# EGGS

## 1. Introduction

*Eggs* are defined herein as eggs from chickens, and refer to both shell eggs and/or egg products. Egg products in liquid, frozen, or dried form contain egg as the principal ingredient. An egg product can be anything from a frozen or dried product made from 100% egg white to a scrambled egg mix that has 51% whole egg. Eggs are primarily used as food. Shell eggs used in the home, restaurants, and institutions are fried, hard-cooked, poached, etc, or are used as ingredients in other foods. Egg products generally are utilized in the food industry.

Eggs contribute important proteins, fats, vitamins, and minerals to the diet. They have many functional properties, eg, binding, whipping, and emulsifying, which make eggs useful in different foods. Comprehensive reviews of the chemistry and biology (1) and marketing (2) of eggs are available.

## 2. Properties

### 2.1. Physical Properties.

The egg is composed of three basic parts: shell, whites (albumen), and yolk. Each of these components has its own membranes to keep the component intact and separate from the other components. The vitelline membrane surrounds the yolk, which in turn is surrounded by the chalaziferous layer of albumen, keeping the yolk in place. Egg white (albumen) consists of an outer thin layer next to the shell, an outer thick layer near the shell, an inner thin layer, and finally, an inner thick layer next to the yolk. Thick layers of albumen have a higher level of ovomucin in addition to natural proportions of all the other egg white proteins. This ovomucin breaks into shorter fibers when the egg white is blended on a high speed mixer (3), or when the egg white ages. Viscosity is greatly reduced when the egg white is blended in this way.

Table 1 shows the various physical properties for components of eggs (4). Specific gravity of whites, yolks, and whole egg is the same, ie, density is 1035 $kg/m^3$ ($64.6\ lb/ft^3$ = 8.63 lb/gal) for all three types of egg products shown. The viscosity of blended liquid egg components varies over a wide range of temperatures; at temperatures higher than those indicated in Table 1, the protein starts to denature and coagulate, increasing viscosity.

### 2.2. Chemical Properties.

Egg white contains mostly proteins having the physical and chemical characteristics given in Table 2. Some proteins in egg white have biological activities that protect from microbiological growth, eg, lysozyme lyses certain bacteria, conalbumin ties up iron, and avidin binds biotin. Most of these activities are destroyed when the egg white is cooked. pH of liquid egg white is normally about 9.0. However, egg white from freshly laid eggs has a pH of about 7.6. pH increases quite rapidly as carbon dioxide escapes during storage. The high 9.0 pH of natural egg white retards the growth of many bacteria.

The yolk is separated from the white by the vitelline membrane, and is made up of layers that can be seen upon careful examination. Egg yolk is a complex mixture of water, lipids, and proteins. Lipid components include glycerides, 66.2%; phospholipids, 29.6%; and cholesterol [57-88-5], 4.2%. The phospholipids consist of 73% lecithin [8002-43-5], 15% cephalin [5681-36-7], and 12% other phospholipids. Of the fatty acids, 33% are saturated and 67% unsaturated, including 42% oleic acid [112-80-1] and 7% linoleic acid [60-33-3]. Fatty acids can be changed by modifying fatty acids in the laying feed.

Yolk can be separated into two fractions, granules and plasma (5), by high speed centrifugation. Granules contain a high percentage of high density lipoproteins (HDL) and lesser amounts of low density lipoproteins (LDL) and water-soluble proteins (phosvitins). The plasma contains water-soluble proteins (livetins) and finely dispersed LDL; most of the glycerides reside in this LDL fraction. The glycerides apparently form the inner core of the LDL, which is surrounded by a phospholipid shell, with protein wrapped around the shell. Half of the water in egg yolk is bound to the proteins and lipoproteins; half is free. The pH of yolk is normally about 6.6, and in freshly laid eggs it is 6.0.

Table 3 indicates the nutritional composition of the three types of egg products, plus the shell egg itself. Eggs, considered to be one of the most nutritious foods, have the highest quality protein of any food, and are important as a source of minerals and certain vitamins. Lipids in eggs are easily digested, and the amount of unsaturated fatty acids is greater than in most animal products.

