably not be able to use sensory criteria to determine whether a food that is still in date is out of compliance with some quality level, since tests to determine whether a given product is of some designated sensory quality require taste panels trained in specific areas. This is not applicable to regulatory methods. However, if a physical or chemical method could be correlated highly with a sensory test, compliance testing would be simplified.
2. **Nutrient loss** would be easier to measure than would sensory quality, since it can be done objectively in an analytical laboratory. However, nutrient content of the same food commodity can vary; also, some foods are naturally poor in some nutrients, are not eaten to provide those nutrients, and may be of good quality even if they lost a certain percentage of the nutrients. Thus, critical nutrient loss methods are useful only where they are highly correlated with overall sensory quality losses,
3. **Perishability time** categories, which establish a date by a set number of days after processing, are more relevant for highly perishable foods that have a minimum of processing, However, modern processing conditions and new types of packaging can increase the shelf life of some foods to the point where time categories are not meaningful unless continuously modified to reflect new circumstances.

Enforcement and Liability

Open dating raises some unique problems of enforcement and liability. Enforcement, for example, raises two serious points: 1) enforcement with respect to quality standards in establishing the date and 2) sale of a product after the date. Liability in open dating presents unique difficulties because most other labeling requirements only involve the processor, but open dating involves wholesalers and retailers as well. This leads to questions of who is ultimately liable and whether existing law is adequate to determine liability.

In general, the findings in these areas are:

1. An enforcement system where processors establish reasonable dates that must be approved by the appropriate executive agency has many advantages over a system where the enforcement agency performs the necessary laboratory test to determine the validity of open dates. It is less expensive, would not lead to a decline in quality specifications for the date, and would avoid questions of a processor’s liability.
2. Consumer complaint-based enforcement for products sold at full price after the stated date (i. e., the consumer complains to the appropriate authority) is less costly than Government agency inspection for out-of-date products and can be very effective,
3. Some foods that are beyond date could be sold to consumers, perhaps at a reduced price, because the foods will still be safe.
4. Federal/State cooperation on enforcement is feasible. However, in order to have each State enforce a Federal mandatory program, the Federal Government may have to provide 100 percent of the costs. If not, the States would prefer enforcement at the Federal level.
5. There have been no court decisions on the questions of liability for deteriorated

food that has been open dated. If there were a Federal requirement for open dating, the Federal Food, Drug, and Cosmetic Act (FDCA) seems to provide several mechanisms by which to ensure compliance, especially as it relates to adulteration and misbranding. However, if literally interpreted, FDCA does not provide for abuses to food products in distribution that could cause the date to be involved. In addition, the meaning of a sell-by date is somewhat vague. This date suggests that the product can be consumed for a reasonable period of time after the date with no recognizable difference in the food's quality. Omission of information disclosing the ensuing consumption period could constitute the omission of a material fact rendering the product misbranded. These areas should be specifically addressed in the legislative history of any open-dating provisions.

CONGRESSIONAL OPTIONS

There are three basic options for Congress to consider in the open-dating issue. Congress can:

1. Allow the present **voluntary system** to continue by taking no action. Under this system, the private food sector is developing and adopting open-dating standards.
2. Choose a **mandatory system,** which would require the use of specific open dates.
3. Choose a **voluntary/mandatory system,** whereby the Federal Government develops guidelines, and processors who elect to open date are required to follow those guidelines.

If Congress chooses Options 2 and/or 3, it can either specify the detail or leave it up to others, such as an appropriate regulatory agency or an industry association. In other words, Congress can legislate which type of dates for which food and how those dates are to be determined, or it can delegate the task.

These options are not mutually exclusive. Congress can select one option, two options, or a combination of all three. For example, Congress can decide to leave open dating of bulk fresh produce as is, under a voluntary system; make open dating of other perishables and semiperishables mandatory; and place long shelf-life foods under a voluntary/mandatory system. In addition, the type of date selected can vary by individual product. In short, many potential combinations exist (see chapter IX for a more detailed discussion).

Voluntary System

If Congress opts for the status quo, it will be supporting a system in which the private food sector will presumably continue to develop and adopt open-dating standards.

Pros: The principal advantage to this system is that it allows processors flexibility in determining whether or not to open date and minimizes the cost to the Federal Government and industry, compared with the other systems. Moreover, under this approach 21 States and the District of Columbia have adopted open-dating laws over the past 8 years and have done so with a minimum amount of regulatory control and enforcement.

This option would allow time for specific research to better gauge the cause-and-effect relationship between open dating and spoilage reduction. Specific areas in which further data is needed include: the amount and kinds of food sold nationally that are not fresh, better quantification of costs, and an improved scientific base to accurately determine freshness dates, The experience of States that have adopted open shelf-life dating will be helpful in obtaining the above data.

Cons: The most serious perceived disadvantage of this approach is the lack of uniformity in deciding: 1) which products to date, z) which date to use, 3) how to display the date, and 4) what scientific guidelines should be used to determine the date. In addition, inventory-control procedures are relatively more difficult, which could result in more food waste than under a mandatory system. Also, some industries may not adopt the program.

Mandatory System

A mandatory system would require the use of specific open dates.

Pros: The principal advantages of this system is that a mandatory system would provide uniform regulations; tighten inventory control, which could reduce food waste; provide higher quality and nutritive levels for more food; and set criteria for calculating accurate open dates.

Cons: The principal disadvantage is that, with the exception of using a "pack date, " it would be difficult to implement in the short run of 2 to 5 years for semiperishable and long shelf-life foods because of insufficient data on shelf-life stability of these product categories. However, since many perishable products are presently open dated, data are available to implement a mandatory system for perishables,

Other disadvantages would be: 1) costs would increase to Government for developing and enforcing regulations and to industry for compliance, compared with a voluntary/mandatory system, 2) out-of-date products maybe usable but returned and wasted (unless special arrangements are made for their use), 3) development of regulations would be time-consuming for both Government and industry, 4) innovation in terms of incentives to develop new processing techniques to increase shelf life could be stifled, and 5) small processors could be forced out of business.

If a mandatory policy is selected, Congress must decide who should specify the technique, criteria, and type of enforcement system. To specify these areas, there are two basic ways Congress can legislate. Congress can either specify the details itself or charge others with the responsibility for doing so.

Congress Specifies the Detail

Open-dating techniques. Congress could specify the use of one or a combination of the following open-dating techniques: pack date, sell-by date, best-if-used-by date, or some combination.

Pros: The advantages of a mandated technique by product or product category include uniformity in all States and less potential consumer confusion.

Cons: The disadvantages include:

- It would be more difficult to change a technique over time than if specifications were left up to the appropriate regulatory agency.
- A continuous legal and/or legislative process may arise in an effort to change dates over time. This could be an expensive process for industry, Government, and ultimately for consumers.

Open-dating criteria. In addition, Congress could decide which criteria must be used for which date or dates. In other words, which categories of sensory quality, nutrient loss, and perishability to use.

Pros: The advantage of mandating specific criteria used in establishing dates includes standardization among products and/or product categories.

Cons:

- Neither Congress nor the Secretary of the appropriate executive branch agency currently may have the technical ability and data necessary to specify criteria for each food item.

49-394 O - 9 - 2

- Technological innovation could be stifled because criteria could not be easily changed.
- The criteria may not likely be based on sensory quality parameters because it would be more difficult to regulate than would other criteria. This could be an advantage for some products and a disadvantage for others, depending on what test index is chosen.

An alternative to mandating specific criteria is to allow a range of criteria. The advantage of mandating some range of criteria is that both sensory and nutritional criteria would likely be included within the range. The disadvantage is that there would not be standard criteria for similar products.

Enforcement and liability. Congress has two basic options for determining the enforcement system and for establishing liability as it relates to open-date labeling:

- **Use Existing Laws**

Pros—Enforcement: Allowing the existing laws to specify enforcement simplifies the procedure and minimizes the cost and time for both Government and industry.

Cons—Enforcement: Existing law does not specify what should be done in the case of: a) food that is still edible but past date and b) food that is beyond criteria but not past date.

Pros—Liability: Existing laws covering liability already offer several devices through which manufacturers, wholesalers, and retailers might be held liable for violations of an open-dating requirement.

Cons—Liability: Since there is no definitive legislative or judicial definition of the legal significance of an open date, application of existing law remains speculative.

- **Pass New Laws**

Pros—Enforcement: Legislating new enforcement procedures has the advantage of allowing Congress to address specific items such as use of State enforcement officials and/or complaint-based enforcement by consumers for beyond-date compliance and disposal of edible food that is out-of-date.

Cons—Enforcement: Writing a new law to adequately provide for enforcement increases both time and cost to Government and industry.

Pros—Liability: Writing new legislation that specifies liability and penalties, if any, for open-date labeling could provide consumers with more confidence in an open-date labeling system.

Cons—Liability: It is a difficult and burdensome task to ascertain liability to the firms responsible.

Leave Implementation of Detail to Others

Delegating the specifics to either the appropriate executive agency or the private sector would have the following results: 1) it relieves Congress of the necessity to make these determinations and 2) it would be easier to change a technique over time than if specifications were decided by Congress.

- **Appropriate Executive Agency**

—Open-Dating Techniques

Pros: The advantages of this option, as with congressionally mandated detail, include uniformity of the open-dating technique for all food processors producing a single product. Also, the regulatory procedure would allow industry and consumers more involvement than would the detailed statutory approach.

Cons: The disadvantages of allowing executive discretion include the potentially large costs in time and money both Government and industry would incur before the regulations could be developed.

—Criteria

The advantages and disadvantages of establishing open-dating criteria are the same for an executive agency as those discussed for Congress.

• **Private Sector**

—Open-Dating Techniques

Individual processors could be allowed to choose the dating techniques and make them defensible to the appropriate Secretary.

Pros: Allowing individual processors to have this freedom would allow the marketplace to determine the best system.

Cons:

• Lack of uniformity of date types on similar products could confuse consumers and retailers.
• The retailer may have problems using open dating for inventory control when there is a lack of uniformity on similar products.
• Small processors may use pack dates since they might not be able to do the necessary research to establish sell-by or use-by dates.

As an alternative, an industry association could be allowed the freedom to choose the dating techniques and make them defensible to the appropriate Secretary.

Pros:

• Date types on similar products would be uniform.
• Consumers could have input into industry association meetings to establish dates, especially if the association decision were subject to Secretarial review.

Cons:

• If the system were voluntary/mandatory, it would allow nonmembers of the industry association to do nothing.
• If mandatory and nonmembers of the industry association have not had an opportunity to participate in the process of choosing a technique for dating, this could lead to legal problems such as antitrust or restraint of trade.
• There may be more than one industry association to which one processor belongs, and these associations might establish two different techniques.

—Criteria

Pros: The advantages of allowing processors to specify criteria for establishing open dates include:

• Sensory criteria could be part of the input when considered appropriate for the particular product.
• Through the appropriate Secretary, consumers could have a continuing voice in what criteria is used.

Cons:

• Secretaries of the regulatory agencies involved would have an additional burden of reviewing the criteria submitted to them.
• Costs to Government could be quite high relative to other options.

Voluntary/Mandatory System

A voluntary/mandatory system is one in which the Federal Government develops guidelines, and processors who choose to open-date food products are required to follow these guidelines.

Pros: This system establishes a mechanism for uniformity to open-date food products, and it provides individual food processors the basic option of determining whether or not to open-date products.

Cons: Costs to Government would increase for developing and enforcing regulations and to industry for compliance. Development of regulations would be time-consuming for both Government and industry.

Note that if the Congress chooses this option path, the issues discussed under the mandatory system become relevant.

Chapter II

Consumer Perspective on Open Dating

Since consumers are the ultimate users of open dating, an integral part of this assessment is consumer interest in and perspective on open dates for food. The background for this section comes from an Office of Technology Assessment nationwide survey of consumers in 1978 to determine their attitude about open-date information, usefulness and understanding of dates, and preference among dates. The survey itself consisted of a questionnaire sent to a statistically selected sample of 3,000 consumers. *

ATTITUDES TOWARD OPEN DATING

According to the survey, almost all shoppers (96 percent) were concerned about getting the freshest food products possible. About 1 in 10 (11 percent) felt that a lot of food they buy from grocery stores is spoiled.

Although the consumers were concerned about food freshness, their awareness of open dates varied considerably. The dates themselves—their presence and form—varied by both product and by store.

Nearly all the shoppers (96 percent) were aware of dates on milk. At least half noticed dates on other perishable products such as bread, eggs, ground beef, and round steak.

On a few semiperishable items such as cheese, luncheon meats, and cereal, a majority of shoppers also noticed dates. However, for most other semiperishable items, only a few noticed the date.

Only about 12 to 14 percent of the shoppers said they were aware of dates on nonperishable or long shelf-life food items such as canned soup and canned vegetables, but this is not too surprising since a smaller proportion of these products are open dated, compared with perishable products.

Eighty percent of the consumers surveyed considered open dates to be useful. This figure compares with 67 percent in a 1973 U.S. Department of Agriculture (USDA) study on open dating and 90 percent in a similar study by USDA in 1976. Thus, open dates are considered by many to be useful in food shopping.

The OTA survey found that 62 percent of the consumers sort through items with an open date to find the freshest product. This compares with a 61-percent response to a similar question in the 1976 USDA study. Therefore, retailers selling foods with open

*OTA commissioned this survey, recognizing that other surveys have been completed on this subject. The OTA survey provides more detailed information on consumer preference and is more recent than the other surveys. This survey is available on request.

dates have an incentive to keep tight control over their inventory if they want to avoid consumer culling.

Shoppers in the OTA survey were asked to rank the following four different types of information that may be found on food labels: 1) open date, 2) recipes and cooking instructions, 3) list of ingredients, and 4) nutritional information (table 2). They were asked to do this for several perishable and long shelf-life food items.

The survey found that the open date is the most important piece of information on the package label for fresh meat and frozen vegetables and is second in importance to the list of ingredients on a canned soup label. Thus, among the various types of information on a label, open dates are considered useful for both perishable and long shelf-life foods.

Table 2.—Consumer Usefulness of Information on Food Packages (percentage of respondents)

	Most useful			Least useful		
	Frozen vegetables	Canned soup	**Fresh meat**	Frozen vegetables	Canned soup	Fresh meat
Freshness date	50	24	**91**	7	29	(a)
Recipes and cooking instructions	22	19	**2**	47	45	54
List of ingredients	19	43	**4**	22	10	30
Nutritional information	10	16	**3**	22	15	14

[a] Less th-an"O 5—percent

UNDERSTANDING OPEN DATES

Since different types of open dates with different meanings appear on various food products, consumer understanding is a key factor. Therefore, the survey asked the consumers to identify the correct type of date on milk, breakfast cereal, and ground beef (table 3).

The results were mixed. Nearly three-fourths of the shoppers knew that the date on milk is a sell-by date. However, only one in four identified the date on breakfast cereal as a use-by date; over one-third thought it was a sell-by date. For ground beef, only one-third knew the date was a pack date, while almost another third thought it was a sell-by date.

Therefore, aside from milk, it seems there is considerable confusion over the meaning of specific open dates. The illustrations of various products on pages 16 & 17, with dating highlighted, give visual evidence to the confusion of consumer understanding.

Table 3.—Consumer Understanding of Freshness Dates (percentage of respondents)

	Milk	Breakfast cereal	Ground beef
When it was packaged	9	8	34
Last day it should be sold	74	35	31
Last day it should be used or eaten	15	26	9
Have never not iced a date on a package of this product	2	31	26

NOTE Percentages in boldface Indicate correct answers

PREFERENCE AMONG OPEN DATES

With different types of dates now in use, consumer preferences can be useful in determining open-dating policy. The OTA survey, therefore, asked consumers to express their preferences for different types of dates or combinations of dates for various food items. Some consistent patterns appeared, as shown in table 4.

The most preferred form of dating was a combination date rather than a single date. In fact, almost two out of three (64 percent) said they would like to see two dates, either sell-by and use-by or pack and use-by. (Consumer representatives on the OTA panel also preferred combination dates.)

Table 4.—Consumer Preferences for Open Dates (percentage of respondents)

Preferences among single dates and combinations

	Most important	Least important[a]
Both sell-by and use-by date	37	25
Both pack and use-by date	27	37
Only use-by date	16	42
Only sell-by date	9	60
Only pack date	7	75
Both sell-by and pack date	5	59

Preferences among single dates for selected foods

	Last day used	Last day sold	Date packaged	Would not use date	Seldom/ never purchase
Perishable products					
Milk	43	37	18	(b)	1
Ground beef	39	24	33	1	4
Round steak	37	23	32	1	7
Semi perishable and nonperishable products					
Cheese	44	34	18	2	1
Canned tuna fish	43	21	20	8	7
Frozen vegetables	43	24	23	4	7
Flour	35	26	24	11	3
Cake mix	34	25	22	8	11
Jelly	30	18	18	17	17

Preferences among combination dates for selected foods

	Sell-by and use-by	Pack and use-by	Sell-by and pack	Only one date	No date
Perishable products					
Milk	46	28	7	19	(b)
Ground beef	39	33	8	19	1
Round steak	39	33	8	19	2
Semiperishable and nonperishable products					
Cheese	40	30	8	21	1
Frozen vegetables	35	33	8	21	3
Canned tuna fish	31	32	8	22	6
Cake mix	27	29	8	29	6
Flour	26	30	8	29	6
Jelly	23	23	7	31	16

[a]Ranked lower than third most important
[b]Less than 0.5 percent

Dating Techniques of Various Food Products
What Do They Actually Mean?

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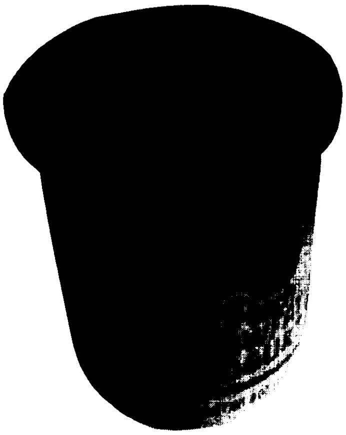
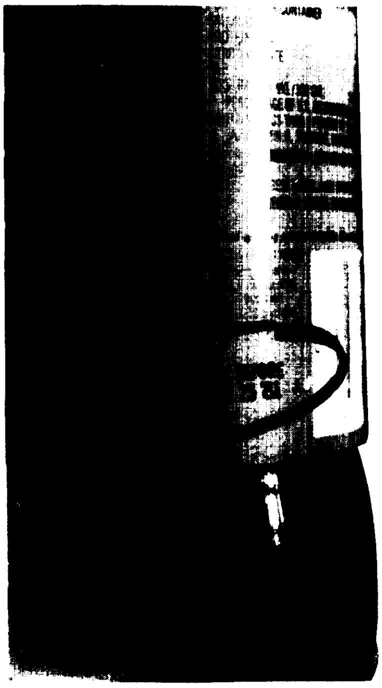
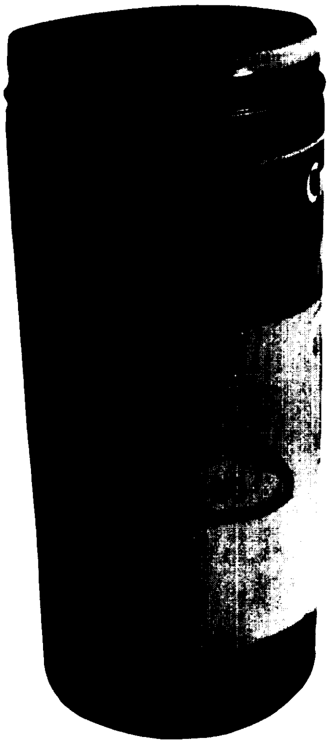


Remains Fresh I-Week After Date Shown

Sell By



Buy Before



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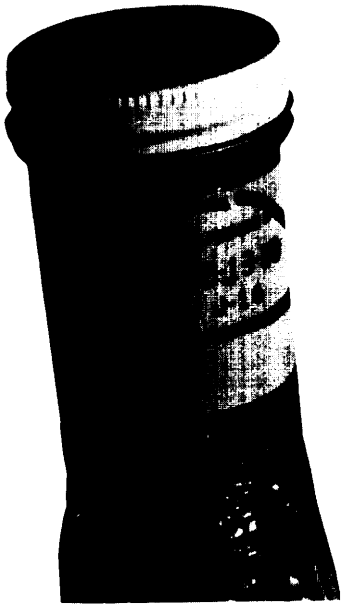
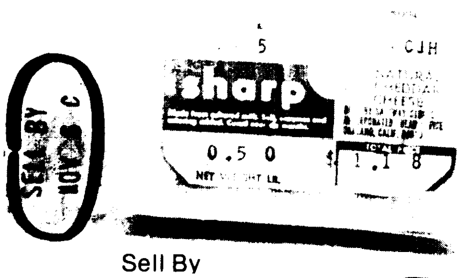
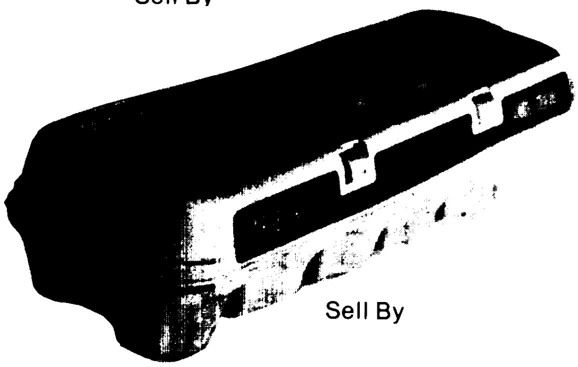


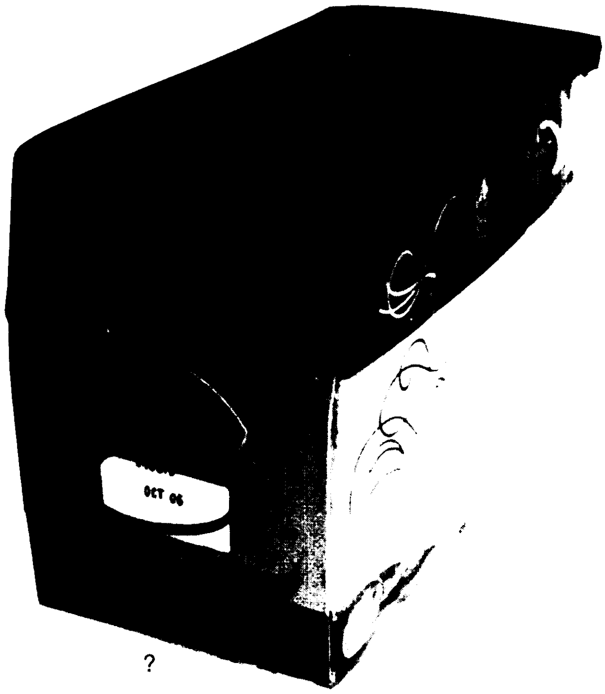
Best When Purchased By



Sell By



Sell By



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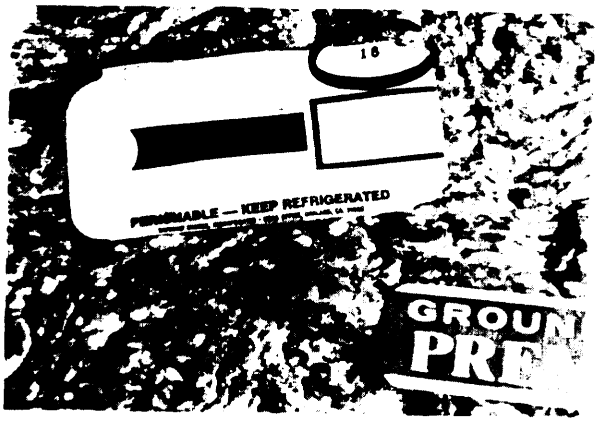

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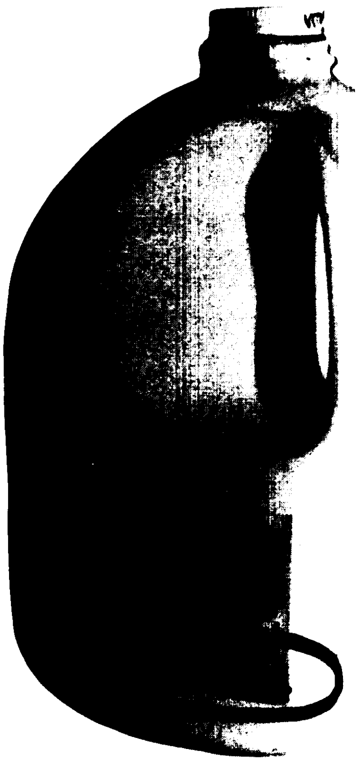
Best When Purchased By



Sell By

This leaning towards more than one date indicates that consumers want as much information as possible on product freshness. However, a significant minority (19 to 31 percent, depending on the specific food product) desired only one date.