Cholesterol has received the most attention of the components in eggs. Considerable controversy surrounds the role of dietary cholesterol in eggs and the part it plays in the development of arterioschlerosis. The concentration of blood cholesterol is not affected strongly by dietary cholesterol, but rather is dependent on the degree of saturation of dietary triglycerides (10). The USDA has found that the average large egg contains 22% less cholesterol than previously believed (11). Cholesterol is an important part of the animal tissue and cells, eg, it is necessary in the production of Vitamin D, certain hormones, and bile salts. It is carried to the tissues by blood. The body maintains a certain cholesterol level, and synthesizes any additional amount that is not supplied by the diet. There is evidence that high levels of egg in the diet do not present a greater risk of heart disease in a normal individual (9). However, as a precautionary measure, diets low in cholesterol may be advised for persons having higher than normal blood cholesterol levels, and for persons who may be prone to heart disease.

The egg shell is 94% calcium carbonate [471-34-1], $CaCO_3$, 1% calcium phosphate [7758-23-8], and a small amount of magnesium carbonate [546-93-0]. A water-insoluble keratin-type protein is found within the shell and in the outer cuticle coating. The pores of the shell allow carbon dioxide and water to escape during storage. The shell is separated from the egg contents by two protein membranes. The air cell formed by separation of these membranes increases in size because of water loss. The air cell originally forms because of the contraction of the liquid within the egg shell when the temperature changes from the body temperature of the hen at 41.6°C to a storage temperature of the egg at 7.2°C.

**2.3. Functional Properties.** Eggs function in different ways to give food products certain desirable characteristics.

*Coagulating and Thickening.* Egg protein denatures when heated over a wide range of temperatures (from 55 to 90°C). This denaturation is an important property and is the reason eggs bind or thicken foods such as cakes, custards, omelets, and puddings. The heat coagulating characteristics of egg white protein has been demonstrated in the baking of an angel food cake; no other protein material has been found to substitute for egg whites in an angel food cake.

*Whipping or Beating.* Eggs incorporate air when beaten with a mechanical device, such as a wire whisk, resulting in the formation of foam. Egg white can be easily whipped into stable foams by itself or when mixed with other ingredients, such as sugar. Proteins of egg white unfold at the surface, ie, surface denature, to give the foam a strong supporting structure.

Whole egg and yolk, which contain a large amount of lipids in a highly emulsified state, also foam but at a lower rate than egg white. If the emulsion is broken, whole egg or yolk loses the ability to foam. The foaming properties of eggs are quite sensitive, and can be adversely affected by certain processing procedures, eg, heating liquid to high temperatures, or drying the products.

*Emulsifying.* Emulsifying ability in eggs has always been attributed to phospholipids, but other components such as protein also contribute. For example, liquid egg white does not have as good emulsifying properties as liquid egg yolk (12) when substituted on a weight-for-weight liquid basis, for which the egg white would have one-fourth the solids of egg yolk. However, if dried egg white is used on a basis of just one-half the solids of egg yolk, the emulsion is extremely stable and is more like the emulsion formed with egg yolk. It has been indicated that when lipids, including phospholipids, are extracted from whole egg, the remaining portion has good emulsifying properties (13). An excellent example of the emulsifying properties of egg is in the making of mayonnaise, where egg is the only emulsifier. Eggs must support a stable emulsion containing a minimum of 65% vegetable oil. Emulsifying properties are also important in many baked items where fats and oils are present.

*Miscellaneous Functions.* Eggs retard crystallization of sugar and contribute to smoothness, moistness, and certain desirable textural characteristics of baked goods and candies. By binding ingredients together, eg, in cakes, eggs offer a barrier against water evaporation. Thus eggs also help retard moisture loss during baking and storage.

Eggs have a distinct flavor that makes them desirable for eating by themselves. They also contribute to the flavor and mouthfeel of baked goods and other food products in which they are used. The natural color in egg yolk comes from xanthophylls and other fat-soluble pigments. Eggs contribute color to the products in which they are used, although this is seldom the primary function. Although egg color can be substituted by other coloring materials, there are some products in which U.S Federal Standards permit only eggs as the coloring material, eg, in egg noodles.