If just one date were to appear on food packages, the use-by or best-if-used-by date was the most preferred. This was true regardless of the perishability or shelf stability of the product.

Second choice to the use-by/best-if-used-by date is the date currently placed on specific products. For example, most respondents preferred the sell-by date to the pack date for milk, but just the opposite for ground beef and round steak.

Among combination dates, a sell-by/use-by date was preferred for the three perishable products and for two out of six semiperishable and nonperishable products. The pack/use-by combination was the second most preferred, and very few respondents preferred the sell-by/pack combination.

Preliminary results of nationwide hearings in 1978 by the Food and Drug Administration (FDA), USDA, and the Federal Trade Commission shed further light on the issue of consumer preference in open dating. For those consumers requesting a combination of dates, a pack/use-by date was favored for long shelf-life foods and a pack/sell-by or pack/use-by date for perishables.

In conjunction with the above hearings, FDA commissioned a food-labeling survey in late-1978. Summary results of that survey on open dating are very consistent with the findings of the OTA survey.

DIFFERENCES AMONG SUBGROUPS OF SHOPPERS

A number of demographic variables were examined to determine if certain subgroups within a population might show different attitudes and behaviors with respect to open dating of foods. Race/nationality, education, age, income, family size, and religion were explored.

Not surprisingly, in a large number of comparisons across many items, some differences appeared. For example, in high-income, high-education, and large households, slightly more respondents felt open dates were useful. Generally, though, demographic differences were not impressive. At any rate, such differences do not seem crucial for establishing an open shelf-life dating policy because in all groups the majority of respondents indicated that open dates were useful.

Chapter III

Benefits of Open Dating

As soon as harvested or slaughtered, most foods begin to deteriorate in quality. Some exceptions are fruits picked prior to ripening, such as bananas, and red meats and seasoned prepared foods, which first improve in sensory quality before they deteriorate. Subsequent processing is done to slow down the rate of deterioration and thus increase shelf life, thereby preventing waste.

The type of process used to preserve food largely determines the shelf life of a product (e.g., canning gives a longer shelf life than refrigeration). In addition, environmental conditions can also directly affect food quality and speed up deterioration. Conditions such as high temperature, high humidity, light, and contact with air (oxygen] all speed up this quality loss.

However, open dating in itself only sets the time of shelf life of foods—by necessity ignoring the changing environmental factors by assuming the food is held under certain average conditions. If the date is based on these average storage conditions, the closer to the date (except for a pack date), the lower is the quality.

Ideally, dating information should take into account the environmental factors as a function of time. Although current technology is unable to do this, technology is being developed that will measure the influence of both time/temperature fluctuations on quality deterioration. Currently, a device can be attached to a food package that can measure the reaction to a specified time/temperature relationship or exposure to some temperature above a set limit. The device must be designed to respond to temperature change in the same way as the food product.

Studies on the reliability of these devices indicate two major problems: 1) they become unreliable if exposed to high temperature prior to activation, and 2) in many cases, their responses do not match manufacturers' specifications. Although these devices have been modified since the aforementioned studies were published, the major problem is still to develop an indicator that exactly matches the sensitivity of a particular food to a change in temperature and/or other environmental factors. (For more information, see appendix C).

Therefore, with the gap in technology, the focus of this analysis is by necessity one-dimensional (open shelf-life dating) for a multidimensional problem of food-quality preservation.

Despite the limitations just outlined for open dating, many benefits are attributed to it. This chapter identifies and analyzes these potential areas, including food quality, nutrition, food safety, inventory control, and education.

FOOD QUALITY

Whether open dating benefits product quality is of primary importance, given the fact that most food deteriorates with age. There are no published studies that show that open dating leads to the availability of higher quality foods.

An open date may not provide an assurance of high quality, since storage conditions are critical to the quality of all foods and can be highly variable. For example, if semiperishable and long shelf-life foods are temperature-abused and are stored long enough, a decline in quality may be detected. A food with a more recent date that has been mishandled will be of substantially lower quality than an older dated food that has been stored under ideal conditions.

In order to achieve high quality at point of purchase, then, the food must be of high quality initially and must be handled under proper storage and distribution conditions. If both of these criteria are not met, the date on the package (unless it is a pack date) could be meaningless as well as misleading. Also, storage conditions after purchase could greatly affect the shelf life of the product.

Nevertheless, today's consumers believe an open date assures "acceptable" quality; such assurance is their primary reason for wanting an open date. However, in actual fact, a situation may evolve in which consumers believe that a date will be helpful to them in terms of "better" quality when the state of the technological capabilities may be such that the benefits will be considerably less than what is expected.

Even foods produced under the same conditions at a single location may undergo many different time/temperature/humidity changes when they are distributed around the country. Thus, an open date based on average climatic conditions may be an adequate quality measure for some northern parts of the country where temperatures are lower, but inadequate if the product were held under high temperature/humidity changes when distributed around the country. It is possible that requiring an open date could improve the control over foods during distribution to the point that the date would be an assurance of high quality.

In an in-store U.S. Department of Agriculture (USDA) experiment where open dating was introduced, the incidence of consumer complaints on food items most often cited previously as spoiled or stale was reduced by 50 percent. Store losses in dollar values and package rehandling also were reduced.

Attributing these results to open dating was questioned by those reporting the study findings. The reason was that the study showed a reduction in complaints about spoilage for both open-dated and non-open-dated food in the same store. Thus, some of the improvement may have been because of increased confidence in the freshness of all food sold in the store (to which open dating could have contributed), rather than changes in the food itself—i.e., less spoilage.[1]

'Food Dating: Shoppers Reactions and The Impact on Retail Foodstores, Market Research Report No. 984 (Washington, D, C,: U.S. Department of Agriculture, 1973).

NUTRITION

Open dating could be of some value if used with nutrition labeling. The nutrition label already has a time factor built into it because the values on the label are required to be within established statistical limits at the time of the sale of the food. In order to set the nutritional levels, the manufacturer may have made a judgment about the length of time and environmental conditions involved in the distribution of the food and how these conditions would affect nutrient loss of the most unstable nutrients, such as vitamin C. However, as with quality, improper storage conditions could result in greater nutritional losses than predicted under average conditions.

Thus, as previously discussed for quality, an open date could be used to ensure improved handling conditions that could result in less nutrient loss. But whether this would improve the nutritional status of Americans is questionable.

FOOD SAFETY

Open dating has little or no benefit in terms of improved microbiological safety of foods. For foods in general, microbiological safety hazards are a result of processing failures, contamination after processing, and abuse in storage and handling. These factors are all independent of the age of the product and have little relationship to an open date, In fact, an open sell-by or use-by date could have an adverse effect on food safety if consumers took it to be an assurance of food safety. For example, "Well, it looks, smells, and feels bad, but the date says it's good for another month, so I'll use it. " Poor manufacturing processes can still exist with an open-dating system, and consumers could be given a false sense of security. A date with specific storage information (e.g., "keep cool after opening") could, however, reduce hazards.

INVENTORY CONTROL

At the processor level, adequate inventory control is currently provided by the coded dates now being used on food packages. Distribution centers of manufacturers and central warehouses of supermarket chains can also use the code for proper stock rotation, although they do not always do so.

Consumers, however, feel that inventory control via coded dates really breaks down at the end of the distribution chain, The local store managers and supermarket stock clerks may or may not use the coded dates. Because they are in code, consumers cannot use them to decode each product. Open dating could obviously tighten inventory control by both the retailer and the consumer.

USDA found that in their in-store experiment, open dates encouraged better food-handling practices by making store personnel aware of the need for rotation. Confusion among clerks about when to rotate or remove products was reduced, and closer attention was given to expediting sale of products near the end of their shelf life so they did not have to be discarded.[2]

[2]Ibid.

EDUCATION

An important benefit of open dating could be the education of the food manufacturer and the consumer. Much of the consumer's education about a particular product usually comes from the food industry in the form of advertising and package information. Thus, the research forced on the manufacturer in order to establish an open date is a form of self-education in terms of analyzing distribution conditions and studying how specific foods deteriorate. Open dating in the long run would increase the body of knowledge about the quality and chemistry of food products. The food industry as a whole should be certain that the information given in an open date is not misunderstood in terms of quality, safety, and nutritional assurance.

Chapter IV

Alternative Open-Dating Techniques

Converting codes to open dates offers many possibilities. The date could be any of four possible dates, or a combination of dates, and there is a variety of ways the date could be presented.

Basically, the types of open dates are:

1. **date of pack or manufacture,**
2. **pull date or sell-by date,**
3. **best-if-used-by date,**
4. **expiration date or use-by date, or**
5. **combination of two of the above.**

The meaning of these dates is not necessarily obvious. The pack date refers to the day, month, and year the food product was processed or packed for retail sale. The pull or sell-by date refers to the last date the food product should be sold in order to allow the consumer a reasonable length of time in which to use it. The best-if-used-by date is the date after which the food is no longer at its most acceptable level of quality. The use-by date is the date after which the food is no longer at an acceptable level of quality.* The terms "pack," "sell by," and "best-if-used-by" will designate these alternative open dates, respectively.

METHOD OF OPEN DATING

This section is a general discussion of open-dating methods. Appendix A offers a detailed discussion by major food category of the advantages and disadvantages of each method.

*Food scientists make this distinction between use-by and best-if-used-by dates. Consumers do not necessarily see the difference. Many think either of these dates indicate the date at which food is no longer at an acceptable level of quality.

Pack Date

A pack date is the only date that could be put into effect in the near future if an open date were mandated for all food products. Compared with the other dates, it is also the least expensive because it requires only historic data—i.e., the time of the event is known without research or estimation. However, it may not be the best date for all food products.

The pack date, as defined above, has three problems:

1. the condition and length of time the product was held before being packaged is not considered,
2. some products such as fresh meat can be reconditioned and repackaged for sale, and
3. ages of separate components in a multicomponent food such as a dried soup mix could vary.

In regard to the first point, some consumers feel that manufacturers store food in bulk for an unreasonably long time before putting it in the final package. Manufacturers, on the other hand, feel they should be allowed to hold commodities for as long as is economically expedient if they use ideal conditions of storage that minimize possible quality loss. Examples of kinds of foods that would fall in this category are foods frozen in bulk before being packaged, such as concentrated orange juice, some vegetables, concentrated milk to be used in ice cream, and flour.

For most perishable foods, a pack date would be of minimal value to the consumer if used by itself. For example, with milk and dairy products, it would only indicate the date the milk was processed or packaged. It would not give the consumer any information as to quality or how long the products should remain at a level of acceptable quality. For precut/prepackaged meats, poultry, and fish, the use of a pack date would give the consumer some information as to general product quality but may also give a false sense of quality assurance if the product is repackaged under different conditions to lengthen shelf life or if held in frozen storage for some period of time before being offered for retail sale.

For shelf-stable engineered or multicomponent foods, the shelf life is determined by the age and quality of the various components—which could vary widely. A pack date alone would give too little information for the consumer to make any estimate of quality or shelf life. Examples of these multicomponent foods include dried soup mixes, cake mixes, canned mixed fruits and vegetables, helper-type meals, and meat substitutes.

Foods for which a pack date seems reasonable are prepackaged fresh fruits and vegetables. These food products are not processed to lengthen shelf life and cannot be frozen for any part of their storage life without serious alteration of product quality. Thus, the use of an open pack date would actually convey to consumers freshness information (assuming immediate packing after harvest).

The use of a sell-by or best-if-used-by date for prepackaged fresh fruits and vegetables would require the retailer to estimate when the product would reach its peak of ripeness or begin to exhibit significant and detectable loss of quality. Because fruits and vegetables of different varieties, and even within the same variety, may mature at different rates depending on the size, storage conditions, and other factors, such a date could not be established with a reasonable degree of accuracy.

Sell-by and Best-if-Used-by Dates

Information for scientifically determining these dates does not always exist, as for the pack date, so processors and manufacturers must frequently estimate or create a date. In order to set a valid sell-by or best-if-used-by date, the following information must be obtained:

1. a measure of some initial relevant quality factor that can be used to estimate a decrease in consumer acceptance,
2. a reliable method to measure that quality factor on a statistically sound basis,
3. the distribution system times and conditions,
4. the average time the product is held in the consumer's home before use, and
5. the amount of quality loss allowed before the product is considered unacceptable for sale at full price or for use.

A sell-by date could be set if the average time the product is in the distribution system is known, but it must also assume some knowledge of how long it will take the average consumer to handle, store, and use the food in the home under conditions that will retain good quality. Thus, storage and distribution information is necessary to establish any date other than a pack date. If this knowledge is not available, the date is not meaningful and might be misleading.

There are regional problems involved with use of open dates for products such as dried snack foods, pasta, and breakfast cereals that are distributed nationwide and are subject to extremes in temperature and humidity conditions, For example, for any food where gain or loss of moisture is related to quality (e.g., loss of crispness in potato chips), a date for reaching the critical moisture content could be established for any given distribution area, but it could be costly to do.

If, on the other hand, the end destination is unknown, the date could be set for the worst possible conditions. The problem with this approach would be that a large percentage of the food going to areas of the country with moderate conditions would still be good when marked out of date. For example, if the open date must be set to allow for moisture gain in a high humidity area such as Mississippi, national distributors would either have to protect all packages against extreme conditions and charge consumers for such steps, or suffer product losses. These considerations could result in some companies withdrawing from national distribution.

The sell-by date is usually used in conjunction with foods that have a short shelf life after the date of sale, if properly handled. Milk and dairy products, such as yogurt, are labeled in this way, and, in fact, some packages may give further information as to days of shelf life beyond the selling date.

The sell-by date is the single most useful date for wholesalers and retailers. Its advantage is that it is unambiguous relative to the best-if-used-by date. Both wholesalers and retailers know the normal amount of time any given product requires to move through their segment of the marketing system. This knowledge in combination with a recommended sell-by date gives the wholesalers and retailers the means to assure freshness through inventory control.

OTA's consumer survey found that the sell-by date is not the open date that consumers prefer for food products, however. In both the perishable, semiperishable, and long shelf-life food categories, consumers preferred the best-if-used-by date to the sell-by date or pack date. Except for prepackaged fresh meat, the sell-by date says little or nothing about when foods should be used or when the quality may be detectably worse.

A best-if-used-by date, on the other hand, does not permit wholesalers and retailers the same ease or potential accuracy in inventory management that a sell-by date allows. These dates require wholesalers and retailers to individually and subjectively determine allowance for home storage time on each individual product in order to calculate a sell-by date—i.e., the date they need for management purposes.

For processors, a best-if-used-by date is more useful than a sell-by or use-by date. They feel it is the most informative to the consumer and, with the exception of the pack date, the least arbitrary and restrictive. To the processors, the sell-by and use-by dates imply that at some moment in time a dramatic change will take place in the quality and suitability of the product. That is, before a given date, the product is acceptable; afterward, it is not and must be discarded. This, of course, is not true, but processors fear that consumers might interpret it this way. Therefore, they prefer the best-if-used-by date, feeling it carries the connotation that there is a slow but continuous loss of quality, and for the greatest satisfaction to the consumer, the food should be consumed by that date.

The best-if-used-by date is being examined by Codex Alimentarius, the international organization for food labeling standards. These standards say that for all products the first date that should be looked at is the date of

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minimum durability, which translates to a best-if-used-by date.

A modification of the best-if-used-by date is the best-if-used-within date. In this instance, phraseology such as "best if used within 30 days of June 1" becomes a compromise between what retailers and consumers desire from an open date. For example, the best-if-used-by date indicates that the product should be used on or before the date specified. "Best-if-used-within" indicates the product should be used within 30 days of June 1. The difference between the two dates is that the former gives only a use-by date. The latter gives both a sell-by date and use-by date. In this example, the sell-by date is June 1. The use-by date is 30 days after, or July 1. These phrases offer an unambiguous sell-by date for the retailer, while at the same time giving consumers a use-by date.

To Remain in Grade Use- (Sell-) by Date

An alternative to a use- (sell-) by date or, more specifically, instead of "best-if-used-by" may be a term that would indicate how long a food may be held and yet remain at a quality level practically indistinguishable from that quality inherent in the original pack date. This may be accomplished by using a term such as "to remain in grade, use (sell) by. " For example, if a product is found to be of top quality and is graded and labeled "grade A," "prime," or "fancy," the open date would indicate how long it may be expected to remain at top quality. If it is labeled "grade B" or "choice," the open date would indicate how long the unit is expected to remain at the declared second quality level, etc.

Although such terminology would be limited to products that have precisely defined and generally recognized and accepted quality grades and standards, for those commodities where it could be used, it would have the advantage of specifying the quality levels expected to be retained—not just a vague "best," or "acceptable." A corollary benefit would be that if the date should be exceeded before use (or sale), there need not be the implication that it is unsafe and should not be used.

Integrating open dating with grade labeling has the potential of simultaneously strengthening and appreciably reducing costs of implementing both. It may even be argued that grade labeling must include open dating, since "nothing is forever. " This may be the solution to the difficult problem of limiting the life of a grade after it is posted on a label. For example, a carton of eggs labeled "grade A" could be assumed to remain "grade A" forever unless the grade declaration would include an open date. This benefit need not be limited to perishables. In-grade life of relatively stable foods, such as canned vegetables, can vary substantially not only among commodities but even within commodities.

A disadvantage of an integrated system is that it would work only for those products where the grade is equated with freshness-quality attributes. Products such as beef, pork, lamb, and poultry would therefore be excluded, since the grade is based more on compositional/conformation characteristics.

Another disadvantage is that many consumers have little knowledge of what grades mean, So, equating an open date with a grade would result in consumer confusion.

Combination Dates

As reported in chapter II, the OTA consumer survey found that the most preferred dates were combination dates. Specifically, the combination of sell-by and use-by dates was most preferred, followed by a pack and use-by combination. Obviously, combination dates supply the most information to consumers.

Such a system is visualized as "retailer sell by" and "consumer use by" on the same product— similar to the best-if-used-within date, which is in itself a combination date. On some products, a combination date could give the optimum information to both the wholesaler/retailer and the consumer. From a cost standpoint, combination dates would be more costly than a single date, In addition, multiple dates would take more label space, which from industry's viewpoint could be used for other information.

A key issue in using combination dates is whether they will result in consumer confusion or education. For example, it can be argued that if only one type of open date were used on all products, potential consumer understanding could be at a maximum. Conversely, if consumers were confronted with several different types of open dates, confusion could result.

If one accepts this "inverse" relationship, one could argue from a consumer viewpoint that a single type of open date should be used on all products, regardless of other factors, such as product deterioration. The alternative viewpoint is that even if this "inverse" relationship does exist, efforts could be made to educate consumers on the use of different types of dates.

Results from the OTA consumer survey lend support to the latter viewpoint in that they tend to refute such an inverse relationship. The results suggest that a majority of consumers think that combination dates would be beneficial on at least some products. Presumably, if the consumers thought different kinds of dates for different products would be confusing, they would not feel that combination dates would be useful.

The benefit of adopting a standardized open date for all products is simplicity. Wholesalers, retailers, and consumers would know or eventually learn how to use and deal with that standardized date. However, a standardized date may not be the optimum one for certain products.

IMPLEMENTATION

Storage Instructions

Based on the OTA survey and other surveys, it is apparent that consumers feel that as much information as possible should be included on the food package, including storage instructions as well as an open date.

As discussed earlier, the shelf life of food is based on some definite conditions of storage. If these differ significantly from those anticipated, the shelf life of the food will vary, being shorter if the actual conditions turn out to be more unfavorable, and being longer if they should be more ideal. Thus storage instructions, if observed, would enhance the usefulness of open dates, but they raise the increasingly critical problem of space on the label.

Processors in the OTA working group feel that the presently used instructions found on some food products such as "keep refrigerated, " "keep in a cool, dry place, " and "keep frozen until used" are adequate. In addition, available space on the package is not adequate for elaborate storage instructions, and too many other regulations relating to required information and size of print used would be affected. There is little doubt that consumer education about proper storage instructions is an important—and necessary—part of open dating. Such education might be accomplished through use of television, pamphlets, or posters, however, rather than the package label.

Type of Date Marking

With respect to the actual date itself, consumers surveyed and consumer representatives on the OTA working group wanted the month, day, and year.[1] The most preferred

[1] *Food Do ting:* Shoppers Reactions and The Impact on Retail Foods *tores*. Market Research Report No. 984 (Washington, D. C.: U.S. Department of Agriculture, 1973).

form was "8 May 78" rather than "May 8, '78," "5/8/78, " or "8/5/78" because of "possible confusion. " (Such a form also takes up less space than "May 8, '78.")

Preliminary results from the 1978 consumer hearings held by the Food and Drug Administration (FDA), the U.S. Department of Agriculture (USDA), and the Federal Trade Commission (FTC) support these findings. In fact, indications are that the vast majority prefer an alphanumeric date—"8 May 78" or "May 8, '78"—to a date in all numerals—"5/8/78" or "8/5/78."

Processors, wholesalers, and retailers have no significant problems with these preferences. However, the possible exclusion of the year could be made for highly perishable products such as fresh meat and bakery products, and omission of day of the month for long shelf-life foods. This is a common feature found in many countries that open date their food products.

As far as actual implementation goes, a three-letter designation could be used for the month: JAN, FEB, MAR, APR, MAY, JUN, JUL, AUG, SEP, OCT, NOV, DEC. However, the fact that these designations require a combination of 20 letters, in addition to numbers, complicates high-speed printing operations. Still, too much confusion could result from using numbers alone. For instance, for the first 12 days of any month, the day of the month could also be the number of the month itself.

For some food packages, there are technological problems in printing dates. Frozen food packages—especially cardboard—present a challenge because cardboard tends to return to its initial shape when a date is embossed on it; the wax loses its effectiveness as a humidity barrier if the date is cut into it; and inks do not mark well on wax.

The type of package employed should not influence the specific information provided by the date, but it could determine the particular technique by which the date and associated information are applied on the container. For example, it may be impractical and dangerous to emboss a retortable pouch, and some type of printing or sticker label might need to be designed. Also, it is generally acknowledged that open-date printing would have to be done at the point of packaging on preprinted labels with space left for an open date. It would be difficult to make labels with the proper information ahead of time because of the logistics of processing.

Despite the technological problems, the major impact on food manufacturers of applying open dates would be that more package space would be taken away from them which must be used for the label. This could lead to a decrease in the availability of small single-serving packages that may not have the added space required.

The impact on other groups would be the increased need for education. Precision and brevity of terms and easily recognized dates are important for the consumer to understand the date itself as well as to help those involved in the distribution and marketing system.

EXEMPTIONS

There are specific food products that should be exempted from open dating. These are: a) bulk fresh fruits and vegetables—those products sold unpackaged at produce counters; b) fresh meats, poultry, and fish that are cut and prepared in the retail store, are not frozen at any time during their storage life, and are not packaged in any container or wrapping prior to sale; c) salt; and d) crystallized refined sugar.

The principal reason for exempting bulk fresh fruits and vegetables and fresh meat, poultry, and fish from open dating is that the quality of these products is normally determined by sight, touch, and smell before purchase is made. Because these products are subject to varying rates and types of deterioration, including physical destruction as a function of consumer handling, it would not be possible to arrive at a meaningful shelf-life date for each product. There would also be problems in physically placing a date on individual items, and the cost of such a program would be prohibitive.