## 3. Shell Eggs

**3.1. Production.** Figure 1 is a schematic diagram of a plant operation handling shell eggs, as well as dried egg products. Most production is carried out on farms having 30,000 hens or more per flock or house. Almost everything in the house is automated, eg, feeding, watering, ventilation, and gathering and sorting of eggs. Eggs are put on filler-flats and placed on racks to be transferred to the processing area. The racks are brought into a refrigerator at about 10°C until they are picked up for transfer to the shell egg or egg products plant. The eggs are usually tempered at 10°C before going to the egg products plant where they are broken and separated into whites, yolks, and mix, ie, standardized whole egg solids.

**3.2. Grading.** Eggs are graded and sorted according to size and to quality factors, which include both shell and interior quality. Historically, all eggs were candled by hand. The egg was placed before a candling light and given a quick twist. Appearance and motion of the yolk and size of the air cell gave an indication of the interior quality. Candling is also used for detecting and subsequently removing eggs with blood spots, and those with checked or cracked shells and other obvious defects. In modern processing, eggs are flash-candled on a continuous conveyor within a short time after being laid. Because of their freshness, most eggs have uniformly high interior quality where the proportion of thick to thin egg white is relatively high.

Grading provides a standardized means of describing the marketability of a particular food product. Through the application of uniform grade standards, buyers, sellers, and consumers can communicate through a common language. The USDA has developed quality grade and size standards (see Table 4) for shell eggs.

In order for shell eggs to be eligible for a USDA grade designation, they must be graded by a plant grader and then certified by a USDA grader. Officially graded shell eggs that pass the examination and are eligible for the USDA shield are identified as AA, A, or B (see Table 5). The lastest amendment to requirements became effective June 19, 2006. The final rule published in the April 19, 2006 Federal Register can be viewed electronically (15). These standards are used by trade organizations for establishing shell egg prices.

Most shell grading services are provided at packing plants throughout the United States and occasionally at terminal markets. Federal graders and federally licensed State graders are trained to provide these services. The services are voluntary and are provided on a fee basis to plants requesting service. The cost-per-dozen basis is minimal (16).

*Quality Specifications.* Eggs are downgraded according to specific conditions of the shell.

*Dirty.* The shell is unbroken and has adhering dirt or foreign materials, prominent stains, or moderate stains covering more than one-fourth of the shell surface.

*Checks.* The individual egg has a broken shell or a crack in the shell, but the shell membrane is intact and its contents do not leak.

*Leakers.* The shell and membrane are broken so that the contents are leaking. USDA regulations prohibit use of this type of egg for human consumption.

*Grade AA and A Quality.* These eggs are described in Table 5. They are generally recommended for most household uses. However, lower grades can usually be used for many cooking and baking purposes. Higher grade eggs have somewhat better functional properties, such as foam-forming power.

One of the quality changes in eggs during storage is the thinning of the thick whites, which results in a lower grade of eggs. This can be noted through a candling light by a more distinct appearance and greater movement of the yolk. This can also be observed when the egg is broken out on a flat surface. Large percentages of the thick whites of the fresh egg cause the egg to stand high. Eggs of poorer quality spread out and the yolk flattens. Height of the egg when broken out is one way of expressing the quality factor determined by a formula which relates to the egg white height and the weight of the egg.

Eggs also lose quality by bacterial contamination, usually because of improper shell egg cleaning or washing procedures. When eggs are washed at a temperature less than the temperature of the egg, wash solution can be pulled in through the shell because of the contraction of the egg contents. Such eggs are found to be more susceptible to spoilage, particularly if the wash water contains iron. Iron overcomes the ability of conalbumen to inhibit bacterial growth, and wash water contaminated with iron may allow certain bacteria to grow, resulting in spoilage of the egg (17).

**3.3. Processing.** Methods for handling shell eggs are highly automated. This includes collecting, sorting, washing, sanitizing, drying, candling, and packing.

Almost all eggs are washed before they are packed except in countries where washing of eggs is prohibited by law, ie, The Netherlands. They then are dried to prevent bacterial contamination. Washing is usually done in a continuous system where eggs are conveyed through a washing chamber. Temperature of the wash solution should be 32°C or higher, or 11°C warmer than the eggs being washed. This assures that the wash solution is not drawn in through the shell. After washing, the eggs are rinsed and sanitized with either a chlorine or iodine solution.

Eggs are generally packed with the large end up, and are sprayed and coated with mineral oil at this end to retard escape of carbon dioxide and water, thus retaining quality for longer periods. Eggs are packed for either retail or wholesale (commercial) use. For retail use, the usual pack is one dozen eggs per carton. For commercial use, there are 30 dozen eggs per case.

Eggs that do not qualify as AA or A quality, but otherwise have good interior quality, are usually moved to an egg breaking operation for use in egg products. Sometimes eggs are transported directly to the breaking operation from the laying houses, and all eggs are used for the production of egg products.

## 4. Egg Products

**4.1. Manufacturing.** The first step in making egg products is breaking and separating the whites from the yolks or breaking out the eggs as whole egg. Equipment for handling, washing, breaking, and separating the eggs is shown in Figure 2. An automatic loading device picks up eggs from filler flats and deposits them on a conveyor of an egg washer. The eggs that pass through the washer are simultaneously scrubbed by brushes and flushed by wash solution containing a cleaning compound; they are then rinsed and sanitized using a solution of either chlorine or iodine. Next, the eggs pass through a candling inspection area before being fed to the egg breaking/separating machine. This machine cracks and opens the shell, and deposits the contents into a device that separates the whites from the yolks. Single-tier, single-row machines are operated at speeds up to 32,000 eggs per hour, ie, 90 cases per hour or 9 eggs per second. The double-tier, single-row machine (Fig. 2) is rated to operate at twice this capacity. These speeds are made possible by using a yolk detection device to divert any egg white that has yolk in it onto the mix tray. The systems require three persons as operators. A loader presents the shell eggs to the automatic loader and at the same time inspects and removes any eggs that should not be broken on the machine; the inspector of the washed shell eggs removes any eggs that are not properly cleaned or have other obvious defects; and an egg breaking and separating machine operator inspects eggs that have been broken and separated, and controls the operation speed of the entire system.

As Indicate in Figure 1**b**, three components, ie, whites, yolks, and mix, flow away from the breaking machines to small inspection vats. After inspection, the liquids are pumped through filters or centrifuges, and then through cooling plates to a storage vat where they are held for further processing. The solids of yolk and whole egg (or mix) are usually standardized at this point by the addition of whites or yolks.

The egg products are finally processed and spray-dried. Sometimes liquid egg whites are concentrated before spray-drying by ultrafiltration or reverse osmosis procedures. Table 6 presents the effect of egg quality on the different egg product manufacturing processes.

**4.2. Pasteurization.** All egg products must be pasteurized to render them *Salmonella*-negative. Conventional plate-type pasteurizers having the usual attachments, including holding tubes, flow diversion valve, regeneration cycle, etc, are used. Minimum pasteurization requirements are based on the bacterial kill obtained when heating whole egg to 60°C for a holding time of 3.5 min. Because of viscosity, flow of egg liquid is laminar, as opposed to turbulent, through the holding tubes. Because flow is laminar, the holding time of the fastest particle is only one-half that of the average holding time; the average holding time is 3.5 min, but holding time is actually 1.75 min for the fastest particles. The ultrapasteurization flow through the holding tubes is turbulent flow because of high velocities used.

Table 7 shows the minimum pasteurization conditions required by the USDA. It is necessary to pasteurize all egg products under these conditions, except for egg white which is to be dried.

There are three additional acceptable methods for pasteurizing egg white. In one method, a stabilized liquid egg white is pasteurized at 60°C for a minimum holding time of 3.5 min (19). The white is stabilized by adjusting pH to 7.0 using lactic acid, and adding aluminum sulfate which complexes with conalbumin to give greater heat stability. The adjusted pH stabilizes the other proteins of the egg white, eg, lysozyme, ovomucoid, ovomucin, and ovalbumin.