A date of any kind is not meaningful for certain foods such as salt and crystallized refined sugar, which when held under proper conditions are good for 10 to 20 years. These products however, do not have an infinite shelf life because if held at high humidity, they can cake. From a practical viewpoint, though, there are very few situations in which food is actually stored 10 to 20 years. These foods could be said to have a shelf life so long that it is not a relevant factor in their purchase or use.

Chapter V

Establishing Open Dates

In order to establish a fairly accurate open date (except a pack date) for a particular food, one needs to know how that food deteriorates. All foods begin to deteriorate at some speed (rate) as soon as they are packaged and continue to deteriorate until they may no longer be acceptable. Some foods deteriorate relatively quickly and others very slowly.

Food shelf life is not totally dependent on time but also on environmental conditions such as temperature, humidity, light, and oxygen. The prime factors—temperature and humidity-may increase deterioration as they rise, or slow the process as they become lower. However, their impact depends on how widely they vary and on the product itself. Also, as the food deteriorates, the process may accelerate because of its own momentum.

Examples of possible modes of deterioration, the most critical environmental factors; and the most feasible open date for some perishable, semiperishable, and long shelf-life foods are listed in table 5. The primary mode, if known for normal conditions, is in bold italic type. How foods deteriorate may change radically with sterilization procedures, packaging, condition of raw material, etc.

As can be seen in table 5, in no case is safety a concern in any of the normal deteriorations of food. In cases of certain meats or poultry, foodborne infections that might be disseminated by the product could make the question of safety more relevant than for other foods. However, for most food, other factors that result in an inedible product occur before a point of health hazard is reached if the product has been properly processed, packaged, and not abused or contaminated.

Most perishable and semiperishable foods degradate mainly on sensory quality criteria. For example, fresh meat degrades mainly by bacterial activity and oxidation that cause an off-flavor development and loss of color. This is readily recognizable by consumers.

In contrast, many long shelf-life foods degradate mainly on nutritional criteria. For example, frozen fruits and vegetables are consumed 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. In addition, most long shelf-life foods are packaged so that it is impossible to examine the contents. Consumers cannot recognize loss of sensory quality until the product is unpackaged after purchase. Open shelf-life dating is, therefore, as applicable to long shelf-life foods as it is to perishable and semiperishable foods, particularly if these foods are stored in the distribution system or home for a fairly long period of time. Some type of date is useful to ensure proper rotation and give

Table 5.—Major Modes of Deterioration, Critical Environmental Factors, Shelf Life, and Type of Open Dating by Food Product

Food product	Mode of deterioration (assuming an intact package)	Critical environmental factors	Shelf life (average)	Date most suitable for product	Additional information
Perishables					
Fluid milk and products	bacterial growth, oxidized flavor, hydrolytic rancidity	oxygen, temperature	7-14 days at refrigerated temperature	sell-by	length of time product can be stored at home
Fresh bakery products	staling, microbial growth, moisture loss causing hardening, oxidative rancidity	oxygen, temperature, moisture	2 days (bread) 7 days (cake)	sell-by	
Fresh red meat	bacterial activity, oxidation	oxygen, temperature, light	3-4 days at refrigerated temperature	pack or sell-by[a]	
Fresh poultry	pathogen growth, **microbial** *decay*	oxygen, temperature, light	2-7 days at refrigerated temperature	sell-by[a]	length of time product can be stored in home either frozen or refrigerated
Fresh fish	bacterial growth	temperature	14 days when stored on ice (marine fish)	pack (catch date)[a]	
Fresh fruits and vegetables	microbial decay, nutrient loss, wilting, bruising	temperature, light, oxygen, relative humidity, soil & water, physical handling	(b)	pack[a]	
Semiperishables and perishables					
Fried snack foods	rancidity, loss of crispness	oxygen, light, temperature, moisture	4-6 weeks	sell-by or best-if-used-by	home storage information such as "store in a cool, dry place"
Cheese	rancidity, browning, lactose crystallization	temperature	processed cheese 4-24 months; natural cheese 4-12 months	best-if-used-by	
Ice cream	**graininess caused by lactose crystallization,** loss of solubilization (caking), lysine loss	fluctuating temperature (below freezing)	1-4 months	sell-by or best-if-used-by	recommended home storage temperature
Long shelf-life foods					
Dehydrated foods	browning, rancidity, loss of pigment, loss of texture, loss of nutrients	moisture, temperature, light, oxygen	dehydrated vegetables 3-15 months; dehydrated meat 1-6 months; dried fruit 1-24 months	sell-by or best-if-used-by	estimate of shelf life beyond sell-by date; store in cool, dry place
Nonfat dry milk	*flavor deterioration,* loss of solubilization (caking), lysine loss	moisture, temperature	12 months	best-if-used-by	

Table 5.— Major Modes of Deterioration, Critical Environmental Factors, Shelf Life, and Type of Open Dating by Food Product—Continued

Food product	Mode of deteriorate ion (assuming an intact package)	Critical environmental factors	Shelf life (average)	Date-most suitable for product	Additional information
Breakfast cereals	rancidity, loss of crispness, vitamin loss, particle breakage	moisture, temperature, rough handling	6-18 months	best-if-used-by or sell-by	recommended storage conditions
Pasta	texture changes, staling, vitamin and protein loss	too high or low moisture, temperature	pasta with egg solids 9-36 months; macaroni and spaghetti 24-48 months	best-if-used-by	
Frozen concentrated juices	loss of turbidity or cloudiness, yeast growth, loss of vitamins, loss of color or flavor	temperature	18-30 months	sell-by or best-if-used-by	month of high quality left in home storage
Frozen fruits and vegetables	loss of nutrients; loss of texture, **f/aver, color:** and formation of package ice	temperature	6-24 months	best-if-used-by	recommended storage conditions
Frozen meats, poultry, and fish	**rancidity,** protein denaturation, color change, desiccation	temperature	beef 6-12 months veal 4-14 months pork 4-12 months fish 2-8 months lamb 6-16 months	best-if-used-by	recommended storage conditions
Frozen convenience foods	rancidity i n meat port ions, weeping and curdling of sauces, loss of flavor, loss of color	oxygen, temperature	6-12 months	best-if-used-by	recommended storage conditions
Canned fruits and vegetables	loss **of** *flavor,* texture, color, nutrients	temperature	12-36 months	best-if-used-by	
Coffee	**rancidity,** loss of flavor and odor	oxygen	ground, roasted, vacuum-packed, 9 months; instant coffee 18-36 months	best-if-used-by	
Tea	loss of **flavor** absorption of foreign odors	moisture	18 months	best-if-used-by	

[a] This date applies only if the product is packaged prior to sale If unpacked or sold in bulk prior to sale this product is exempt from an open date
[b] Depends on the specific commodity Sweet corn has a shelf life of 4 to 8 days and apples range from 3 to 8 months at ProPer temperature For this specific information see Theodore Labuza et al Open Shelf Dating of Foods. Dept of Food Science and Nutrition University of Minnesota report prepared for the Office of Technology Assessment 1978
NOTE When known the primary mode of deterioration is in bold italic type

the consumer an index of when foods should be used.

Since the mode of deterioration and critical environmental factors determine the shelf life of a product, they should be considered in selecting the type of open date. In general, for perishable products, the most feasible date is the pack or sell-by date. For example, almost all fresh red meat is packaged by the retailer who deals directly with the public. The meat may have been slaughtered from 1 day to 2 weeks previously. Since carcasses of properly handled beef are essentially sterile internally, it is the packaging procedure that initiates color change and bacterial spoilage. Because the shelf life of fresh meat is relatively short beyond the date of packaging, a pack date or sell-by date may be sufficient for consumer use and understanding.

A best-if-used-by date would also be useful to the consumer for fresh meat and other perishable products. However, these products are very sensitive to temperature changes, which can result in very rapid deterioration. Thus, the potential for consumer abuse may be too great for a best-if-used-by date to be a practical alternative.

In general, the most suitable date for long shelf-life foods is the best-if-used-by date. For example, with canned fruits and vegetables, 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 pack seasonal crops 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 of the product. This would be especially true in years when an overabundant crop would force the canner to sell some products the following year.

A sell-by date is not applicable to cans that are often stored in the home for some long period of time after being sold. The best-if-used-by date could be useful to consumers because it would give an appreciation of the shelf life of the product if conditions of storage were known or uniform. (For a detailed discussion by product, see appendix A.)

ALTERNATIVE CRITERIA

The general criteria to establish a sell-by or best-if-used-by date will depend on what the date is meant to imply. A sell-by date should mean that there is still high-quality life left for some time period of home storage under reasonable conditions. A best-if-used-by date further states this by projecting a reasonable time period. It is not possible to set an exact end to shelf life (a definite use-by date) for any food product.

Such criteria would have to be based on what degree of change caused by each of the deteriorative reactions in table 5 would lead to a “significant” loss in high quality. This would apply to rancidity, flavor loss, browning, textural change, etc. Such tests for sensory quality (taste panels, preference tests, etc.), although well-developed and used in product testing, would be difficult to use in a regulatory sense to determine whether a specific food was in or out of compliance at a certain date unless the regulators were trained for each product. What is needed in this sense is a chemical or physical index that changes in a similar manner to the sensory changes.

Sensory Quality

Although more difficult to measure in certain cases, sensory quality is the most important characteristic for consumers and processors alike, and in some cases with foods of long shelf life, this quality may also be an indicator of nutrient quality. This is not true for shorter shelf-life foods such as milk.

Manufacturers define their own quality standards through elaborate product development studies, many of which include sensory testing, when they put a brand name on a product with a best-if-used-by date. In this way, they assume quality loss up to that point is still acceptable enough that the consumer will buy the product. If consumers buy the product and find it below their own quality standards, they will probably not buy the product again.

Consumer reaction, then, is the key to quality standards, because Government regulatory agencies would not have available the needed methods to determine whether a given food that is still in date is out of compliance with some quality standard. For example, if an inspector picked up a can of soup and took it back to the laboratory, he might not have the scientific tests available which could determine with any degree of accuracy if that soup is of a designated quality and therefore acceptable to the consumer.

Assuring compliance with sensory quality might be feasible if the sell-by or best-if-used-by date were coupled with official Government or widely accepted industry quality grades. Thus, instead of merely stating "use-by" or "best-if-used-by" when there is no defined "best" quality, the open date could be preceded by a statement such as "to remain in grade, use by. "

The addition of an open date to a grade declaration would automatically solve the existing serious problem of unlimited guarantee of a specified quality grade level from the time the grade is marked on the container until its destruction. The more perishable the product, the more important would be the grade/open-date combination, While canned green beans could well remain in grade for a year or longer provided the container is undamaged and not exposed for long periods to high and/or fluctuating temperatures, fresh green beans could go out of grade in just a few weeks, or even days,

Open dating, when coupled with quality grade levels, can be based on accurate, rapid, and scientifically sound methods of analysis for some foods. However, open dating based on retention time within the grade can be applied only to those few hundred items for which generally recognized and approved grades already exist. These items are those for which grade levels can be measured accurately and precisely.

Nutrient Loss

Another measure of shelf life could be the loss of a certain percentage of a critical nutrient, such as vitamin C. This factor would be much easier to measure than overall quality, since it can be analyzed accurately and rapidly in the laboratory. The same would be true for moisture gain or loss of a critical value that would cause some textural change, such as loss of crispness of a potato chip.

However, many scientists favor a specific sensory quality criteria for each type of food rather than a given percentage loss of an unstable or critical nutrient for all commodities. Nutrient content of even the same foods can be quite variable, particularly the vitamin content of many raw agricultural commodities, For example, two tomatoes picked at the same time can vary significantly in vitamin C content. More importantly, some foods are naturally poor in some nutrients, are not eaten to provide those nutrients, and may be of good quality even if they have lost a certain percentage of the nutrients. In other words, if a food only contains 1 percent of the U.S. recommended daily allowance of vitamin C, a 10-percent decrease in this low amount would most likely have an insignificant effect on overall nutritional status of the consumer.

If nutrient loss is to be used as one index of quality loss, foods would have to be examined on a product-by-product basis. In essence, this has already been done for nutrition labeling. However, to prove that a loss in nutrients is of significance to overall quality of each and every commodity would be difficult.

Perishability Time Categories

Some States with open-dating requirements use perishability time categories to establish an open date. The three general categories are: perishable, semiperishable, and nonperishable. Time categories can be relevant for highly perishable foods that have a minimum of processing such as fresh meat or milk. However, processing conditions and types of packaging can increase the shelf life of semiperishable and long shelf-life foods to the point where such perishability time categories are not meaningful unless continuously modified to reflect new circumstances. For example, semiperishable foods can be defined as those foods with a shelf life of greater than 7 days but less than 90. Under this system, in general temperature and environmental conditions, most potato chips would be defined as semiperishable. However, if they were packed in a foil pouch under nitrogen with added antioxidants, the chips might last for up to 6 months and would not fit the category.

Some States have met this problem by developing a nonperishable or long shelf-life food category that can be defined as foods with a shelf life of greater than 6 months. As pointed out earlier in this report, this is, in fact, a scientific misnomer, for all foods decay at some rate by some means. Even in the above example with potato chips, if the new method of packaging gave an average shelf life of 120 days but the product was abused in distribution and held at high temperatures (38 °C) for a few days, it could deteriorate fast enough that it would no longer meet the criteria of nonperishability. Therefore, perishability terminology cannot be logically backed-up scientifically since one can control or change shelf life through varying processing, packaging, and environmental conditions.

Basing open dating on time categories could also be a hindrance to implementing new technology. For example, better packaging can increase shelf life of potato chips from 90 to 120 days, even in regions with high humidity. However, this better packaging would not be used if potato chips could not be sold at full price after 90 days no matter what their quality may be.

SCIENTIFIC TESTS AND DATA NEEDED

To develop sell-by or best-if-used-by dates scientifically, each manufacturer would need to conduct shelf-stability studies on each product and determine the point in time at which sensory quality falls below the point of consumer acceptance. This is very time-consuming and difficult to determine unless the food has a short life under constant normal environmental conditions.

Knowledge of temperature and humidity conditions encountered during distribution are necessary to set the sell-by or best-if-used-by dates. A manufacturer can determine this in one of two ways. He can put a product out in the marketplace, pick up samples at various times and places in the marketing channel, and test the quality of the samples at regular time intervals to establish the appropriate date for the product. But for products with several years shelf life, such as canned vegetables, these studies could take as long as 3 to 4 years.

The other alternative for the manufacturer is accelerated shelf-life tests (ASLT). These tests would be necessary for new-product development and could be advantageously used for existing products where shelf life under normal marketplace conditions is very long. ASLT involves subjecting the product to two or three given constant environmental conditions and measuring the rate of quality loss at each condition. A mathematical formula can then be established for the rate of deterioration as a function of temperature and/or humidity and used to predict the time needed to reach an unacceptable amount of change during distribution and storage.[1]

In a select sample of 50 food manufacturers, OTA found that the scientific approach described in this section and in the background report is frequently not utilized except by major corporations with highly qualified scientific personnel. The low use of shelf-life testing results from lack of knowledge and, more importantly, lack of experience in determining the shelf life of established foods as well as the costs involved.[2]

The major impact of developing scientific data would fall on the food manufacturer. A significant amount of time and money must be used to establish a data base for each product because broad generalizations cannot suffice, Because of the cost, most manufacturers would probably consider these data to be of a proprietary nature and would not release it to the Federal Government or the scientific literature. Another impact would be that the wholesalers, distributors, food brokers, and retailers would need to supply information on each product's history, as regards time, temperature, and humidity conditions encountered along the way to final sale.

Since shelf-life testing is product-specific, it would be very expensive for the Federal Government to undertake these types of tests for all food products. The Government could, however:

1. Support research into modeling shelf-life studies for various reactions leading to loss of quality under variable time/temperature/humidity conditions.
2. Support or conduct research into development of reasonable cost devices that could be attached to food packages which could detect the impact of time, temperature, and humidity on shelf life of an individual food.

‘Theodore Labuza et al., “Open Shelf-Life Dating of Foods,” Department of Food Science and Nutrition, University of Minnesota, report prepared for the Office of Technology Assessment, 1978.

‘Ibid.

IMPACT ON TECHNOLOGY DEVELOPMENT

An open-dating system based on perishability time categories with a sell-by date, such as many States have now adopted, can inhibit efforts to improve processing technology, packaging methodology, and a distribution system that would extend the shelf life of many foods. This is because there is no benefit gained in improving a food if it cannot be sold at full price beyond a certain date after manufacture. However, if manufacturers are allowed to use the best-if-used-by date on a voluntary basis that they feel is reasonable, the incentive to do research to extend the date may be greater than it is now.

From the consumer's viewpoint, however, extending the date may be a processor's attempt to make old foods taste and look good, at the risk of some additives. Many consumers today are extremely distrustful of food additives used simply to extend shelf life. Also, consumer distrust may be a reason why UHT (ultra-high temperature) milk has not been widely accepted in the United States. Because of improved sterilization techniques, this milk can remain shelf-stable for at least 6 months at room temperature.

Another pitfall to consider is that too much emphasis in product development may be put simply on extending shelf life and thus decrease efforts to develop a wide variety of other interesting and convenient foods that are enjoyable but which may not have an extremely long shelf life. It is impossible, however, to project such an impact at this time.

At present, theoretically accurate and reliable shelf-life indicators for some types of food products exist that could measure the reaction rate of food to both temperature and moisture. However, these indicators are not technologically or economically feasible for individual consumer-size packages.

If such indicators were in widespread use, food companies buying commodities or ingredients from other food companies could include a value on the indicator as part of their specification for the ordered food. Some Government contracts currently mandate use of shelf-life indicators in shipping frozen food cases. The use of indicators could well be extended to other cases or pallets of food. However, the indicators may never become inexpensive enough to warrant their use on individual consumer packages, They would probably cost at least as much as the package itself.

Open dating could have a real impact on labeling technology. There would be increased incentive to develop quick-drying inks and ways of printing on difficult surfaces, especially at high speed. At present, it is not possible to do this, and the materials are not available, according to the industry. New unidirectional shrink-film that can be preprinted without distortion as the label is applied could be the answer. It is currently used for bottle labels.

The other major issue is in the area of quality standards. With the exception of the commodities for which there are now quality grades and standards, no specific guidelines exist for thousands of new, fabricated, and processed foods. However, the vast sources of existing knowledge on which Government and industry quality grades are based could be tapped.

If a best-if-used-by or sell-by dating system were imposed, research by Government, universities, and industry laboratories would be stimulated. They would most likely center on:

1. shelf-life indicators,
2. modes of deteriorations and quality indicators,
3. prediction of packaging requirements, and
4. more precise and objective methodology for measuring changes in sensory quality attributes.

Chapter VI

Alternative Open-Dating Systems

There are three basic systems that could be used for open dating: private voluntary system, mandatory system, and voluntary/mandatory system. With a private system, the industry develops and adopts standards voluntarily. With a mandatory system, the use of open dates would be required by law. If the system were nationwide, the Federal Government would develop regulatory guidelines. Under a voluntary/mandatory system, only processors who elect to open date their products would be required to follow Federal guidelines.

An outline of the three systems is given in this chapter. For an analysis of congressional options among these systems, refer back to chapter I.

VOLUNTARY SYSTEM

This system is in current use because processors who open date their food products have chosen to do so. It is the preferred system by many processors because it allows flexibility in terms of:

1. whether or not to open date,
2. which products to date,
3. which date to use, and
4. which tests to use to determine the date.

On the other hand, the system has led to confusion because there are no standards to be followed. Some processors date their products, while others do not. Those that do can select any date, can display it in any fashion, and can establish the date by any testing procedure.

This nonuniform system also can make it more difficult for inventory control in the distribution channel, which can result in food waste. In addition, it can increase food waste in the home because the consumer does not know the food is approaching an unacceptable quality level.

MANDATORY SYSTEM

The mandatory system is used in 21 States and the District of Columbia for open dating of some food products—mostly milk and milk products. As with the voluntary system, there is no uniformity on a national scale. Since nationwide distributors must meet different State requirements, the result is higher costs, which mean higher prices for consumers.

A Federal mandatory system is preferred by many consumer representatives because it would provide:

1. uniform regulations throughout the United States,
2. tighter inventory control in the distribution channel, and
3. higher quality and nutritive levels for some foods.

The major impact of the system would be on the processor. It would be very difficult for processors to comply with a mandated sell-by or best-if-used-by date within the next 2 to 5 years, particularly for semiperishable and long shelf-life foods. This is because there is a lack of currently available data on shelf-life stability for many food products. A mandated sell-by or best-if-used-by date at this time would force "manufacturers to guess about the shelf life of their products and/or to extend the known shelf life of one product to encompass other similar products, which would not necessarily benefit the consumer. Time to phase in the program would allow industry to establish the necessary data on shelf life of their food products,

An alternative would be that the regulatory agency could mandate that all food in a certain category had to meet a minimum date. If a company could not afford testing to demonstrate a longer shelf life, they could use the established, mandated minimum. If they could demonstrate a longer shelf life, they could use that date. If their product could not meet the minimum shelf life, they would either have to change the process, go out of business, or challenge the legality.

Objections to this alternative include the fact that a minimum shelf life for a product would be similar to a standard of identity, which specifies the minimum composition of many processed foods. The Government would have to identify criteria for each particular food category and be able to defend the criteria and the minimum shelf life. For example, if the Food and Drug Administration (FDA) developed a best-if-used-by date for each product category, the agency would, in effect, be assuring the public that the product is good.

It is more probable that the regulatory agency involved would have to go to the opposite extreme and determine the maximum date that could be put on a product unless the manufacturer could prove otherwise. Since the process would have to be repeated for each specific food, it would be very costly to the Government.

Manufacturers could presently identify and indicate the pack date if it were mandated. The pack date would have to be defined as the date the product was put into the final consumer package for sale and use. However, there are problems in defining the pack date, which were discussed in an earlier chapter, mainly for multicomponent products. If the pack date were mandated, the printing system for the present codes would have to be changed, but the system could be initiated immediately.

The impact of a mandatory system on retailers and wholesalers would vary, generally by size of operation. That is, smaller businesses tend to have fewer inventory turnovers per unit of time, so they could be adversely affected by out-of-date stock. Mandatory open dating would likely have the least impact on national chains, the next least impact on smaller independent retailers/wholesalers, and the greatest impact on "mom and pop" stores. Convenience stores would be affected much like national chains.

Because of the potential adverse impact on small retail stores, a mandatory system might exempt smaller stores, based on number of employees or gross dollar sales. However, such an exemption could mean that these stores would receive products that were pulled after date from shelves of larger nonexempt stores and shipped to them by distributors (either manufacturers, representatives, or wholesalers). In the end, an exemption could work to the disadvantage of small retailers, regardless of the intent of the exemption.

Some consumers prefer a completely mandatory system, arguing that it would both educate consumers about how long a food can last as well as help stock rotation. Under a voluntary system, these benefits are piecemeal.

VOLUNTARY/MANDATORY SYSTEM

This system would combine the characteristics of the voluntary and mandatory systems by allowing the processors the choice of open-dating food products, but requiring that once they elect to do so, they must do it in a prescribed manner, This is essentially the system used for nutrition labeling.

A voluntary/mandatory system would have a number of the advantages of the two other systems, It would allow the processor to choose whether or not to open date and to elect which products to date. However, since the processor who elects to open date must do it in a certain way, the result would be uniform open dating throughout the United States. Also, because processors would have a choice about open dating their products, this system should not have an adverse effect on smaller processors or retailers,

Of course, another factor to consider is consumer pressure, Consumers could effectively pressure processors who do not use open dating by purchasing products from those firms that adopt open dating.

This had been the case under the voluntary/mandatory system on nutrition labeling, In 1973, when nutrition labeling regulations were issued, very few products had a nutrition label, By 1978, 40 percent of the leading national brands, 25 percent of the remaining national brands, and 44 percent of private labels displayed nutrition information on major packaged processed foods. In terms of dollar sales, this represents 39 percent of the $24 billion of packaged processed foods sold. ’

The voluntary/mandatory system appeals to processors because it allows them the option about open dating their products. It also allows them time to collect scientific data on a product-specific basis to determine the dates.

The system also appeals to many consumers because when products are open dated, every processor must meet specific requirements. This provides for a more uniform system and reduces consumer confusion.

However, compared with the voluntary system, this system would increase costs to Government for developing and enforcing the regulations and would increase costs to industry for complying with the regulations. In addition, developing the regulations in the first place would be time-consuming for both Government and industry.

‘Raymond Schucker, “A Surveillance of Nutrition Labeling in the Retail Packaged Food Supply” (Washington, D. C.: U.S. Department of Health, Education, and Welfare, Public Health Service, Food and Drug Administration, 1978).

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Chapter VII

Enforcement and Liability

Open dating, as it exists today, has a built-in enforcement mechanism through the consumer. If a consumer is aware of date marking, understands it, and uses it, out-of-date products with a sell-by date will not be purchased at full prices.

In most States, provision is made for sale of these products at a reduced price. If the product cannot be sold, most manufacturers will take the product back and refund the retailer. The same is true if consumers feel a product is not up to the quality desired, they can return it and get their money back from most retailers.

Some consumers feel, however, that returning a product is too time-consuming and unfair to them. They look to open dating as the institution of a fail-safe system—i.e., anything purchased with an unexpired sell-by or use-by date would not be bad; it would presumably be of excellent quality. Unfortunately, as pointed out in the previous parts of this report, such a guarantee is an impossibility, since unintentional abuse during distribution can severely reduce food quality even though an item is dated.

The type of enforcement and liability would depend very much on the system used. With a pack date, there is no liability except from the standpoint of misbranding if it is made mandatory and left off the package. It would be up to the Federal or State inspection systems to routinely survey the market for such violations, and the liability would be the same as at present for misbranding. The sell-by and best-if-used-by dates are another matter, however, as discussed in this chapter.

METHODS OF ENFORCEMENT

If the date were a sell-by or best-if-used-by date, there could be two types of enforcement. The first would be before-date enforcement. In other words, if a date is based on some standard such as loss of sensory quality and the food is found to be below that standard before the date is reached, it would be in violation. The second type of enforcement would involve offering a product for sale after the date (beyond-date enforcement).

Before-Date Enforcement

Two types of before-date enforcement are discussed and are presently used for enforcing labeling standards. Note that they lead to substantially different potential costs and liability.

One method is to construct an enforcement scheme that would allow processors to establish reasonable dates (be they sell-by or best-if-used-by) for each individual product and/or process within a product. Thus, canned green beans may have different sell-by dates, for example, than canned peaches. Also, glazed frozen shrimp may have longer sell-by dates than frozen shrimp that are not glazed. Processors in this scheme would be required to justify the "reasonable" dates chosen, presumably before instituting the system and if asked by the regulatory agency. Tests and data would be necessary to support the claim made for reasonableness by the processor for his date.

A second method could be for an enforcement agency to spot check products at the processor and retailer level via laboratory testing. A regulatory agency could sample products from the processor's line or purchase products at retail and perform appropriate laboratory tests for nutritional and/or sensory characteristics. However, the laboratory testing would vary from quick and simple for some products to difficult and costly for most products. The regulatory agency would still need the information of the first method to determine whether the product was within the quality limits for the date set.

With spot-check enforcement, food producers might feel the necessity of setting quality specifications for a date as low as possible in order to protect themselves in case the product is severely abused during distribution. The quality standards would probably be much lower than those at which the processors currently try to sell their products—in other words, lower than those the consumer currently expects and finds. It should be noted that spot-check enforcement of label claims is presently done by Federal and local agencies. The Food and Drug Administration (FDA) is preparing to initiate this enforcement scheme to help enforce nutrition labeling declarations.

The first method would be considerably less expensive to enforce and would not lead to a decline in quality specifications for the date. In addition, the first alternative would avoid liability questions raised by the second alternative. The second scheme raises questions about the extent of manufacturers' liability, especially if the product tested were purchased at retail. If the product chosen for testing had been abused in the distribution channel (e.g., high temperature in frozen food), processors could conceivably be held responsible for the actions of distributors over which they have no control.

Beyond-Date Enforcement

Two alternatives are possible. One is complaint-based enforcement, the other is spot-check enforcement.

Complaint-based enforcement would involve a consumer's return of a beyond-date product, or the out-of-date product would simply go unsold, thus indicating consumer displeasure or disinterest. This system would be possible with sell-by or best-if-used-by dates, but not a pack date. Enforcement costs would be minimal.

A second alternative would be to have an enforcement agency randomly spot-check retail stores for merchandise that was beyond date. Costs of this alternative would be considerably higher than complaint-based enforcement. In the case of pack dates, spot checks could be made at the origin of retail packaging, so this alternative could cover any type of open date.

Again, the manufacturers who set the highest standard would run the greatest risk of being in technical violation of their own standard. For this reason, food should be allowed to be sold after a sell-by or best-if-used-by date, since the date is only an estimate.

Especially with semiperishable and long shelf-life foods, there should be no discernible difference between quality shortly before the date and shortly after. Even with perishable foods, open dating is not a safety issue, since there are laws currently in effect that make it illegal to sell unsafe food. If consumers refused to pay full price for over-age food, it could be offered at a reduced price.

FEDERAL/STATE ENFORCEMENT

As discussed earlier in this report, 40 percent of the States have some type of mandatory open-dating law that they are currently enforcing. Thus, an alternative to exclusive Federal enforcement would be cooperation with the States. Basically, this type of cooperation could be achieved either through cost-sharing programs or model regulations,

Cost-sharing programs can be in the form of contracts or grants. The most common arrangements are 50-50, although there are some arrangements with 80 percent Federal and 20 percent State and some with 90 percent Federal and 10 percent State. Contracts are formal agreements between Federal and State governments to perform specific tasks over a specified time period. Grants are lump-sum payments to States for use at their discretion in a general area.

OTA found that Federal and State officials prefer contracts over grants for the purpose of cooperating on enforcement. The advantage for Federal officials is that specific tasks are identified and both parties know what is expected for satisfactory performance. For the States, the advantage is that in most cases, multiyear contracts can be established which will provide a continuous source of funds for the States to perform their tasks.

Grants are viewed as "one-shot" affairs, and States cannot depend on them for continuous funding, Federal officials also take a dim view of grants because they are not specific in terms of tasks to perform. This makes it difficult for Federal officials to judge each State's performance.

The basic problem with these cost-sharing programs is nonparticipation by the States. The program works only if States feel there is a need for a specific activity or that they are going to benefit directly. Thus, States that presently have open-dating legislation will be more likely to participate than those that do not. If States do not participate, there is no equivalent means of enforcement. This is the present situation with the Fair Packaging and Labeling Act (FPLA). FDA is doing little FPLA enforcement in States where there are no contracts.

In the final analysis, the Federal Government must assume enforcement responsibilities if States decide they do not want to cooperate. Experience with cost-sharing or partial-funding programs such as the Wholesome Meat Act indicate that the States are not likely to cooperate. One-hundred percent Federal funding may have to be provided to ensure State cooperation. Otherwise, State officials are not going to look with much favor or give priority to a program the Federal Government will have to take over if States are not willing to do it.

To qualify for 100-percent" funding, States must have a law that is at least as encompassing as the Federal law. To illustrate, if a State has no law or a law that is less than the Federal law, it would not qualify for funding. However, if the State had a law that was more encompassing than the Federal law, it would qualify.

States adopting the Uniform Model Act have a history of adding to their laws and acts, areas that are above and beyond those of the Federal Government. Thus, if an absolutely uniform open-dating law or regulation is desired, using State enforcement will not ensure this outcome,

The alternative to a cost-sharing program is a model State regulation applicable to State and local jurisdictions. The National Bureau of Standards has designed such a model for open dating. The model provides for the use of a sell-by date on perishable and semi-perishable foods but does not address the basis on which to establish the date and excludes products for which a date would be useful and feasible. Four States have adopted the model to date. As a result, the Association of Food and Drug Officials is considering preparing its own model regulation for open dating.

The Association has designed the Uniform Food, Drug, and Cosmetic Act, which has been adopted by some States. The Act could be amended to include food-labeling areas like open dating.

The Act as currently written is State-oriented, since each State can change the Act to meet its individual situation. It is purely a model and not sufficient in terms of enforcement. A State may adopt the model regulation but may not enforce it if funds have not been allocated.

Although there is the possibility of Federal funds for States that adopt the model Act, Congress would have to first amend the Food, Drug, and Cosmetic Act. Presently, FDA does not have the authority to establish contracts for which it does not have basic responsibility by law.

LIABILITY

There is a difference in establishing liability between open-date labeling and most other food-labeling requirements. For example, in nutrition labeling, basically only the manufacturer, not distributors, is involved in compliance, although abuse in distribution can lead to labels that overstate nutritional value. In open-date labeling, processors, wholesalers, and retailers are all involved in compliance. If a retailer sells a product at full price that is out of date, the retailer, not the manufacturer, would be liable. Naturally, wholesalers and retailers are concerned that if a Federal open-dating system were implemented, this would in effect increase their liability.

At present, there is no definitive legislation or judicial definition of the legal significance of an open date. A search of the literature found no court decisions during the last two decades on the question of liability for spoiled food that has been open dated. Thus, the discussion of this question must be speculative.

In order to assess possible legal consequences, it is necessary to make certain assumptions about the intent and effect of a Federal open-dating requirement. First, such a requirement must avoid as much as possible the technological problems associated with open-date labeling of some foods. Second, it must provide for specific, uniform, and scientifically sound criteria by which the chosen date is established and its validity measured. Third, it must be designed to minimize confusion about the attributes of a food product. That is, the objective of open dating is to increase consumer awareness about food freshness; it is not an indicator of the safety of food. As indicated earlier in this report, consumer confusion on this point could have serious consequences.

Liability Under the Food, Drug, and Cosmetic Act

Food manufacturers and retailers could be subjected to increased liability exposure under the Federal Food, Drug, and Cosmetic Act (FDCA) if a Federal open-dating requirement is intended to relate to the misbranding and adulteration provisions of that statute. To the extent that any food is marketed in a way (for example, without a sell-by or best-if-used-by date, if required) that it becomes misbranded under FDCA, it is an illegal commodity, Additionally, the sale of “spoiled” food is prohibited by the adulteration provision of FDCA, whether or not the label of a product bears an open date.

Liability for such misbranding would flow to the manufacturer who failed to properly label the food, as well as to the intermediate distributors and retailers who sold, or held for sale, the misbranded product. Liability would not extend to distributors and retailers who could demonstrate that they received the misbranded food and delivered or proffered delivery of it in "good faith, "

The FDCA provision that declares as misbranded any food article the label or labeling of which is false or misleading, if taken literally, raises difficult problems from both a compliance and enforcement standpoint, The least of these problems involves food products the label of which might declare that they were packed on a particular date. If the "pack date" is not accurate, the product is misbranded and the manufacturer or packer of the product would be liable for such misbranding. (A retailer who has purchased the misbranded product in good faith and sells it or holds it for sale would probably not be liable.) Pack dates are definite in time and thus can be objectively determined to be either accurate or false.

On the other hand, the other forms of open dates that might be selected ("use by, " "sell by," "best-if -used-by," etc.) only can provide approximations of the ultimate shelf stability of the labeled products. Such dates offer freshness guidelines, but nothing more, and can never be precise. Different food manufacturers are likely to have different quality standards for their products, limiting the "precision" and significance of open dates. Moreover, storage or handling variables to which a product is subjected during its distribution cycle, or even during home storage, can affect the accuracy of all dates other than a pack date on the package.

The sell-by date raises an additional issue. The meaning of this date is somewhat vague. A sell-by date suggests that the product can be consumed for a reasonable period of time after the date with no recognizable difference in the quality of the food. The exclusion of information that indicates the ensuing consumption period could constitute the omission of a material fact rendering the product misbranded. This should be specifically addressed in the legislative history of any open-dating provision.

Literal application of FDCA could result in misbranding of a product because of distribution abuses—abuses that would render the open date inaccurate or misleading. For instance, a phrase such as "use by'* on a food label might lead a consumer to believe the quality of the food will remain unchanged as long as it is consumed by the stated date, If such a product were left an unusually long time in the sun on a retailer's loading dock, for example, that inference would no longer be true. If and when it is discovered that the product is "outdated," it is unlikely that the fact of its storage irregularity would also be discovered. One possible solution to this problem might be to provide that as long as a labeled date is objectively accurate in light of foreseeable marketing conditions at the time a product is labeled, when measured in terms of those criteria specified for the establishment of such a date, that product should be considered to be in compliance with FDCA.

Literal application of FDCA might or might not also result in an illegal product because of abuse in distribution. The same issue arises with respect to the declared net quantity of contents of packaged food. The law permits FDA to enforce it sensibly by determining the average net quantity of contents. There is nothing inherent in FDCA that would suggest that this approach would not be equally applicable for open dating of food.

Civil Liability

In addition to liability under FDCA, there are two theories under which a manufacturer, distributor, or retailer could be held civilly liable to a consumer and/or third party who purchases and/or consumes a "spoiled" food product, the label of which bears an open date, The two potentially applicable theories are: 1) strict product liability under tort law and 2) warranty liability under either the Magnuson-Moss Warranty Act or the Uniform Commercial Code. The viability of either of these theories will depend primarily on what an open date—and especially any qualifying terminology accompanying the date ("use by," "best-if-used-by," "freshness guaranteed if used by,'" etc.)—means to a consumer purchasing the food product. For example, if an open date and/or accompanying terminology were construed to constitute a promise, guarantee, or other affirmation of fact with respect to a food's quality, and a consumer, relying on the dating information, purchased a food that "spoiled" prior to the date, that consumer might be able to recover damages under a breach of warranty theory of civil liability.

Research in the individual States with open-date labeling found no court decisions on the question of liability for spoiled food that has been open dated. Since product liability is almost entirely a matter of State law, a discussion of the theories would be speculative.

The criteria by which an open date is established and by which food quality is measured, as well as the legal meaning and significance of the date, will ultimately determine the viability of the theories noted. These matters should be thoroughly explored and resolved in the legislative history of any open-dating provision. In this regard, it is important that the limitations of open-date labeling be addressed. The legislative history of any open-dating provision must make clear that open dates are only guides to freshness, not safety indications nor guarantees of product freshness. Otherwise, unintended and potentially onerous legal ramifications could arise under both criminal and civil law.

Chapter VIII

Economic and Social Costs

Economic and social costs of open dating are an important consideration. Based on the previous chapters, costs can be discussed in terms of: 1) establishing shelf life, 2) putting the open date on each package, 3) enforcement, 4) comparison with nutrition-labeling costs, and 5) food disposal. At the present time, there are no exact cost estimates for each of these areas. The costs presented are the best estimates available.

COSTS OF OPEN DATING

Establishing Shelf Life

Experts interviewed by OTA grouped the possible costs of establishing the shelf life of individual food products into two categories. The first, for perishable and semiperishable foods, would be about $100,000 per item, requiring at least one investigator and a technician plus facilities for 1 year. Nonperishables would cost $200,000 per item, taking 2 years to determine. These would be one-time costs, but future adjustments in the shelf life would have to be made with each change in product formula, package used, and mode of distribution, thus adding to costs in the long run.

Dating the Package

The cost of putting a date on food packages will vary widely, depending on type of package and method of date placement. For example, for canned products, existing closing machines can be modified to emboss the open date on the can for a cost of between $1,000 and $3,600 per machine. This is a low cost on a per-can basis. However, for perishable products, equipment costs can vary between $1,500 and $15,000 per food product.

Enforcement

In terms of enforcement, if the program were self-enforcing—that is, if there were no penalties for out-of-date food products and the only enforcement were consumers refusing to pay full price for out-of-date food—there would be no cost of enforcement per se. If a legal penalty were involved, the cost of enforcement could be more than $500,000 per year.[1]

Even if the program were self-enforcing, there would be considerable cost in food either sold at a lower price or returned to the manufacturer as unsalable. This cost would vary widely with the length of shelf life, reliability of the distribution system, and popularity of the items. At present, this cost would be difficult to estimate.

[1]U.S. Congress, Consumer Food Act of 1976, report to Committee on Commerce and the Committee on Labor and Public Welfare, U.S. Senate on S. 641, Mar. 4, 1976.

Comparison With Nutrition Labeling

Because there are no good estimates on costs of open dating, a comparison with a similar area of labeling—nutrition labeling—is worthwhile. A survey conducted by the Grocery Manufacturers of America in 1975 indicated that $8.4 billion worth of food products would have nutrition labeling that year, For those products, the initial average cost of putting the information on labels per dollar of sales was estimated at .004 cent, and the average continuing cost at .00016 cent per dollar of sales. Thus, nutrition labeling, which involves complex testing procedures and more information to be printed on the label than does open dating, costs a minimal amount once established. The same should be true for open dating.

IMPACT

Processors

The greatest impact of an open-dating system would be on the food processors, especially if the system were completely mandatory. In this case, much research at high cost would be entailed for each product/package system, and at present, there may not be enough scientists or laboratories trained or available to do the total job in just a few years, Industry would need to apply new or modified films, adhesives, and packaging machines. With a voluntary/mandatory labeling system, the same costs would exist, but only those companies who could afford the costs would undertake the job. This would not tend to reduce market competition as might happen with a completely mandatory sell-by or best-if-used-by system.

Wholesalers and Retailers

With a voluntary/mandatory or completely mandatory system in which enforcement and liabilities required segregation of product, retailers would have two related costs. The first would be more time to inspect shelves to ensure that no out-of-date products were present, and the second would be using space to sell out-of-date products at a reduced cost. The latter could be eliminated by returning the product to the food manufacturer, but that would mean an additional transportation cost and either a remanufacturing or disposal cost. At any rate, the result would be a price increase to the consumer.

Costs of various disposal schemes for out-of-date products can vary depending on the scheme and product category. For example, if mandatory open dating were imposed on fresh meat and poultry, without allowance for reconditioning and redating, the additional costs of open dating could be burdensome for some retailers. The impact would be greatest on smaller retailers who tend to have fewer inventory turnovers. Also, economic incentives already exist for retailers to minimize the amount of meat reconditioned.

Alternative disposal schemes at retail include marking out-of-date stock down in price, allowing return to processors (where appropriate), giving the food t o charities, or simply disposing of it. The first of these is likely the least expensive to the distribution system in the long run, while the latter is likely the most expensive.

Social costs from mandatory open dating include potential for less variety of sizes and more products out-of-stock on retail shelves. Such reaction would be logical for retailers in an attempt to minimize past-date merchandise on their shelves.

Consumers

The overall result of open dating, whether voluntary or mandatory (except for a pack date) would be to increase the cost of food to the consumer, since all the above costs would be passed on as increased price, ' Experts on the OTA working panel could not make an exact estimate of increased cost, but thought it could be between 0.1 and 1 cent per package of food.

The greatest impact on consumers other than cost would be increased education on the storage and handling of foods, which might mean increased quality at point of consumption and an opportunity for purchasing out-of-date bargains.

Government

With a required open pack date, the overall cost to the Federal Government would not be much more than under present food package screening and recall procedures on the basis of misbranding.

*Note that the use of a pack date could also increase costs to consumers if it causes the consumer to reject an otherwise acceptable product because of the date. This effect would be greatest on those products having the longest shelf life.

If the Government were to mandate a use-by or best-if-used-by date with Government-set standards of quality, a large share of current FDA and USDA budgets would be required for the research to set such standards for all packaged foods. Since it would have to be on specific products, consumers would likely complain that the Government is doing the industry's job. In addition, the size of the enforcement and legal force would have to be increased to cope with the problem of retail inspection and control.

If the labeling systems were voluntary, but with a mandated label format and quality standards set by the food companies, there would be little cost impact on the Government except through FDA and USDA education offices to help the consumer understand the label. However, based on problems with nutrition-labeling-education costs, this could be relatively expensive. Other costs to Government would be in enforcement if the correct label format were not used. Another problem would be in setting standards for removal or segregation of out-of-date food, especially with respect to the price reduction that should be used, Chapter IX

Array of Congressional Options

CONGRESSIONAL OPTIONS

This chapter provides a detailed explanation of the interaction among the various issues surrounding open shelf-life dating. As stated in this report, there are many possible combinations, each of which represents a congressional option. The interaction among these is detailed below.

The issues discussed in this report that give rise to congressional options are:

1. Whether open shelf-life dating will be implemented by regulation through an executive branch agency or required through a specific law;
2. Whether open shelf-life dating should be voluntary, voluntary/mandatory, or mandatory;
3. Which products or product categories will be exempt from open shelf-life dating or will have a voluntary/mandatory or mandatory date established;
4. The method chosen for open shelf-life dating.

There are important aspects of these issues that interact to create an open shelf-life dating system for food products. This is illustrated by the decision tree of figure 1.

The first branch, path A, illustrates the distinction between regulation through the appropriate executive branch agency or requiring specifics through statutory law. This is a basic option that underlies each issue specific to open shelf-life dating.

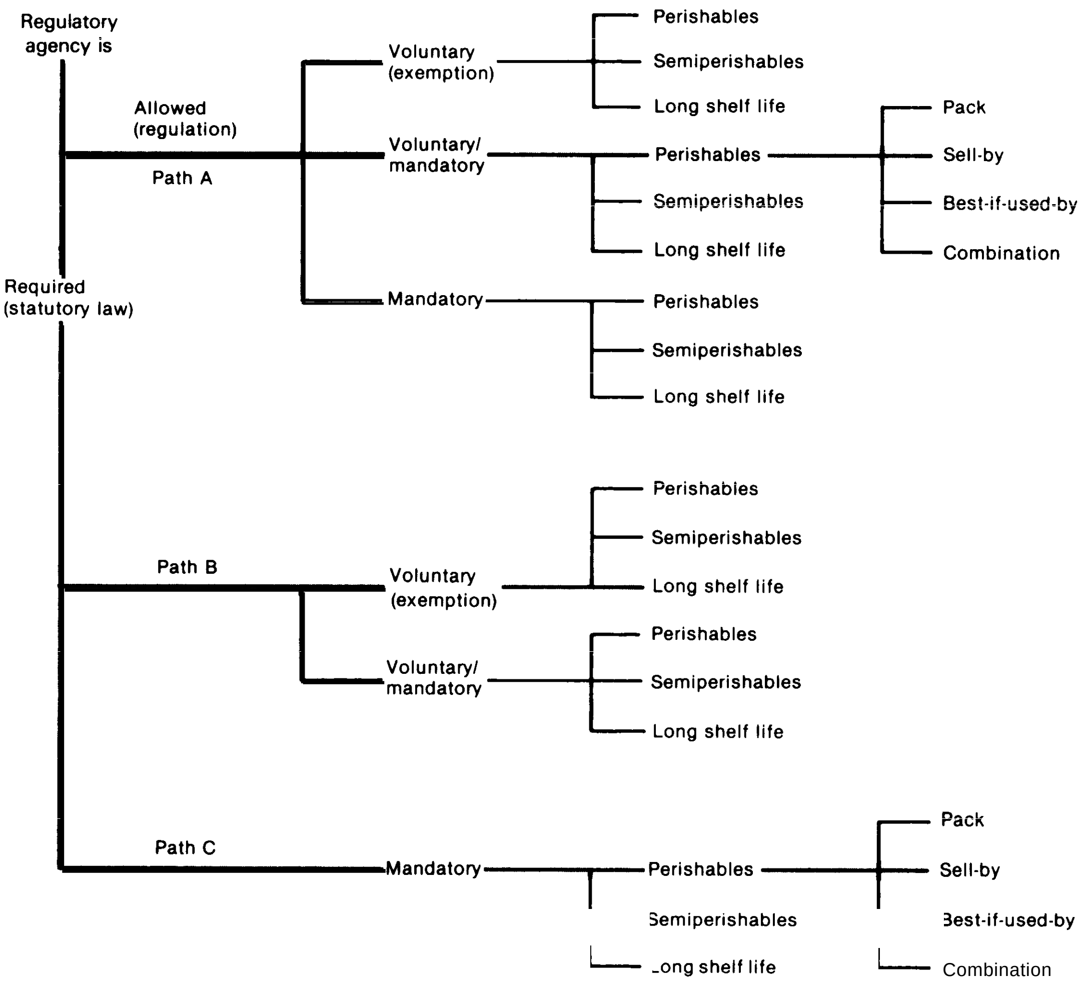
The second branch, path B, illustrates the three possibilities for the degree to which open shelf-life dating would be mandatory. One possibility is to specifically exempt certain products or product categories or to allow present voluntary dating to continue. Another possibility is to opt for a voluntary/mandatory program for certain products or product categories. A third possibility is to make open dating mandatory for certain products or product categories.

The third branch, path C, illustrates that any of the previous options could be applied to product categories such as perishables, semiperishables, or long shelf-life products. Of course, specific products or more narrowly defined product categories also would be appropriate at this point in the decision tree. As an example, a branch could be "strawberries" or "bulk fresh fruits and vegetables, " rather than "perishables."

The extreme right-hand side of the decision tree illustrates the options for the method used to convey an open shelf-life date. These include pack, sell-by, best-if-used-by, and combination dates. Each of these methods of dating represents an option by product or product category.

The decision tree clearly illustrates the interactive nature of the options. That is, if a particular option is chosen under one of the four issues, the impact of it will be different depending on which options under the other issues are chosen.

Figure 1.—Example of Interaction of Congressional Options



To clarify the interactions among the options, several examples are given using figure 1 as the basis for the example. These examples will follow specific paths of the decision tree.

Congress might opt to allow the appropriate executive branch agency to set voluntary/mandatory open shelf-life dating on perishables using a sell-by designation for the date (denoted as decision path "A" in figure 1). This particular path through the decision tree would mean that the specific decisions likely would be made by the appropriate executive branch agency, Also, the specifics of the open-dating system such as the products or product categories and the method for designation of the date would be accomplished by regulation issued by the executive branch agency rather than written into the law by Congress. Congress can stop at any point in the decision tree once the decision is made to allow an executive branch agency to put open dating in place via regulation rather than statutory law.

Note that the alternative paths through the decision tree are not mutually exclusive. One path may be chosen for a particular product category or method for dating while an entirely different path is chosen for another product category or method.

Another specific path through the decision tree is for Congress to write a law that would specifically exempt long shelf-life products from open dating (denoted as decision path "B" in figure 1). This would mean that manufacturers of many canned or frozen products would be exempt from a Government program but could still voluntarily open date their products, as some presently do.

A final example is that Congress could write a law that would place mandatory open dates on perishable products using a sell-by designation (denoted as decision path "C"' in figure 1). The implementation would be the responsibility of an executive branch agency, but the law would be specific with regard to product category and method used to designate the open date.

Similar open shelf-life dating systems are depicted by following the various decision paths through the decision tree. Several paths may be combined to form the basis of an open-dating system. The consequences of the various options are found in the main text.

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 foodborne 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 I 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 myofibular 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 over-abundant 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.

Appendix B

Bask Food Preservation and Deterioration Modes

INTRODUCTION

As pointed out in chapter V, in order to establish a fairly accurate open date for a particular food, one needs to know how that food deteriorates. This appendix contains an in-depth look at the various modes of deterioration and how they impact on open dating. It specifically describes the general modes of deterioration leading to the quality and nutritional losses and types of preservation used to slow down the modes.

MAJOR MODES OF FOOD DETERIORATION

Biological Decay-Preharvest

Prior to harvest and slaughter, foods—whether animal or vegetable—are subjected to a myriad of microbiological diseases, including viruses, molds, yeasts, and bacteria, In addition, some foods before harvest can be eaten by insects, birds, or rodents, or become prone to disease. For plants, competition by weeds can result in poor quality. Controls for such ravages can include pesticides, herbicides, rodenticides, weeding machines, and livestock antibiotics.

Preharvest deterioration as such is not generally considered in open shelf-life dating. However, if food is subject to damage, its initial quality will be less. Since processing does not make low-quality foods better, overall shelf life would be less after slaughter or harvest, as compared with undamaged foods,

Senescence (Aging)

Once a fruit, vegetable, cereal grain, or animal product is harvested or slaughtered, it is separated from its source of nutrients and water. Since it is still a viable living system, the enzymes continue to operate and utilize the carbohydrate and nutrient stores. For fruits, this process can be of benefit because postharvest damage can be repaired. More importantly, fruits can be picked prior to optimum maturity and transported long distances to the marketplace and home, during which time they develop into a high-quality product, If the fruits were picked at optimum ripeness, they could rot before consumption during this transportation. This biochemical process also operates in the aging of meat to achieve the desired degree of tenderness. However, the state of the preslaughter animal is very important and affects the final product quality,

Eventually, though, for all foods, postharvest enzymatic processes lead to degradation of sensory quality, including loss of color, flavor, nutrients, and texture. In addition, the breakdown products themselves damage the tissues such that the decaying process becomes more rapid. To prevent this deterioration, three major control methods can be used: 1) lowering temperature, which slows the rate of the reaction; 2) raising the temperature, which denatures the enzymes and makes them inactive but changes the sensory quality of the foods; and 3) removing or binding water to reduce water availability (or water activity, a_w), which reduces the ability of the en-

49-394O - '9

zymes to operate. Other control methods are addition of acid, thereby lowering pH; reduction of oxygen level or increase of carbon dioxide (CO_2), which slows the reactions; and genetic manipulation of the food to altogether prevent the reactions. With respect to open dating, the effects of aging are important in determining shelf life of fresh fruits and vegetables; whole grain cereals; fresh meat, poultry, and fish; and, to some degree, dairy products.

Microbiological Decay

Micro-organisms are responsible for quality loss of many foods, especially fresh ones. The reason is twofold: I) microbes are everywhere in the environment and can grow very rapidly, and 2) after a food is harvested or slaughtered, it loses to some degree the ability to fight off microbial attack, If the food is physically damaged—even by normal trimming and cutting—it becomes more susceptible to attack,

As noted, microbes can grow rapidly on foods. Starting with one microbe that divides every 10 minutes, in 5 hours (if the nutrients were available), there would be over 1 billion microbes. Much of the same controls used for enzymes can also be used for microbes:

- lower temperature to slow growth,
- raise temperature to kill microbes,
- remove or bind water to slow or prevent their growth,
- lower pH to slow or stop their growth by adding acid or by natural fermentation,
- control oxygen (O_2) level to control population or increase CO_2 level, and
- manipulate food composition to remove nutrients needed by the microbes.

Because in some cases the above methods change the food into a form not desired by the consumer or the method is not adequate to extend shelf life, some chemical means of preservation must be used to slow the growth or kill the microorganisms. Examples are calcium propionate in bread; sodium benzoate in some soft drinks; and natural fermentation that produces alcohol, such as making wine from grapes. Usually only small amounts of the chemicals are used, so that they will have no ill effect on the consumer.

Knowledge of how environmental conditions affect the growth rate of microbes is very important in predicting shelf life, and thus determining the open dating of many foods including:

- fresh and ground meats and poultry;
- fresh fish;
- dairy products such as milk, cheese, and yogurt;
- cured meats such as hot dogs, bacon, and salami;
- pasteurized fruit drinks:
- fruits and vegetables; and
- whole grains.

A second and more serious problem with microorganisms is the fact that some are pathogenic to humans—that is, they either cause an infection when ingested or while growing produce chemicals in the food that are toxic to humans. Most food processes are designed to ensure against contamination with pathogens or growth of the pathogen after processing, For example, fermentation of foods with useful microbes produces alcohol or acid that prevents the growth of pathogens. Some of the major micro-organisms pathogenic to humans in foods are:

- Intoxicants
  - —*Staphylococcus aureus,*
  - —*Clostridium botulinum,*
  - —*Clostridium perfringens, and*
  - —*Aspergillus flavus.*
- Infectious
  - —*Salmonellae* species, and
  - —*Escherichia coli* strains.

In most cases, temperatures below 7° C, food with a water availability of less than 80-percent relative humidity (a_w or water activity of 0.80), and a pH of less than 4,5 are sufficient conditions to prevent the growth of pathogens. Open dating should not be based on the growth of these organisms, since the manufacture and subsequent handling and distribution should ensure absolute control of these pathogens. Unfortunately, if the latter is not done, consumers may have a false sense of security that a food consumed before its sell-by or use-by date is safe when in fact it could cause food poisoning. This fact points to a must in educating the consumer that open dating is not an absolute assurance of food quality or food safety,

Chemical Deterioration

During the processing of foods, tissue damage occurs that causes the release of various food chemical constituents into the cellular fluid environment. These chemicals can then react with each other or with external factors to lead to deterioration of the food and result in a shortening of shelf life, Although many different reactions are important that lead to quality and nutrient loss, the major ones are classified below.

Enzymatic. As mentioned earlier, normal post-harvest enzymatic reactions can lead to a loss in food quality and shelf life. In addition, destruction of cell tissues releases enzymes that can lead to further deterioration. For example, lipoxidase enzymes released from cell organelles called mitochondria can attack lipids and cause rancidity. Similarly, the polyphenol oxidase enzyme can react with some cell constituents and oxygen, causing a brown color, which is typically seen as a deterioration reaction in bruised or cut fruits such as apples or bananas, These reactions are usually very rapid at room temperature once the food is handled but are controlled in the natural state. The reactions can also occur in the frozen state unless the enzymes are denatured by blanching. Enzymatic reactions are also the major mode of deterioration of many refrigerated doughs, since the flour cannot be heat treated because it results in loss of dough functionality. Control of the enzymatic reactions is the same as was discussed for senescence.

Knowledge of how environmental conditions affect the rate of these reactions is very important in predicting shelf life—and thus for open dating. The major environmental factors are oxygen, water, pH, and temperature. Other enzymatic degradations include color losses and vitamin losses, such as loss of vitamin C in fresh produce.

Lipid oxidation. Many foods contain unsaturated fats that are important in the nutrition of humans. Unfortunately, these fats are subject to direct attack by oxygen through an autocatalytic-free radical mechanism that results in rancid off-flavors, making the food undesirable to consumers. Very little fat has to oxidize for the consumer to detect rancidity and reject a food, even though it may still be edible and nutritious. The free radicals and peroxides produced in this reaction can react and bleach pigments, such as in dried vegetables, if stored for a long time; can destroy vitamins C, E, and A; can result in protein degradation, thus lowering quality as may happen during storage of whole dry milk; can cause darkening of fat at high temperature, as happens in deep-fat frying; and can produce toxic substances during long storage that have been implicated in some animal studies as potential carcinogens.

Thus, knowledge of the rate of lipid oxidation is important in foods where it might be the principal mode of deterioration such as in:

- fried snacks (e. g., chips),
- nuts,
- dried meats/vegetables/f ish/poultry,
- cereals,
- wheat germ,
- frozen vegetables/mea ts/fish/poultry,
- some dairy products,
- semimoist meat products,
- precooked refrigerated meats and fish,
- cured meat and fish,
- coffee,
- cooking and salad oils,
- margarine,
- spices, and
- dried vegetables, such as potatoes and carrots.

Rancidity development can be controlled directly by eliminating oxygen (which is very difficult to do) and by adding antioxidants such as BHA, BHT, and EDTA. The rate of reaction also depends on temperature to some degree (rate increases two to three times for every 10° C increase in storage temperature for dry foods) and on water availability y or water activity (a_w). Foods if too dry or not dried enough are more subject to rancidity. For example, as potato chips gain or lose moisture, they become rancid faster. Moisture gain is more detrimental than loss. Light and trace metals (such as used in fortification) catalyze the reaction. Rancidity can also occur in the frozen state where it is more sensitive to temperature changes (rate increase of 6 to 10 times for a 10° C increase in temperature.)

A knowledge of the rate of these reactions can be used to predict shelf life and thus open date foods. Knowing how fast oxygen permeates a food package is also necessary to predict shelf life. In addition, the consumer must be instructed as to the extent and control of this reaction so as to better maintain the quality and nutritional value of the food in the home.

Nonenzymatic browning (NEB). NEB is another major chemical reaction leading to loss of quality and nutritional value. This reaction occurs between reducing compounds (such as glucose, fructose, and lactose) and amino acids or proteins. In addition, browning can result from heating sugars to very high temperatures (carmelization). In certain cases, the reaction is desirable such as in the toasting of bread: the crust formed in roasting meats; malting of barley for beer and spirits manufacture; and the production of syrups, molasses, and caramel candies.

Undesirable aspects of NEB lead to bitter off-flavors; darkening of light-colored dry products, such as nonfat dry milk; loss of protein volubility; toughening of protein foods; and, most significantly, a decrease in protein nutritional quality caused by the binding of an essential amino acid, lysine, in the reaction. NEB is a significant reaction leading to end of shelf life in processed proteins; dry milk and whey powders; dry whole eggs; dehydrated meat and fish; frozen meat, fish, and poultry; breakfast cereals; cake mixes; fortified pasta; intermediate-moisture breakfast bars and mixes; and some concentrated juices. In concentrated juices, ascorbic acid (vitamin C) acts as the reducing compound and results in loss of vitamin value as well.

The environmental factors that control NEB are temperature, pH, and a_w. NEB is more sensitive to temperature than is rancidity in dry foods, increasing four to six times in rate for a 10° C increase in temperature. In foods in which both browning and rancidity can occur, at high temperatures NEB predominates, while at low temperatures rancidity predominates. During processing, exposure time at high temperatures should be minimized, since it leads to excessive browning precursors that can shorten shelf life during subsequent storage. Lowering of pH slows browning but is not a desirable method of processing because of the flavor problem of added acid. The major control of browning is through control of the amount of a_w in the food in which the reaction can occur. The lower the water content, the slower the reaction rate for the foods mentioned above. However, very moist foods such as fresh or canned products brown slowly because the reactants are diluted by the high water content and thus there is a_w (0.6 to 0.8) at which point the food undergoes a maximum rate of browning.

With respect to open dating, knowledge of the rate of browning as a function of temperature and water content is very important in order to predict shelf life accurately. How fast a food package gains moisture will also significantly affect shelf life for these types of products.

Other chemical reactions. Other chemical reactions that can lead to food deterioration include the thermal destruction of vitamins such as vitamins A, B_1, and C; the effect of light on pigments such as the browning of meat and bleaching of chlorophyll; the effect of light on riboflavin; the direct oxidation of vitamin C; and the direct oxidation of carotenoid pigments. In every case, the effect of temperature, oxygen level, moisture content, and light must be known to be able to predict the rate of the reaction so that the time to reach the end of shelf life can be measured. Of importance in all these reactions is a decision as to what extent of deterioration is considered to be the end of shelf life. In many cases, this data must be correlated with actual organoleptic and sensory testing of the food so that the correct index of deterioration can be chosen.

Physical Deterioration

Physical damage can also lead to loss of shelf life. The types of physical damage can be classified into various categories, as was chemical deterioration.

Physical bruising/crushing. This mode of deterioration is related to physical abuse of the food in harvest, processing, and distribution. It is most important to fruits and vegetables, since physical abuse leads to microbial attack and decay. Packaging to prevent abuse is a key to long shelf life. With dry materials such as chips, crushing can lead to unacceptability based on consumer desires, This cannot be equated to open dating or loss of shelf life, but proper packaging and care can eliminate this problem.

Wilting. Fresh leafy and tuber vegetables can deteriorate if subjected to low relative humidity. Under these conditions, they lose moisture to the surroundings, resulting in loss of crispness and an increased rate of senescence reactions with subsequent quality and nutrient losses. Proper knowledge of the rate of moisture loss for various packaging materials and the maximum allowable moisture loss can be used as one means of setting open dates of use for fresh produce.

Moisture loss/gain. With some food products such as candy, semimoist pet foods, cakes, and bread, moisture loss leads to an increase in hardening. If a limit of hardness is known to be unacceptable, predictions of the time to reach this level based on equations that describe moisture change with time can be used as one method of predicting end of shelf life. From this, the open date for use can be set. Similarly, one can predict the moisture loss from flour, pasta, and similar dry products for which a natural loss of moisture occurs and a net weight limit is set for sale.

Some products that gain moisture have a textural limit at which they become too soft, such as potato chips, other dried or fried snacks, and crackers. In addition, some crystalline foods such as salt, brown sugar, convenience dry-meal mixes, dry coffee, dry teas, and dried drink mixes will gain enough moisture to become sticky and caked. Predicting shelf life, based on a gain of a critical amount of moisture, is possible if the temperature/relative humidity conditions are known as a function of time and the permeability of a package to moisture is known.

Temperature-induced textural changes. Temperature fluctuations per se can affect physical modes of deterioration. For example, the continuous rise and fall of temperature around a phase-change point leads to melting of fat and the subsequent deterioration of quality of some candies and formulated foods. In frozen foods, repeated thawing and freezing cause loss of tissue moisture and increased chemical reaction rates. If. the temperature fluctuation does not exceed the thawing point, package ice, caused by evaporation of the water from the food into the package space with subsequent freezing as ice crystals, can occur. This results in consumer unacceptability. In addition, if the water loss is significant from a particular surface region, freezer burn—an undesirable discoloration caused by enhanced chemical reaction— can occur. This also is unacceptable to the consumer. Finally, some temperature fluctuations can result in emulsion destabilization of products such as mayonnaise, margarine, salad dressings, and dessert toppings.

Knowledge of the sensitivity of these reactions to the degree of temperature fluctuation and a knowledge of the possible fluctuations occurring in distribution and in the home are needed in order to predict shelf life, In most cases, manufacturers formulate the product to withstand any abuse that may occur. Heating itself can also cause textural changes. In this case, the reaction is usually desirable as in the canning and/or cooking of vegetables, meat, fish, and poultry, Canning at high temperatures is usually undesirable for fruits as they lose their desirable crisp texture and develop a cooked flavor. However, these textural changes are usually not of concern in the storage deterioration of foods.

Staling. Staling is a mode of deterioration important in processed wheat flour products such as bread and cakes. The reaction is basically a crystallization of amylopectin, one of the major starches present in wheat flour. The rate is increased as temperature decreases—opposite to that of the chemical, enzymatic, and microbial reactions discussed earlier, Thus to prevent staling, the food must not be refrigerated. However, not refrigerating the food can lead to other reactions, causing loss of shelf life.

Chemically induced textural changes. As mentioned in the section on chemical deterioration, both lipid oxidation and nonenzymatic browning can result in breakdown of proteins, leading to toughening and an undesirable loss of shelf life. Control and prediction were discussed previously.

BASIC FOOD- PROCESSING PRINCIPLES

The previous section discussed the modes of food deterioration that lead to loss of shelf life and gave examples of prevention. In this section, the basic principles of the major food process methods are listed.

Use of Temperature

Heat preservation. The use of heat to preserve foods is based on the principles of:

- destruction of pathogens,
- destruction of spoilage microbes,
- denaturation of enzymes, and
- softening of tissues to make them more digestible.

Blanching, a food process, is the application of heat under mild conditions, or at high temperature for a short time, to achieve enzyme degradation, drive out oxygen, and soften food tissues. It is used as a preprocess step for canning, freezing, and drying to minimize quality and nutrient losses before the product is preserved.

Pasteurization is a mild heat treatment used to reduce the number of live micro-organisms in food so as to extend shelf life as well as to destroy key pathogens. A pasteurized product is not sterile, however, so some spoilage organisms can grow back and will eventually lead to spoilage. Pasteurization can also be accomplished at high temperature for a short time period, which results in the same reduction of microbes as under mild heat, but with less cooked flavor.

Canning is the process of heat treatment to destroy all organisms of pathogenic nature and most important spoilage organisms. The safety of the process is based on the time needed to reduce the population of *Clostridium botulinum* by a factor of l-million-million at the most heat-resistant point in the food, since this micro-organism is the most heat-resistant and most harmful pathogen. Not all of these types of organisms are killed, however, since some are more heat-resistant than is *Clostridium botulinum* but do not grow under normal canned-food storage conditions. If the food is subjected to high temperature (40° to 50° C), they will grow, causing the food to spoil. Processing to destroy these organisms will destroy the food quality. Because an adequate heat treatment is used, canned "commercially sterile" foods have lost some color: have lost 20 to 30 percent of some vitamins; have a cooked flavor; and have developed a softer texture. Subsequent deterioration is usually confined to chemical modes of decay that do not require oxygen, since the can is hermetically sealed.

Cold preservation. The basis of refrigeration and freezing is that the lower the temperature, the slower the rate of most deteriorative reactions such as senesence, enzymatic decay, chemical decay, and microbial growth. Microbes, in fact, usually cannot grow below - 5° to - 10° C so that freezing stops microbial growth. In some cases, lower temperature increases deterioration because the fracture of membranes releases degradative enzymes, which occurs in chill injury and freezing of some fresh fruits and vegetables. It has been found also that freezing to just below the freezing point of some foods increases deterioration by chemical reactions. This is because not all the water is frozen out and the chemicals are concentrated in the remaining water. Finally, in refrigerated foods, some microbes grow better at lower temperatures, since they can compete better against other spoilage micro-organisms and have a lower optimum growth temperature.

Control of Water Content

Concentration and drying. As water is removed from a food, less is available as a solvent and medium for the deteriorative reactions. Thus, most chemical reactions decrease in rate as the water content decreases. Unfortunately, in the process of removing water, the reactants first begin to concentrate so that the rate of reaction can initially increase. To prevent this, the temperature is kept low during the process, or the water removal is done rapidly enough to get through the danger zone. The degree of drying or concentration is best represented by a factor that describes the a_w in the food.

Figure B-1 depicts a typical moisture absorption isotherm that gives the relationship between moisture content (on a dry basis) and a_w. On a general basis, a significant amount of water must be removed to lower the a_w significantly below 1 (e.g., at 1 g H_2O/g solids or 50- percent water, the a_w. is still very close at 1.0). A_w can also be defined as relative vapor pressure or by ERH as defined in equation 1:

$$a_w = p/p_o = \%\ ERH/100 \tag{1}$$

where

p = the vapor pressure of water in the food

p_o = the vapor pressure of pure water at the same temperature of the food

% ERH = the percent relative humidity in equilibrium with the food at which it neither gains nor loses weight

Of consequence is the fact that for most foods in their natural state the a_w is high, and thus rates of many reactions including microbial growth are also high. In order to preserve the food, the a_w can be lowered by concentrating, drying, or by adding water-binding agents such as sugars and salt. The point on the isotherm of maximum stability is the BET monolayer value (m_o in figure B-1) which is at a low a_w. In general, the rates of most chemical reactions follow the pattern shown in figure B-2—that is, the rate of reaction increases above the monolayer value, reaches a maximum, then decreases again, Rancidity is unusual in that the rate increases again below the monolayer value.

Basically, as a_w is lowered, microbial decay is inhibited first, with bacteria being the most sensitive and molds the most resistant to lowered a_w. Browning, enzymatic activity, lipid oxidation, and nutrient loss also decrease as a_w decreases, with NEB showing a definite maximum rate at an a_w of 0.6 to 0.8.

Concentration is used basically as a preprocess step for foods such as frozen concentrated juices, concentrated canned soups, condensed sweetened milk, and in the preparation of a liquid concentrate that is to be spray-dried, such as for dry milk, dry coffee, dry tea, and some dry food supplements like yeasts. In these latter processes, preconcentration is used because it is a cheaper way to remove water than is drying. However, because of viscosity effects, not all water can be removed, so further drying is required. During concentration, the temperature is usually low, since a vacuum is used. Thus, a cooked flavor and nutrient losses are minimized.

In drying, heat is applied and the relative humidity surrounding the food is lowered so that the water will be evaporated from the food. To achieve both, the air passing over the food is warmed, supplying the energy to remove the water and lowering its humidity. Solid piece materials like vegetables for soup mixes are dried in an air tunnel at 50° to 65° C for 4 to 8 hours. Slurry material like potatoes are dried in thin

Figure B-1 .—Moisture Content v. Water Activity

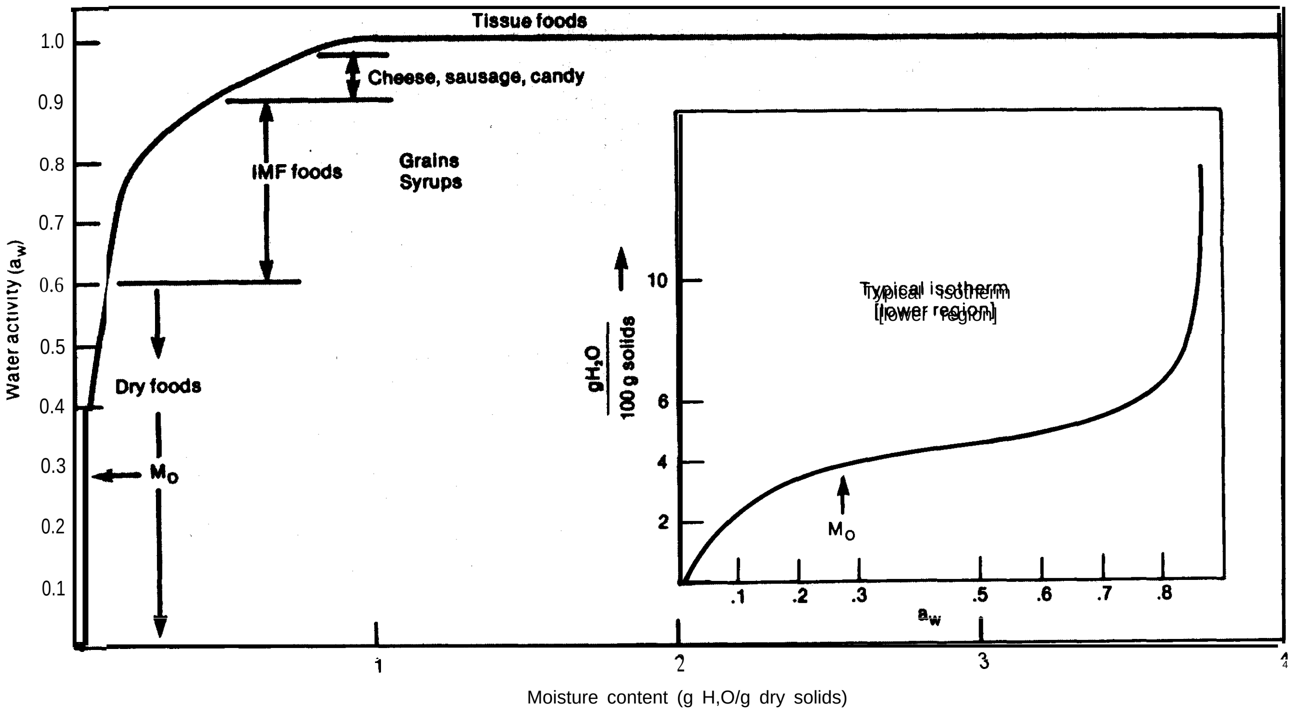
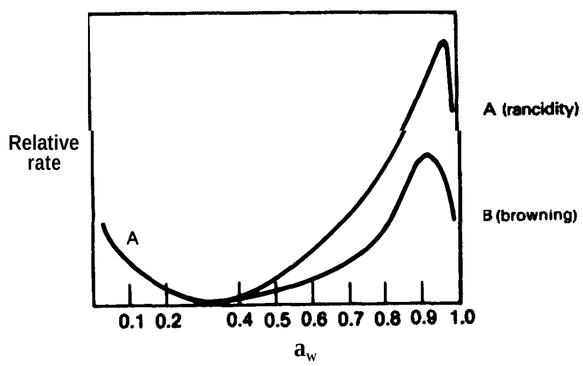


Figure B-2.— Effect of a_w on Rate



layers on hot rotating drums (I ZOO to 1400 C) in 2 to 3 minutes. Although the latter process is at a higher temperature, since it is shorter in time, less quality and nutrient damage takes place. Concentrated liquids can be dried by spraying into a vertical tower through which air at 2o0° to 250° C is passed. In this case, drying occurs in 3 to 20 seconds, so very little damage takes place. Freeze-drying creates the least damage, since it is done at low temperatures in a vacuum. In each case, the principle is to lower the water content and thus the a_w to a level such that during storage, reactions proceed at a very slow rate. The optimum for most foods is at the predicted monolayer value.

It is thus imperative that good packaging be used to prevent the chemical reactions described above, to prevent moisture gain to the point of microbial growth, and to prevent any physical changes caused by moisture gain. If the product contains unsaturated fat, it must also be vacuum packed or nitrogen-flushed to slow the reaction. The rate of oxidation does not drop as much as desired at low oxygen pressure, but the lowering of total oxygen availability limits the overall extent of the reaction. Antioxidants actually have a much better effect on limiting the reaction but may not be able to be incorporated into all dry foods, In some cases like cereals, the antioxidants are lost in the baking process, so they are added into the packaging material.

Humectant use. Rather than removing water by drying, the ability of the water present in foods to act as a medium and solvent can be reduced by adding water-binding agents (humectants) to the food. All dry food solid components have this ability, but the lower the molecular weight, the better the a_w-lowering effect. The common agents used are called humectants. Sugars and salts are such agents, having in fact been used as ancient preservation processes in fermentation, salting, and sugar curing. Addition of sugar or salt in these curing processes is required to lower the a_w to a level below which pathogens and/or spoilage microbes cannot grow, and in the case of fermentation to allow the desirable microbes to grow.

Control of pH by adding acid and growth inhibitors such as antimycotics may be used in conjunction with the humectants where fermentation is undesirable. The result is a shelf-stable food that does not require refrigeration. Common examples are the intermediate-moisture pet foods, confectioneries, some bakery goods, and breakfast tarts. These foods are subject to chemical deterioration because of the high a_w and to moisture loss if left in a dry environment,

Extrusion. Extrusion is a process utilized for many cereal foods, dry snacks, dry animal food, and semimoist pet foods. In this process, a dough is made which is then passed at high pressure by screw action through a cylinder that is heated. The heat causes the components to interact, giving the desired flavor, color, and texture, and as the product releases from the screw, the internal steam in the paste expands and flashes off, This results in further textural changes and drying of the product. In some cases, further air-drying may also be used. Packaging requirements and deterioration mechanisms are similar to that described for dry foods. Of significant importance is moisture gain that can result in a soft, undesirable texture.

Other methods. Deep-fat frying is a drying process in that the hot oil provides the heat to evaporate off the water. In this process, the oil replaces the water in the pores of the food. In baking, the hot air in the oven serves as the drying medium—the longer the baking time, the lower the final moisture of the product. Freezing also can be considered as a drying process; however, the liquid water is converted into a solid that becomes unavailable, It should be noted that for most foods, about 20 to **30** percent of the water is still unfrozen at – 200° C. Therefore, reactions are not stopped by freezing; they are only slowed down due both to lower a_w and low temperature,

Chemical Preservation

Fermentation. Fermentation is one of the oldest of the known food processes. In this method, a desirable organism is allowed to partially convert some of the carbohydrates of the food material into acid, alcohol, and flavor compounds. This can be done naturally by changing the environment, especially the a_w, of the food so that the desired organisms can grow (for example, adding salt to cabbage which inhibits spoilage but allows desirable bacteria to grow). Industrially, a starter culture of the desired organism is usually added to ensure that proper fermentation takes place. The basic principle of the process is to allow the formation of desirable chemicals, such as flavor components and acids or alcohol, the latter of which prevents the growth of undesirable spoilage or pathogenic organisms. The shelf life of fermented foods is limited by the growth of the desired organism. In some cases, further processing is done such as in pasteurizing beer, wine, and vinegar, or the product is kept refrigerated such as in yogurt and cheeses.

Additives. Chemical additives can be used to preserve and/or prolong the shelf life of foods. Each has a specific action by which it operates, The various classes are listed below.

- Acids, such as citric and phosphoric acid. These lower the pH and inhibit undesirable microbes as well as slow undesirable enzymatic and chemical reactions. Acids also contribute to flavor,
- Humectants, such as salt, sugar, and glycerol. These bind the water present, lowering the a_w, and thus reduce the rates of microbial growth, enzymatic activity, and chemical reactions.
- Smoking of foods. This process deposits chemicals from the smoke of burning wood chips onto the surface of foods that inhibit microbial action. The heat also destroys some of the microbes. Because of potential toxicity problems, most manufacturers today use a liquid smoke product from which toxic components have been extracted.
- Metabolic inhibitors, such as calcium propionate and sodium benzoate. These are chemicals that take action against specific types of microbes. They are used where further processing of the food results in undesirable

quality and nutritional changes. Gases can also be used as chemical sterilants and to kill organisms in grain. Ethylene oxide is an example as is chlorine applied in a solution to the surface of fresh meat.

- Anticaking agents, such as the silicates. These are high water-binding agents used in dry-powdered or crystalline foods to prevent caking by selectively binding the water.
- Antioxidant, such as BHA and BHT. These act in the lipid oxidation reaction to slow the rate and thus extend shelf life.
- Chelating agents, such as EDTA and citric acid. These chemicals tie up trace metals to prevent them from catalyzing undesirable reactions such as rancidity.
- Others. Other chemicals such as calcium salts are used to prevent softening of fruits and vegetables during the canning process. Sodium polyphosphates help to hold water in cured and canned meats. Sulfite not only inhibits microbes but slows down enzymatic browning reactions. Some additives are used for mainly esthetic purposes to enhance or restore those flavors or colors lost during normal preservation or for manufacture of engineered foods. Finally, nutrients can be added to restore those lost during preservation.

Separation

Separation processes are used to either create new foods or ingredients, such as making butter out of milk or to transform a raw food into a more digestible or more stable form. Making flour from wheat is an example of the latter. There are many different processes that incorporate in general those methods already discussed above. For example, in the manufacture of instant coffee, the bean is fermented, ground, roasted, leached to form a liquid (the separation step), concentrated, then spray-dried and packaged. The shelf life of the product would depend on the effects of each step.

Gas Atmosphere Control

The shelf life of many fruits and vegetables depends on the rate of respiration after harvest which uses up the stored energy. This rate can be reduced by reducing the oxygen or by increasing CO_2. The methods are generally classified as CA Storage (Controlled Atmospheric Storage) and include:

- reduction and control of O_2 by use of nitrogen,
- hypobaric storage by pulling a vacuum either in a large truck or in a pouch, and
- use of both increased nitrogen and increased CO_2 in the headspace.

CO_2 can also be injected into the headspace of dairy and meat packages to reduce microbial growth and increase shelf life. Vacuum-packaging with CO_2 injection is used to enhance shelf life of poultry products, Overall, shelf life in these cases depends on the degree of maturity after harvest, and temperature and permeability of the package to oxygen and CO_2.

DISTRIBUTION HAZARDS

Once a food is preserved and packaged, it is not stable forever. Each food system slowly decays or deteriorates to the point where it is unacceptable. One goal of open dating could be to give consumers information as to the shelf life of the product so that it is consumed before it is unacceptable. The loss of acceptability, however, may not mean the product is inedible—it only means that the established consumer quality unacceptability standard has been exceeded. The problem is therefore twofold: 1) setting a standard for unacceptability and 2) determining or predicting the loss that occurs from point of distribution to point of consumption.

Data on actual shelf-life modes and shelf life of various products based on some endpoint standards have been collected and are in the main data base part of this study. Appendix C discusses the second problem—that is, based on environmental factors, how can one predict changes in shelf life. The important environmental influences include:

- temperature—increasing, decreasing, fluctuating:
- moisture (relative humidity)—gain, loss;
- oxygen level; and
- light.

Appendix C

Technological Evaluation of Shelf Life of Foods

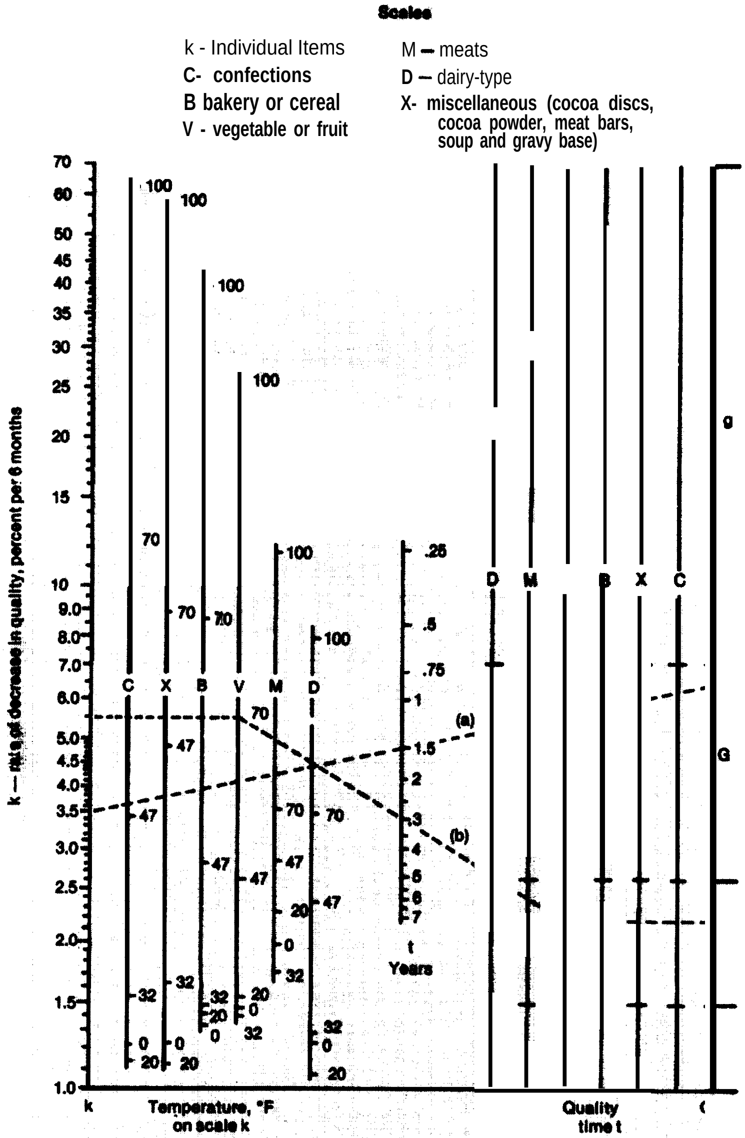
INTRODUCTION

Appendix B covered the major modes of deterioration and the principles of processing foods. It can be concluded from that appendix that one of the major environmental factors resulting in increased loss of quality and nutrition for most foods is exposure to increased temperature. The higher the temperature, the greater the loss of food quality. Thus, in order to predict the extent of high-quality shelf life so as to be able to put a shelf-life date on a product, a knowledge of the rate of deterioration as a function of environmental conditions is necessary.* Coupled with this would be the need for knowledge of the actual environmental conditions to which the various classes of foodstuffs are exposed.

Basically, for each food item, each mode of deterioration was studied at several temperatures for up to 3 years. In addition, information as to temperatures in warehouses, boxcars, etc., was gathered. Many reports and tables resulted from the study. However, much is not applicable today because the various types of foods are processed differently, different packaging systems are used, the distribution system has changed, etc. Nevertheless, one interesting outcome of the report was a nomograph {figure C-1), which gives the prediction of quality for various food classes based on some rate of deterioration and a desired shelf life. What this graph says is that given a certain rate of loss, if it is constant, one can predict the amount of change. Unfortunately, this simple method is not correct for many foods and for many modes of deterioration such as nutrient loss, color change, and flavor change. This appendix covers the basic principles of how temperature and other environmental factors affect the rate of food deterioration and how this can be used to predict the sell-by, best-if-used-by, or use-by date. These methods are not needed for a pack date.

*The U.S. Army supported some major studies during the late-1940's through 1953 to gain this information for the military food supply. The studies are summarized in S. R. Cecil<s and J. G. Woodroof's (1962) "Long Term Storage of Military Rations"' (Ga. Exp't Station Tech. Bull. 25).

Figure C-1 .—Nomogram of Temperature, Time, and Quality for the Military Ration Items Used in the Long-Term Storage Tests



Use of the nomogram (as illustrated by dotted lines):

(a) The k values given for storage of individua tems (figures 9-60) may be used with scales k, t, and Q_k. For example, a k value of 3.5 percent per 6 months resulted in a quality level in the upper range of "good" after 1.5 years of storage, as shown by the point at which the Q_k scale is intercepted by a straight-edge passing through 3.5 on the k scale and 1.5 on the ' scale.

(b) The scales for types of products are used in matched pairs. For example, vegetable or fruit products stored at 70°F (corresponding to an average k value of 5.5 as shown) for 3 years had an average quality rating in the upper range of "fair, since the V scale quality is intercepted at this level by the line passing through 70 on the V temperature scale and 3 on the t scale.

PRINCIPLES FOR THE RATE OF LOSS OF SHELF LIFE

General Rate of Loss of Quality Equation

The loss of food quality for most foods can be represented by mathematical equation 1:

$$\text{rate} = \frac{dA}{d\theta} = kA^n \qquad (1)$$

where:

A = the quality factor measured
θ = time
k = a constant that depends on temperature and water activity
n = a power factor called the order of the reaction, which defines whether the reaction rate is independent of the amount of quality left
$\frac{dA}{d\theta}$ = the rate of change of A with time. A negative sign is used if the deterioration is a loss of A and a positive sign if it is for production of an undesirable end product

Usually, results of shelf-life studies are not obtained as a rate but rather as the amount of A left or produced as a function of time.

Constant Loss of Shelf Life

Based on equation 1, much of the food literature assumes (without truly measuring it) that the value of $n = 0$. This assumption, called a zero-order reaction scheme, then implies that the rate of loss is constant with time as shown in equation 2 for some constant temperature.

$$\text{rate of loss} = \frac{dA}{d\theta} = k = \begin{matrix}\text{constant at some}\\ \text{constant temperature}\end{matrix} \qquad (2)$$

What equation 2 means is that the percent of shelf life lost per day is constant at some constant temperature. This is the assumption used in the nomograph of figure C-1. Mathematically, if equation 2 were integrated, the amount of quality left with time as a function of temperature becomes equation 3:

$$\text{amount left } (A) = \text{initial amount } (A_o) - k\theta \qquad (3)$$

In terms of shelf life, this becomes equation 4:

$$\theta_s = \frac{A_o - A_e}{k} \qquad (4)$$

where:

A_o = initial (zerotime) value of quality factor
A_e = value of A at end of shelf life (could be zero or any other defined value as measured in a consumer test)
θ_s = shelf life in days, months, years, etc

In many cases, A_c is not a very quantifiable, chemically, or measurable value and must be based solely on human panel evaluation. In this case, A_o is assumed to be 100-percent quality and A_e is just unacceptable quality, Thus, the rate of deterioration becomes the rate constant in equation 5:

$$\text{rate of quality loss} = k = \frac{100\%}{\theta_s} = \begin{matrix}\text{constant \% loss}\\ \text{per day}\end{matrix} \qquad (5)$$

This is the assumption used in figure C-1. Technically, the major problem in shelf-life testing is to verify that indeed n = O so that equation 4 or 5 can be used. This is not easy to do, although some modes of deterioration are directly applicable to zero-order kinetics. These include:

- Enzymatic degradation (fresh fruits and vegetables, some frozen foods, some refrigerated doughs);
- Nonenzymatic browning (dry cereals, dry dairy products, dry pet foods, and loss of protein nutritional value); and
- Lipid oxidation (rancidity development in snacks, dry foods, pet foods, frozen foods).

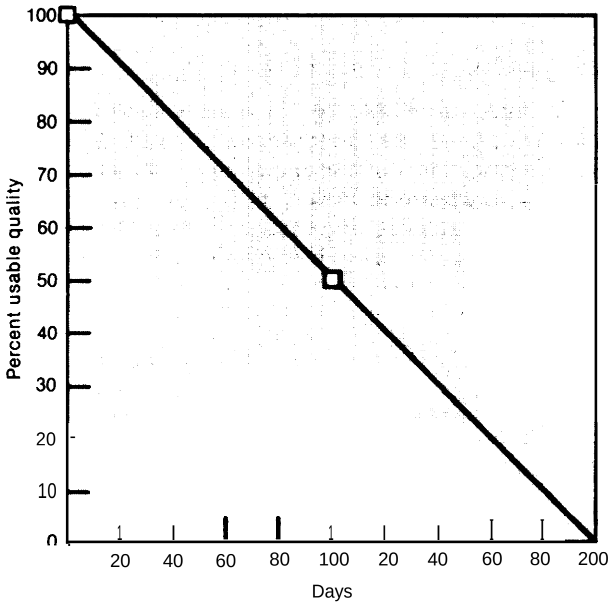
Based on this knowledge, one can predict the shelf life of a food at a given single temperature if the amount of loss at any time is known, For example, if it is known that a certain food has lost 50 percent of its quality in 100 days if held at some constant temperature, then:

$$k = [illegible] = [illegible] = \frac{50}{100} = 0.5\% \text{ per day}$$

Based on this, we could construct figure C-2 which gives the shelf life left as a function of time (k is the slope of the line). As seen at 40 days, there is 80-percent shelf life left: at 160 days, there is 20 percent left: etc.

The main problem in establishing this graph is determining the criteria of what is to be measured. That is, what is A or how much of A must be lost to give an end of shelf life as perceived by the consumer. It must be noted that shelf life is not a function of time; rather, it is a function of the environmental conditions and the amount of quality change that can be allowed. The second problem is that since food distribution occurs at variable temperatures, this data must be collected at sev-

Figure C-2.—Constant Shelf Life Lost



eral temperatures to be useful, Methods to apply this graph to variable conditions are described later,

Quality-Dependent Shelf-Life Loss Function

As discussed above, the shelf life in many cases does not follow a simple constant rate of deterioration. In fact the value of n can range for many reactions from zero to any fractional value or whole value up to 2. In fact many foods that do not deteriorate at a constant rate follow a pattern where n = 1, which results in an exponential decrease in rate of loss as the quality decreases. This does not necessarily mean that the shelf life of foods that follow this scheme is longer than those with a constant loss rate, since the value of the rate constant is very important. Mathematically, the rate of loss is, as shown in equation 6:

$$\text{rate of loss} = \frac{-dA}{d\theta} = k(A) \qquad \textbf{(6)}$$

Integrating equation 6 gives a logarithmic function as shown in equation 7:

$$\ln \frac{A}{A_o} = -k\theta \qquad (7)$$

where
A = amount of quality left at time θ
A_o = initial quality
k = the rate constant in units of reciprocal time

A graphical representation of the amount of quality left as a function of time is not a straight line as illustrated in figure C-3. If 50 percent is lost in 100 days as in the previous example, then at 40 days, there is 76 percent of the quality left. For a constant rate of loss, there would be 80 percent left, At 100 days, both mechanisms give the same percent left, but after this time, the quality loss slows down for the exponential mechanism and theoretically never reaches a zero value, For example, at 160 days, there is 33 percent left, and at 300 days, there is still 12.5 percent left. The types of deterioration that follow an exponential equation include:

- rancidity (in some cases, as in salad oils or dry vegetables);
- microbial growth (fresh meat, poultry, fish, and dairy products);
- microbial death (heat treatment and storage);
- microbial production of off-flavors, slime, etc. (fresh meat, poultry, fish, and dairy products);
- vitamin losses (canned, semimoist, and dry foods); and
- loss of protein quality (dry foods).

Another way of representing exponential decay in figure C-3 is to plot it in semilog as in figure C-4. The slope of this line is the rate that is constant at constant temperature. Typically, for exponential decay mechanisms, the rate constant can be represented by 0,,, which is called the half life. Mathematically, if one knows the amount of deterioration at any time at some constant temperature and if it follows a first-order reaction, figure C-4 can be easily constructed.

Figure C-3.—First-Order Degradation

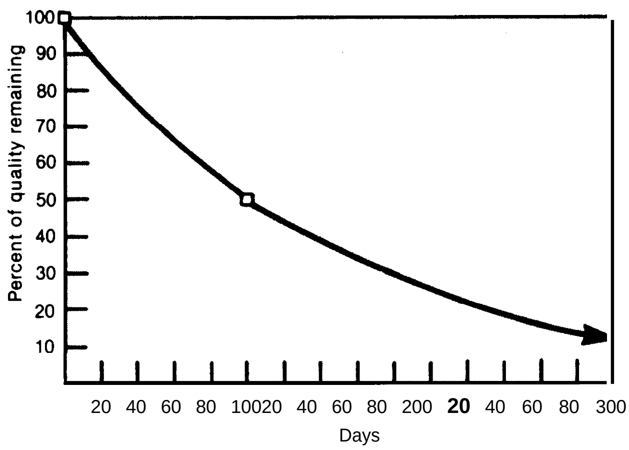
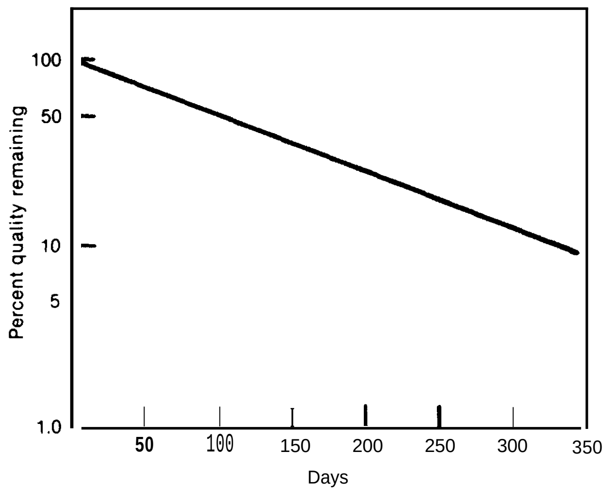


Figure C-4.— First-Order Log Plot



Other Mechanisms of She9f-Life Loss

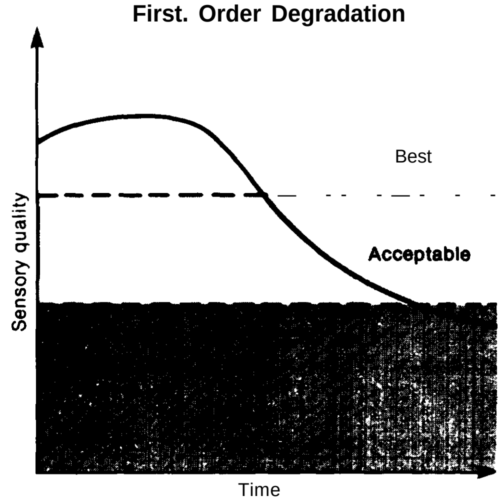
Very little data exists that describes food deterioration by orders other than zero or first. Lee et al. (J. Food Sci. 42:640, 1977) and Sing et al. (J. Food Sci. 41:304, 1976) have described the deterioration of vitamin C in liquid foods such as tomato juice or canned infant formulas by a second-order reaction. In this case, the reaction is dependent on both ascorbate and oxygen—as the oxygen is depleted, the rate of loss of ascorbate becomes less than that predicted by a first-order reaction,

Labuza (Critical Rev. Food Tech. 3:355, 1971) has reviewed the area of lipid oxidation kinetics and has found that oxygen uptake generally follows a half-order reaction with respect to oxygen for relatively pure lipids. However, addition of antioxidants changes the order to first order. In complex foods, however, the data best fit zero-order kinetics.

When sensory quality change is plotted against time, not infrequently the axiom "fresh is best"' is violated. For example, Kramer et al. (J. Food Qual. 1:23, 1977) found an improvement in sensory quality of certain prepared frozen foods after frozen storage for 3 months. After 6 months of storage, sensory quality began to deteriorate and continued by approximately a first-order reaction. The entire curve, however, could best be fitted as a cubic polynomial. Similar results were obtained with reportable-pouch packed items by Salunkhe and Giffee (J. Food Qual. 2:76, 1978). A typical curve for this type of response is shown as figure C-5.

Such sensory responses can be explained on the basis of psychophysical characteristics inherent in sensory evaluations. They do not contradict the above general principles of the kinetics of shelf-life loss. All that is indicated is that consumers prefer (best) what they are accustomed to, which is not always the freshest product. Thus, in the case of preference for 3-month-old frozen foods, the reason was that the products were initially overspiced and reached an optimal flavor blend and intensity after 3 months' storage. In the case of the pouch/canned products, consumers preferred products that were slightly degraded over the fresh. These not-unusual sensory responses indicate first the great difficulty in attempting a generalized prediction equation for shelf life and the need to study each product individually. They also indicate that freshest is not always best, although open dating is predicated on the assumption that consumers are convinced that freshness and sensory quality are the same.

Figure C-5.—Initial Quality Gain Prior to First. Order Degradation



TEMPERATURE DEPENDENCE OF RATE OF DETERIORATION

The above analyses of loss of quality were derived for a constant temperature situation. The temperature-dependent part of the rate of loss equation is the rate constant k. Theoretically, it obeys the Arrhenius relationship which states that the rate constant (or rate) is exponentially related to the reciprocal of the absolute temperature. A plot of the rate constant on semilog paper as a function of reciprocal absolute temperature (l/T) gives a straight line. A steeper slope means the reaction is more temperature-dependent—that is, as the temperature increases, the reaction is faster, It is possible that food can deteriorate by two different mechanisms with different temperature dependencies. For example, dry potatoes can go rancid and can become brown. The rates of each would have different temperature functions. What this means is the dominant mode of deterioration could change with increasing temperature to the faster reaction. This could be a problem in predicting shelf life,

Most data for modes of deterioration in the literature do not give rates or rate constants but rather are in the form of overall shelf life as a function of temperature, Mathematically, if only a small temperature range is used (no more than 20° to 400 C range), the data will give a fairly straight line if the shelf life for some quality measurement is plotted on semilog paper as a function of temperature as in figure C-6, This figure illustrates the temperature sensitivity of two foods or two modes of deterioration, both giving a shelf life of 200 days at 25° C. Theoretically, to construct this plot one needs: 1) some measure of loss of quality, 2) some endpoint value for consumer unacceptability, 3) data to measure the time to reach this endpoint, and 4) experiments to measure this loss for at least two temperatures so the line can be constructed. The more temperatures used, the better the statistical significance of the data.

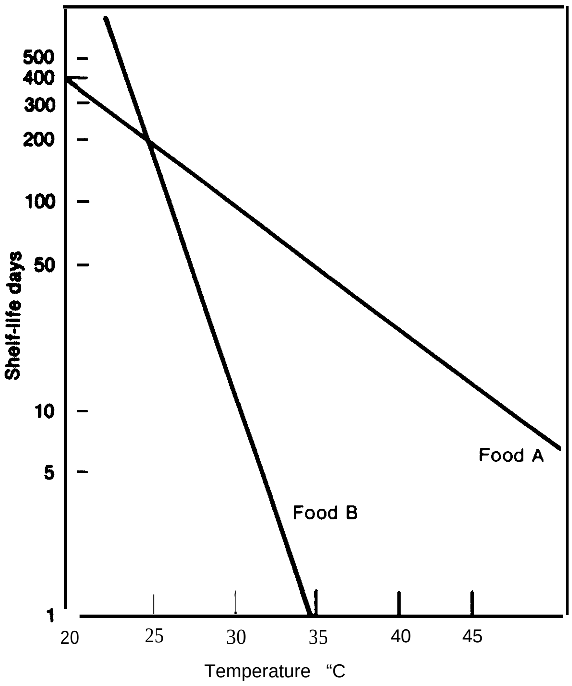
It is obvious from the graph that the steeper the slope, the more sensitive is the food (or the reaction) to temperature. A measure of this sensitivity is called the Q_{10} of the reaction that is defined in equation 8:

$$Q_{10} = \frac{\text{rate of loss of quality at temperature } (T + 10°C)}{\text{rate of loss of quality at temperature } T\,°C} \qquad (8)$$

The Q_{10} can also be calculated from the shelf-life plot as in equation 9:

$$Q_{10} = \frac{\text{shelf life at } T°C}{\text{shelf life at } (T + 10°C)} \qquad (9)$$

Figure C-6.--Shelf-Life Plot



which assumes that the rate is inversely proportional to the shelf life.

As an example from figure C-6, it can be calculated that for food A, the Q_{10} is:

$$Q_{10} = \frac{\theta_s \text{ at } 25° C}{\theta_s \text{ at } 35° C} = \frac{200}{50} = 4$$

For food B, the Q_{10} is:

$$Q_{10} = \frac{800}{3} = 266$$

Thus, food B or reaction B is much more sensitive to an increased temperature than is A.

This graph has practical applications in studying loss of shelf life. To illustrate, if studies at two different temperatures are made, the shelf life at some lower temperature can be predicted if the line is assumed to be straight. One cannot, however, study the deterioration at only one temperature, since it is not possible to predict beforehand the shape of the line or the Q_{10} exactly. Table C-1 illustrates how important the Q_{10} would be in predicting shelf life at lower temperatures. It should be noted that since different reactions may occur at different temperatures to cause end-of-product acceptability, the projected line might be incorrect. For example, in figure C-6, reaction B would cause end of shelf life in 12 days at 30° C, but below 25° C, reaction A is faster and thus would be the controlling factor in end of shelf life if the figure referred to two major deterioration modes of a single food item.

Table C-1 .—Weeks of Shelf Life at a Given Temperature for Given Q_{10}

Shelf life at	Q_{10}: 2	2.5	3	4	5
50° C	2	2	2	2	2
40° C	4	5	6	8	10
30° C	8	12.5	18	32	50
20” C	16	31.3	54	2.5	4.8

SHELF-LIFE Prediction FOR VARIABLE TEMPERATURE

Given that data as to the mathematical representation of the reaction causing end of shelf life can be obtained and a shelf-life plot constructed, some simple expressions can be derived to predict the extent of deterioration as a function of variable time/temperature storage conditions. From this, either a use-by date can be calculated or a sell-by date evaluated in which some shelf life left for home storage is figured in.

Zero-Order Reaction Prediction

For zero order, the expression is as follows in equation 10:

$$\text{amount left (A)} = \text{initial amount } (A_o) - \sum_{i=o}^{i=n} k_i\theta_i \qquad (10)$$

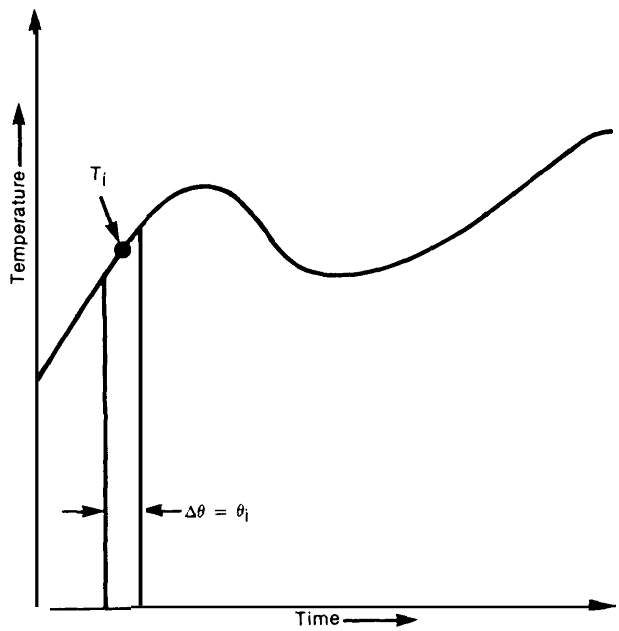
where

$\sum_{i=o}^{i=n} k_i\theta_i$ = amount lost in variable period which is equal to the sum of the product of the rate constant (k_i at each given temperature T_i) times the time interval (θ_i) at the average temperature T_i for the given time period $\Delta\theta$. (The whole sequence being broken into n segments of time.)

If the time/temperature history is broken up into suitable time periods as illustrated in figure C-7, the average temperature in that time period can be found. The rate constant for that temperature is then calculated from the shelf-life plot using a zero-order reaction, and this rate constant is multiplied by the time during the period. These then are added up to get the amount lost for a total of n segments.

If shelf life is based simply on some time to reach unacceptability. equation 10 can be simplified to give equation 11:

Figure C-7.—Temperature/Time History



$$f_c = \text{fraction shelf-life consumed} = \sum_{i=o}^{i=n} \left(\frac{\theta_i}{\theta_s}\right) T_i \qquad (11)$$

This equation says that the fraction of shelf life lost for holding the product at some temperature is equal to the time (θ_i) held at that temperature divided by the total time (θ_s) a fresh product would last if held at that temperature.

To employ this method, the temperature history is divided into n suitable time periods; the average temperature T_i at each time period is evaluated; the time held at that temperature θ_i is then divided by the shelf life θ_s for that given tempera-

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ture. The fractional values are then summed up to give the total fraction of shelf life consumed. The time left at any storage temperature at which the consumer may hold the product is the fraction of shelf life remaining ($1 - f_c$) times the shelf life at that storage temperature from the shelf-life plot.

The U.S. Department of Agriculture (USDA) developed this method, referred to as TTT, or time/temperature/tolerance method (Conference of Food Quality, Nov. 4, 1960, USDA Agr. Res. Service, Albany, Calif.). Extensive references to its use can be found in the literature. For example, Gutschmidt (Lebensmittlen Forschung und Technol. 7:137, 1974) applied this to storage-life prediction of frozen chicken with excellent results, It must be remembered, however, that this only applies for reactions with a zero-order deteriorative mechanism—a constant rate of loss at constant temperature.

Zero-Order Shelf-Life Devices-Present Technology

A device that can be attached to a frozen food package to integrate time/temperature exposure in the manner discussed above has been developed (Kockums Chemical Company, Biomedical Science Division, Reston, Va.), Unfortunately, the device (i-point TTM) can only be used for reactions with the same temperature sensitivity or Q_{10} if shelf life is to be predicted. Those available in 1977 were i-point #1 Q_{10}= 140; i-point #2 Q_{10}= 6; i-point #3 Q_{10}= 36. These devices could be used, however, to evaluate abuse during storage, and modifications can be made to get other Q_{10}'s.

The i-point device is based on an enzymatic reaction that is activated by breaking a seal which mixes the enzyme with a substrate. Color changes that occur with the subsequent reaction can indicate the days of shelf life left or the extent of degradation. Unfortunately, these devices have temperature responses that change above about − 10° C, resulting in a different Q_{10} (of about 2.2). They also have very rapid response times above + 10° C, so they cannot be used for foods with long shelf life (e.g., dehydrated foods).

The present cost of these devices prohibits their use on individual packages, but they can be put on cases or pallets to evaluate abuse conditions, Of course, if they are on the outside of a food carton, they will respond to temperature change more rapidly than does the bulk of the food, so the predicted shelf life would be less than the period of time the food could actually last.

A different device using the gas diffusion principle, which also integrates time and temperature, is available (Info-Chem, Fairfield, N.J.). After activation, a gas crosses a permeable barrier in the device to react with another chemical, causing a color change along a scale. The barrier property controls the temperature sensitivity. The Q_{10}'s are: TTW^{-10} Q_{10}= 1.68; TTW^{-15} Q_{10}= 2.29; TTW^{-20} Q_{10}= 2.88; and TTW^{-25} Q_{10}= 4.03.

A factor limiting the use of these latter devices is that they respond much too slowly at temperatures below freezing, so they probably cannot be used for refrigerated frozen foods. Even at 4° C, the devices all have a response life of 750 days. If the reaction rate were faster or the indicator was made more sensitive, they could be especially useful for very sensitive refrigerated pharmaceuticals to indicate if the drugs have been abused by holding at high temperatures. However, the devices are applicable for semiperishable foods with a shelf life of 30 days to 1 year at 15° to 38° C.

Other devices are available that integrate time and temperature but have much shorter response times. The 3-M Company (Minneapolis, Minn.) and Tempil Company (South Plainfield, N. J.) have developed abuse temperature/time integrators. These devices use the melting-point principle in which a waxy material melts at a given response temperature and is absorbed by a wick that develops a color along a visible scale (much like a thermometer) as long as the device is held above this critical response temperature. The device does not integrate absolute shelf life as the other devices: rather, it integrates exposure to some temperature above a set limit. This, however, is useful if the product has a very high Q_{10} (i.e., the food is very sensitive to high temperature). The devices are also useful for products with a shelf life of less than 1 week.

Several studies in the past have been made to test the reliability of these time/temperature integrators (K. Hu, Food Technology, August 1972; K. Hayakawa, ASHRAE J., April 1974; C. Byrne, Food Technology, June 1976; and A. Kramer and J. Farquhar, Food Technology, February 1976). In essence, they have found that many of these indicators become unreliable if they are exposed to high temperature prior to activation. In addition, the response characteristics in many cases do not match manufacturers' specifications.

Since these studies were published, the indicators have been modified, so performance may be better although there is nothing available in the scientific literature, However, the major problem is still to develop an indicator that exactly matches the Q_{10} for the food if it is to be used on an individual food package to indicate amount of shelf life left. The Australians have devised such an indicator that has the capability of electronically setting the exact Q_{10} desired (J. Olley, Int'1 Inst. of Refrigeration, Australian National Committee, Joint Meeting of Commissions, Melbourne, Australia, September 1976). The device is useful as a research tool for monitoring a distribution system but is not practical for everyday use on packages. The significance in stimulating further development of shelf-life devices is that they could give the shelf life directly and would be a major benefit to the consumer.

Exponential Decay Shelf-Life Prediction

As with the mechanism measuring the constant loss of shelf life, an equation can be developed to predict the amount of shelf life used up as a function of variable temperature storage for foods that decay by an exponential mechanism. Equation 12 is:

$$A = A_0 e^{-\sum_{i=0}^{n} k_i \theta_i} \qquad (12)$$

where A is the amount left at the end of the time/temperature distribution, and $k_i\theta_i$ is as was discussed for the constant-loss equation. Unfortunately, there are no reports in the literature for testing the validity of this equation in the measurement of shelf life as has been done for constant loss rates for frozen foods. However, application of this equation to the calculation of quality losses, nutrient destruction, and microbial death during the thermal processing of canned foods has been successful (M. Lenz and D. Lund, J. Food Sci. 42: 989, 1977; J. Food Sci. 42: 997, 1977; and J. Food Sci. 42: 1002, 1977). Therefore, there is no reason to believe that this equation and approach is not applicable to predicting storage life of foods.

Currently there are no devices that have a first-order response, and the zero-order devices mentioned above should not be used for a food which decays by first order unless the extent of reaction which terminates shelf life is only a small fraction of the total reaction that can occur, Further research is needed in this area.

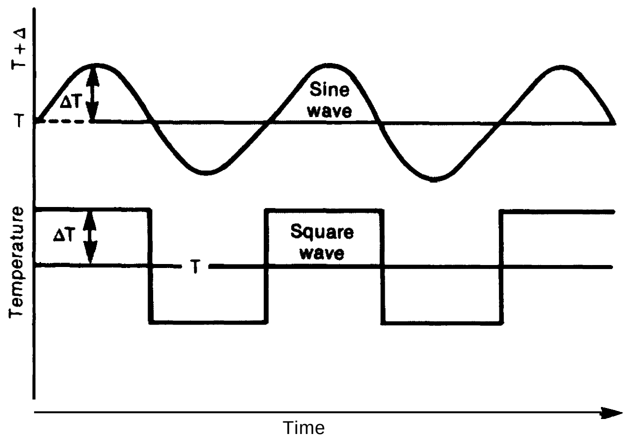
Sequential Fluctuating Temperatures

In some cases, a product may be exposed to a sequential regular fluctuating temperature profile, especially if held in boxcars, trucks, and certain warehouses. This is because of the daily day/night pattern. Many of these patterns can be assumed to follow either a square-wave or sine-wave form as shown in figure C-8. The amount of deterioration occurring in this storage sequence can be calculated by the formulas previously presented if the proper order of reaction is used.

There have been some papers published that have developed formulas for calculating the amount deteriorated for either square-wave or sine-wave functions. The classic papers have been by Hicks (J. Coun. Sci. Ind. Research, Australia 17:111, 1944), Schwimmer et al. (Eng. Chem. 47:1149, 1955), and Powers (J. Food Sci. 30:520, 1965). Although not stated exactly in these papers, the derivations they presented were all for zero-order reactions. Unfortunately, subsequent work by some researchers has unknowingly used these equations for predicting changes that occur for first-order reactions such as microbial growth and vitamin C degradation. Recently, Labuza (J. Food Sci. 44, 1979) has derived the applicable functions for exponential reactions, but they have not been tested as of yet.

It also should be noted that using the mean temperature for either the sine or square wave to predict the loss that occurs does not give the same results as the actual amount of degradation. This is because the shelf life (or the reactions causing it) are exponentially related to temperature; thus the actual amount of degradation is always more.

Figure C-8.—Sequential Regular Fluctuating Profile



Based on this, the reaction can be assumed to be occurring at some effective temperature that is greater than T mean. In the same paper Labuza (1979) has derived the necessary equations.

Other Temperature Effects

Two other phenomena can occur in foods as a function of temperature that lead to loss of shelf life—namely, staling and phase change. Staling is a process which occurs in bakery items and is related to the crystallization of starch components. In staling, the rate of loss of shelf life increases as temperature decreases. The kinetics are exponential in nature with a Q_{10} of around 2 to 3. For a recent review of staling, see W. Knightly, Bakers' Digest, No. 5, 51: 52, 1977.

A second area is that of phase change including thawing, freezing, and fat-melting—solidifying phenomena. Although no mathematical models can be developed to predict how these would affect loss of shelf life, it is known that thawed frozen foods are very subject to microbial deterioration, and the melted fat can oxidize faster as well as cause loss in desired texture. Commercial devices that indicate whether a frozen product has been exposed at temperatures where it can possibly thaw have been developed by the same companies that have made the time/temperature integrators. These are cheap enough to be used on individual food packages and would be useful to indicate abuse. However, a major drawback is that the device could melt before the food does and thus would not be truthful.

UTILIZATION OF TEMPERATURE-DEPENDENCE EQUATIONS

The previous section outlined the means by which equations could be used to predict shelf life, Obviously, these equations could be used to set a sell-by date in which the fraction of shelf life used up in the distribution/marketing system could be calculated. From this, information could be included on the package that would indicate the expected shelf life for given storage conditions in the home. Similarly, the same calculations including specified home storage could be used to set a use-by date. However, some of the problems that could occur which would make these calculations meaningless are:

1. The product used to develop the shelf-life data or graph may not be the final product marketed, since the shelf-life studies should start early in the product development.
2. As in 1, the product tested may be produced in the lab or pilot plant and therefore will not be subjected to the same conditions as would the product produced in the plant.
3. The ingredients can vary because of growth conditions, rain, sunshine, etc., as well as genetic variety. The ingredients may also be stored for variable times.
4. Labels must usually be made early in the year prior to the growing season so that if effects as in 3 occur, it would be impossible to account for them.
5. The calculations to set the date must be developed for the average conditions. Some products thus will be out-of-date before the time on the label just because of statistical variation.
6. Some products may be mishandled by distributors and supermarket personnel and thus could lose shelf life before the label date.
7. Product shelf-life tests can only be done on individual packages. During a large part of the distribution time, though, these packages are in cartons, which in turn are in cases, which are in pallets. Therefore, exposure to the external conditions is not so drastic—especially for those cartons in the center—and the product may have a shelf life greater than the label states, Good food could then be wasted.

Since other factors could also be included in this discussion, it is obvious that setting a true shelf-life date for each package cannot be done. Only averages can be calculated, and these only where good data exist. Collecting this data is a very time-consuming and expensive process, especially where sensory panel evaluations must be used. Thus, it is probably best to not require open dating of all food products but to mandate what can be put on the label if open dating is used. Based solely on kinetic implications with respect to temperature, a sell-by date with home-storage information or a best-if-used-by date seems most logical.

MOISTURE EFFECTS ON SHELF-LIFE PREDICTIONS

Moisture Gain or Loss Equation to Reach Critical Value

Moisture gain by dry or semidry foods can lead to several modes of deterioration, including microbial growth, loss of crispness, loss of softness, hardening, and caking. The moisture gain or loss for a food held at constant temperature and exposed to a given external relative humidity can be predicted from simple engineering relationships as reviewed by Labuza et al. (Trans. ASAE 15: 150, 1972). The basic equation 13 is:

$$\text{rate of moisture gain per day} = \frac{dw}{d\theta} = \frac{k}{x} A \; (P_{out} - P_{in}) \qquad (13)$$

where

$\frac{dw}{d\theta}$ = grams water gained or lost per day

$\frac{k}{x}$ = package permeability to water

P_{out} = vapor pressure outside the package

P_{in} vapor pressure inside the package— ie , the vapor pressure of water from the food

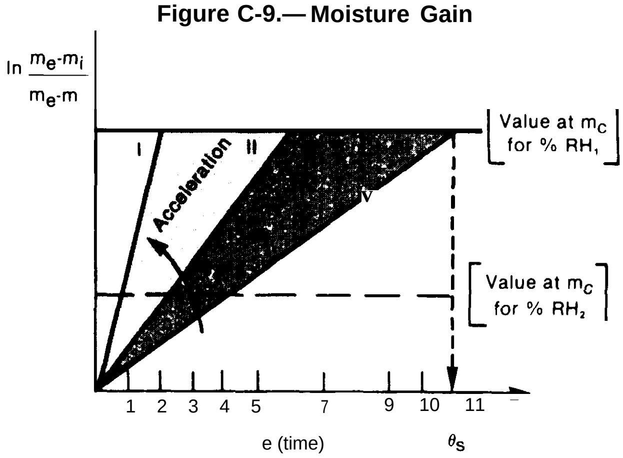
A = package surface area

As with temperature, an increase in external humidity conditions would decrease the time it would take for a given packaged dry food to reach the undesirable moisture content. The factors that would be needed to predict this time include:

- The moisture absorption isotherm as in figure B-1.
- The package film permeance k/x. Manufacturers usually list a range of values for a given packaging film. However, actual values can be obtained by simple tests.
- The ratio of the package area (A) to dry weight (W_s) contained,
- The initial moisture content m_o and critical moisture m_o above or below which one should not go. The critical moisture me—the point of unacceptability—must be found from studies of the food at different moisture.
- The relative humidity and temperature to which the product will be subjected, From this and the isotherm equation m_e, the moisture content the food would achieve if it had no package can be found. In addition, the value of the vapor pressure of water (P_o) at the temperature of the test can be obtained from standard tables.

Given these values, equations 14 and 15 can be found, which give the time (θ) to reach a certain moisture content (m). The exponential term of moisture is plotted as a function of time in figure c-9.

Figure C-9.— Moisture Gain



$$\theta_{gain} = \frac{\ln\left[\frac{m_e - m_i}{m_e - m}\right]}{\left[\frac{k}{x}\;\frac{A}{W_s}\;\frac{P_o}{b}\right]} \qquad (14)$$

$$\theta_{loss} = \frac{-\ln\left[\frac{m - m_e}{m_i - m_e}\right]}{\left[\frac{k}{w}\;\frac{A}{W_s}\;\frac{P_o}{b}\right]} \qquad (15)$$

As indicated in figure C-9, if condition III were the actual food-package system, storage under condition I would decrease the time to reach the critical moisture by a factor of 11-2, or 5.5 times. This would occur if the film used had 5.5 times greater water permeability. The same acceleration in loss of shelf life would occur if the product were stored at a temperature that would raise the vapor pressure of water (P_o) by 5,5 times. At 100-percent relative humidity, the vapor pressure of water ranges from about 17 mm Hg (at 20° C) to 72 mm Hg (at 45° C). Therefore, a decrease in the loss of shelf life of about 4.5 times would occur if the product were stored at the higher temperature and same relative humidity.

Food package size also can affect shelf life with respect to moisture gain. Since the ratio of package area to food weight contained (A/W,) decreases by one-third R (where R is the average radius), a package of smaller size has a shorter shelf life as compared to a larger one.

In practice, in testing for shelf life of foods, researchers use a combination of higher humidity (percent RH) and temperature **(T)** than the food would normally be subjected to. Most food processors suggest, for dry foods, that the average temperature/humidity during distribution is 21° C at 50-percent RH and thus apply some factor by which the food shelf life under the adverse condition is multiplied by to give the average shelf life,

Using this method and equation 13, the shelf life of a food for which the mode of deterioration is moisture gain or loss can be predicted if the external conditions of distribution and marketing are presumed to remain constant. However, in the real world, the humidity can vary as well as the temperature, Fluctuating temperature effects were discussed previously. In general, higher humidities are associated with higher temperature, but no exact pattern of correlation exists. For example, if a T/percent RH distribution were known as in figure **C-10,** the time θ to reach a given change in moisture would have to be calculated by breaking up total time into n small $\Delta\theta_i$ parts. For each $\Delta\theta$, a T_i and percent RH_i could be read off the graph. Then to get the change in moisture for that segment of time (starts at m_i and ends at m_{i+1}), one must:

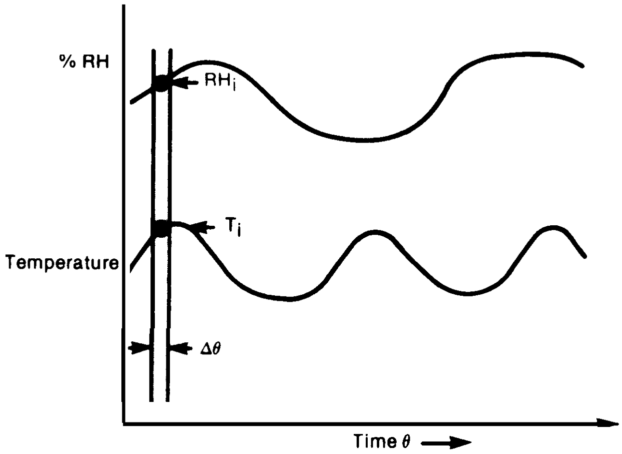
- Determine the vapor pressure P_o from a standard table.
- Derive a new m_e from the isotherm for the new external percent RH_i. If m_e is less than m_i at $\Delta\theta_i$, the loss equation would be used; if it is greater than m_i, the gain equation is used,

From these steps, the value of m as a function of time could be calculated, and thus θ_s could be found, These calculations, in fact, could be used to predict the net-weight losses of cereals and flour under given variable external conditions—another currently controversial regulatory issue.

Constant Weight Loss Prediction

Two situations exist in which a more simplified version of weight loss can be derived: 1) loss of moisture from frozen foods and 2) loss of moisture from fresh produce such as meats, fish, vegetables, and fruits, In both cases, a constant external humidity and constant temperature are assumed, based on the fact that either frozen or refrigerated storage is used. The solution for both situations is based on equation 13.

Figure C-10.—Storage Conditions



$$\frac{dW}{d\theta} = \frac{k}{x}A\ (P_{in} - P_{out}) = \frac{\text{grams } H_2O}{\text{day}}$$

Given that k/x, the area **A,** the external humidity and P_{out} **are** constant, the question is to determine if **Pin is** constant. By definition, Pin is the vapor pressure of water in the food. For a frozen food, **Pin is** determined solely by the temperature that pure ice would have at the storage temperature and thus could be read from a standard table. Since fresh produce have moisture contents in the range of 60 **to** 98 percent and the loss of weight to reach an unacceptable quality is not large, the vapor pressure pin **is** equivalent to that for liquid water **at the storage** temperature. Thus equation 13 becomes equation 16:

$$\text{constant loss of moisture} = \frac{\Delta W}{\Delta\theta} = \frac{k}{x}A\Delta p = \frac{\text{grams of water}}{\text{lost/day}} \qquad (16)$$

If m_c is the critical moisture content as set by net-weight limitations or by quality and m_i is the initial moisture for a package containing W, grams of dry solids of a food, the time to reach end of shelf life is determined by equation 17:

$$\theta_s = \frac{(m_i - m_c)W_s}{\frac{k}{x}A\Delta p} \qquad (17)$$

This equation could be used to predict how long a food would last for certain conditions. For example, for a vegetable like celery in a package for which we would want 12 weeks of shelf life before it lost enough water to lose crispness, at a refrigerated storage of 5° C, the following conditions could prevail:

P_{in} = 654 mm Hg
P_{out} = 80 percent R H X 6.54= 523 mm Hg
normal condition of storage
.". Δp = 1.31 = 654 - 523

If the celery had an initial moisture content of 95 percent and there were **10** ounces in the bag, the dry weight W_s would be 14 grams. Celery loses its crispness when it loses about 5 percent of its weight in water (m_c = 18; m_i = 19). Using polyethylene with a k/x = 1 and a bag of **0.1** m^2, the shelf life would be about 3 months based on water loss, thus achieving the 12 weeks, Of course, in this time, microbial growth could decay the food.

The realistic problem is defining some critical moisture content for the particular food. In real life, both temperature and humidity vary: thus an iterative procedure as described earlier must be used based on a constant weight loss by equation 16 for each of these periods.

Moisture Change for Constant External Temperature and Humidity Conditions

In a classic research endeavor, Karel and Labuza developed the mathematical techniques that combined the equations for prediction of moisture change with the reaction kinetics of various modes of deterioration as a function of a_w (Air Force Contract F **41-609-68-C-0015,** February 1969, Optimization of Protective Packaging of Space Foods). These theories were tested in detail by Mizrahi et al. for predicting loss of shelf life of dehydrated cabbage undergoing nonenzymatic browning by a zero-order mechanism (J. Food Sci. 35:799, 1970, J. Food Sci. 35:804, 1970). The results were extremely satisfactory.

The basic steps needed to be able to predict end of shelf life under these conditions are:

- Store the dehydrated product at several constant temperatures and various relative humidities and measure extent of deterioration with time. Much data like this is available in the literature for dehydrated foods, especially concerning vitamin loss. At least three humidities (a_w's) are required. The reaction order must be determined.
- Decide what extent of deterioration is considered to be unacceptable. Plot the log of the time to reach this extent for constant temperature versus the a_w of the product as in figure C-11, Generally, a straight line above the monolayer water activity should be obtained at constant temperature.
- Using either the moisture gain or loss equation and proceeding step by step as previously described, predict the moisture content change as a function of time for some constant external temperature and humidity (figure **C-12).**
- Using the m versus θ graph, divide the time into small $\Delta\theta$ segments (figure **C-12)** and measure the average moisture content in this time period.
- For each moisture content and temperature, calculate the change in quality using the previously developed equations.

As noted, these steps have been tested and found to be very good in predicting shelf life, Mizrahi and Karel (J. Food Sci. 42:958, 1977) have recently shown that this procedure can be simplified by storing the food in a very permeable material at a given high-relative humidity and

Figure C-II .—Shelf Life as a Function of a_w and Temperature

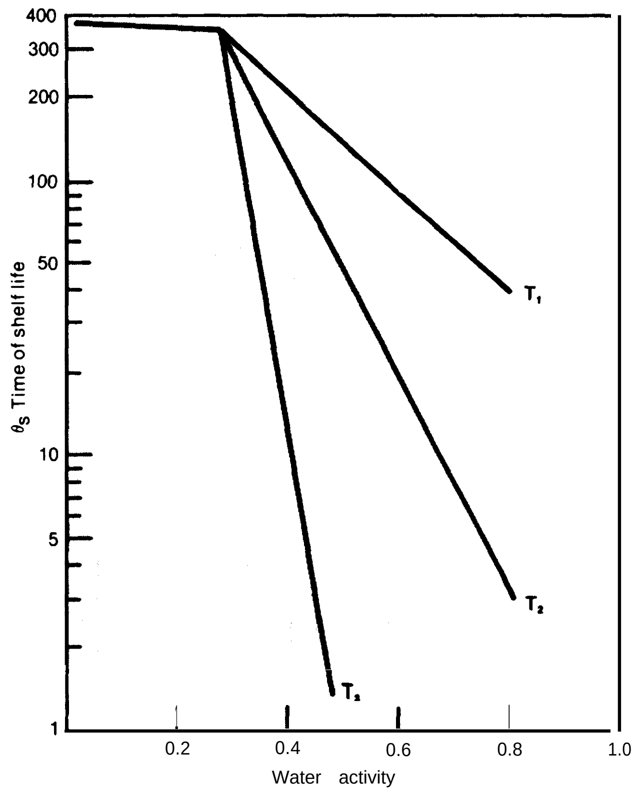
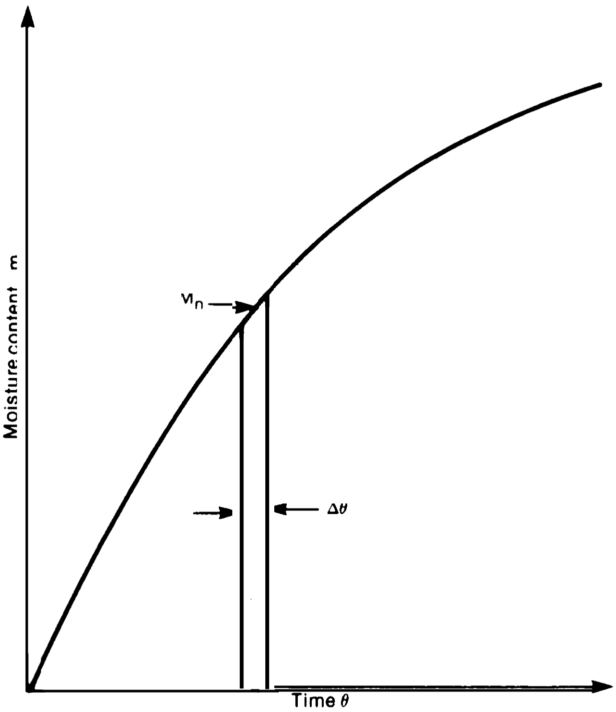


Figure C-12.–Calculated Moisture Content v. Time



comparing the extent of degradation to any other condition by a ratio method. As in the above solutions, this assumes constant external temperature and humidity.

Moisture Change Under Variable External Temperature and Humidity Conditions

The previous section described predicting the loss of shelf life for constant external humidity conditions. The same procedures can be used to calculate the extent of reaction for variable temperature and humidity conditions applying the kinetic derivations as a function of temperature from the section "Shelf-Life Prediction for Variable Temperature. " The first step would be calculating the moisture content as a function of time for a variable time/temperature/humidity distribution as previously shown. Then, applying either zero- or first-order kinetics, the extent of degradation is calculated for small time segments knowing the moisture content, a_w, temperature, and external relative humidity at that point.

Although this is the real world situation, no literature exists that has tested this idea, so it is not known how good the predictions would be for estimating a shelf-life date that could be used on a food package. Even more critical is the fact that the external humidity distribution is even less well-known for food systems and is not as easily predicated as is the external temperature distribution, Therefore, only rough estimates can be made of the actual loss of shelf life.

Of course, another way that this could be controlled would be to use a pouch with a very low water permeability, thereby eliminating the moisture-change problem. This could extend food shelf life, but at the expense of using more precious raw materials (petroleum, aluminum, etc.) and at greater cost to the consumer, It is this tradeoff that the consumer must make in terms of food purchase—that is, a longer guaranteed shelf life at a greater cost, or a possible out-of-date food at lower cost. In addition, no devices exist that can integrate time/temperature/humidity conditions with respect to shelf life,

OXYGEN EFFECTS ON SHELF LIFE

Introduction

oxygen availability is another factor that can affect the time to reach end of shelf life and thus the open date put on a food package. Several reactions in which the rate is a function of oxygen availability include:

- microbial growth,
- senescence of fruits/vegetables,
- browning of fresh meat,
- rancidity (lipid oxidation), and
- vitamin C deterioration.

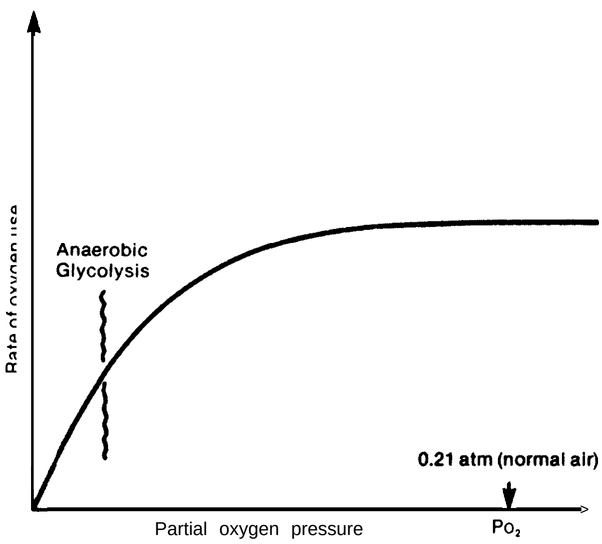
Very little information is available on the use of shelf-life prediction equations with respect to oxygen as well as temperature and moisture content. Karel (Food Technol. 28:50, 1974) has reviewed this area. Part of this void is caused by the difficulty in 1) designing simple equipment to control oxygen levels during experiments that utilize oxygen as one parameter and 2) measuring and controlling oxygen in food packages,

Fruit and Vegetable Senescence

Once fresh produce is harvested, it continues its biological processes of drawing upon internal starch and sugar stores for an energy supply. This will continue until the supplies are depleted or the buildup of breakdown products affects the tissue in such a way that spoilage or microbial attack occurs. This rate of biological reactivity is a function of oxygen availability in terms of oxygen pressure as described by figure C-13. As seen, the lower the oxygen pressure (Po_2), the lower the rate of oxygen uptake via respiration, or conversely, the lower the rate of loss of stores. Thus, a **low Po_2 will give** a longer shelf life. Unfortunately, below a certain Po_2 level, an anaerobic process of incomplete breakdown occurs in which acids and alcohols are produced that also destroy the food quality. Thus, a lower limit exists.

Some fresh produce is preserved using this principle of limiting oxygen availability by: 1) holding under partial vacuum (hypobaric storage), 2) flushing the truck or storehouse with nitrogen to force out the oxygen, or 3) flushing and sealing in a semipermeable pouch, In addition, CO_2 may also be added. This slows the rate of oxidation by mass action, since CO_2 is a product of the oxidation process. Jurin and Karel (Food Technol. 17:104, 1963) have done some of the classic work in this area, They showed that the shelf life of a food in a pouch can be predicted graphically.

Figure C-1 3.—Senescence Rate as a Function of O_2



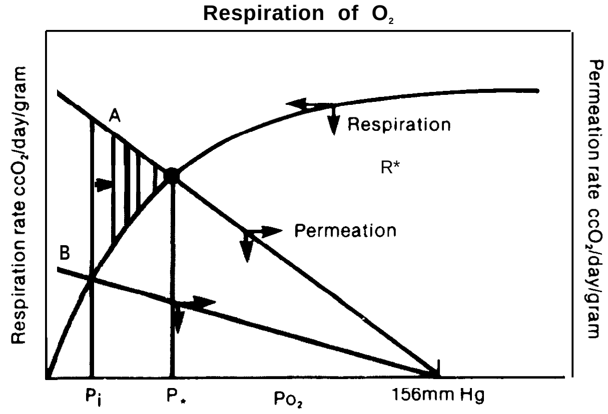
Basically, figure C-13 illustrates this concept. The graph is constructed from data of respiration rates; then the equation for gas permeation into the pouch is drawn on the graph.

Since the external oxygen pressure essentially remains constant, except as one travels up or down a mountain or in a plane, the rate of oxygen permeation is a constant. Thus, the rate as a function of the internal oxygen level is a straight line, which can be superimposed over the oxygen uptake graph as in figure C-14. Lines A and B represent two different films of different oxygen permeability.

Figure C-14 can be used to illustrate what would happen if a product were packaged in a film with a permeability described by A and at an initial oxygen partial pressure P,. Initially, oxygen flow into the pouch is greater than uptake, so oxygen pressure rises, slowing the flow and increasing the uptake. At some point, the two rates are equal—that is, the flow rate just matches the reaction rate. In other words, the package will remain at some constant internal oxygen level and the uptake will become constant. If the total oxygen uptake to reach end of shelf life is known, the shelf life can be easily calculated by dividing the total uptake by the constant rate.

To increase shelf life, all one has to do is lower the film permeability such as seen for B, ensuring that the new oxygen level is not below the point where anaerobic glycolysis occurs. This method has been put into practice with much success, but few film types are available with sufficiently low oxygen permeance to be able to control shelf life to the desired value. Most oxygen-impermeable films also retain moisture that tends to induce mold growth on the product surface. In addition, most data is at a single temperature. Since the Q_{10} for respiration is about 2 to 3, data must be ana-

Figure C-14.— Rates of Permeation and Respiration of O_2



lyzed as a function of temperature also, utilizing the techniques described previously.

Rancidity

Labuza (Critical Reviews of Food Technol. 3, 1977) reviewed the relationship of oxygen to stability of foods with respect to rancidity. A situation similar to that of respiration exists in that the oxygen uptake follows the same pattern. However, there is no lower oxygen critical limit—the lower, the better, in fact—and CO_2 does not slow the reaction.

Simon et al. (J. Food Sci. 36:280, 1971) was the first to apply this to oxidation of a dehydrated shrimp product using the same type of mathematical and graphical analysis. Karel's group (J. Food Sci. 37:679, 1972) did a more in-depth study in which moisture was also simultaneously diffusing into the package for potato chips stored at constant temperature and external humidity. Very elegant computer-based solutions were presented. However, the time to develop the necessary data for equation development for most foods would be far in excess of that desirable in shelf-life testing or product development.

Basically, it can be stated that methods can be developed to predict the end of shelf life when caused by oxygen-sensitive reactions that also depend on a_w and temperature.

Appendix D

Status of Open Shelf-Life Dating Regulations for Selected Countries and International Food Labeling Organizations, 1978

Country/ organization		Code or open date[a]	Type of date	Date display: Day/month/year	Date display: Month/year only
BRITISH COMMONWEALTH					
United Kingdom	Code	Open date recommended for short life, 6 months only		≤ 3 months	> 3 months
Ireland	*Code or open*	No guidelines			
India.	*Code or open*	No guidelines	——	For code	
Australia	*Code or open*	Open date recommended for short life, < 90 days		≤ 3 months	
New Zealand	*Code and open*	Required for some products	Pack	≤ 3 months	> 3 months
EUROPEAN					
Netherlands	Open	Determined for each product by Commodity Board Recommended for short-life, cold-stored products	——		
Switzerland	*Code or open*	Recommended for most milk, meat products; frequently more than one date used voluntarily	——		
Sweden	*Open*	Required for short-life, cold-stored products	——		
Germany	*Code and open*	For milk products and others with shelf life < 1 year			
Yugoslavia	Code	Open *pack date required*			
USSR	*Code*	Required only on secondary container	Pack or use-by		
ASIATIC					
Japan	Code in Arabic or Latin	Open date recommended for some milk, meat, and fish products	——		
Thailand	Code	Open date voluntary, used for some products	——		
Iraq	——	Will conform to Codex Alimentarius--on exports	—	Day/month required if code	
Israel	Code or open				
LATIN AMERICAN					
Mexico	Code or open		Use-by	For code	
Costa Rica	*Code or pack date*	Under consideration		For code	
Venezuela.	Code or open		Use-by		
Argentina	*Code or lot no.*	No requirements for open dating	——		
Brazil	Code or lot no	No requirements for open dating	—		
AFRICAN AND OTHERS					
Philippines		No specific requirements or guidelines			
Egypt		Inspect all exports for conformance with importing country regulations			
Nigeria		Conform to requirements of importing countries to extent local facilities allow	——		

[a]Bold italic type indicates *mandatory* requirements

Country/ organization	Code or open date[a]		Type of date	Date display: Day/month/year	Date display: Month/year only
Libya	*Code or open*	Conform to requirements of importing countries to extent local facilities allow			
INTERNATIONAL ORGANIZATIONS					
Codex Alimentarius.	*Code or open*	Open dating required for baby food	Best-if-used-by		
European Economic Community.	*Open*	Open dating required for all products	——	< year	> year
Central American Economic Community,	*Code or* open		Pack		

[a]Bold italic type indicates *mandatory* requirements
SOURCE OTA Survey

Appendix E

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