In another method, hydrogen peroxide can be added to the liquid egg white after it has been heated at 52°C for a holding time of 1 minute (20) to inactivate the natural catalase and to allow the hydrogen peroxide to react against bacteria. Holding time after addition of the hydrogen peroxide is 2.5 min at 50°C. The catalase is then introduced into the egg white to inactivate the hydrogen peroxide and disperse it. A final method involves heat treating dry egg white at greater than 54°C for a minimum holding time of 7 d. Combination liquid heat treatment with the heat treatment of dried egg product kills bacteria and gives greater assurance against the presence of *Salmonella* (21).

Pasteurizing of egg white could cause adverse effects on whipping properties. Whipping aids are presented as an optional ingredient in liquid and frozen egg white. For example, triethylcitrate [77-93-0], $C_{12}H_{20}O_7$, is sometimes added as a whipping aid, as well as a gum to increase viscosity and to improve stability of the egg white foam.

**4.3. Liquid Egg Products.** Liquid egg products include egg white; egg yolk; whole egg; extended shelf life refrigerated liquid egg products, ie, whites, yolks, whole; and concentrated sugared whole egg. These products, generally consumed by large users such as large bakeries who have the necessary handling equipment, are usually transported by refrigerated tank truck holding approximately 20 t. Liquid whole egg and yolk must be held below 5°C; egg white must be held below 7°C. Portable refrigerated vats that hold about 500 kg of product are also used. Bakeries and users must have adequate refrigeration facilities for holding liquid egg products in smaller containers for 30 days maximum.

Liquid egg products must be of excellent microbiological quality with very low total bacteria counts. Pasteurization conditions are more severe than conventional methods for pasteurizing egg products, and aseptic packaging is usually necessary for the success of these products.

Newer liquid egg products are refrigerator shelf-stable for at least 30 days (21) and are aseptically packed in containers holding 13.62 kg of liquid egg product.

A room temperature shelf-stable sugared whole egg with a custard-like consistency has been developed. The concentration of whole egg is great enough, and the sugar level high enough, to give low water activity and good stability at room temperature.

**4.4. Frozen Egg Products.** Frozen egg products include egg white, plain whole egg, whole egg with yolk added (ie, fortified), plain egg yolk, fortified whole egg with corn syrup, sugared egg yolk, salted egg yolk, salted whole egg, and scrambled eggs and omelets. Egg products are frozen in a blast freezer at −40°C for up to 72 h, and then held for storage at −24°C. They are used by large and small bakeries and for other uses.

Whole egg changes consistency during freezing. When thawed, it has a watery, separated appearance. After passing through a strainer or mixing in a vat or container, it appears to be uniform and smooth.

Gelation of egg yolk occurs below 6°C. When frozen egg yolk is thawed, it has a gel-like consistency and is difficult to handle, requiring special equipment; water is sometimes added in order to thin the thawed frozen yolk. Frozen yolk products have ingredients such as sugar or salt added to reduce gelation and improve ease of handling.

**4.5. Dried Egg Products.** Dried egg products are listed in Table 8.

Most dried egg products are made by spray-drying, which produces a powder form. For almost all egg whites, and some whole egg and yolk products, the natural glucose is removed before spray-drying. This gives dried egg white products excellent stability under almost any storage conditions (22), and dried whole egg and yolk products good stability under room temperature as well as refrigerated storage conditions (23). Glucose causes the browning reaction to occur in dried egg products. The reducing group of the glucose reacts with the amino groups of the protein leading to browning, poor solubility, off-flavor, and off-odor developments.

*Dried Egg White.* Glucose may be removed from egg white before drying by bacterial fermentation using a controlled bacterial culture, fermentation using baker's yeast, or oxidation of glucose to gluconic acid using a glucose oxidase/catylase enzyme system. For oxidation, the oxygen is supplied by addition of hydrogen peroxide; reaction rate is controlled by the amount of enzyme, temperature, and rate of hydrogen peroxide addition.

Whipping aids help to preserve the whipping properties of dried egg white. Sodium lauryl sulfate [151-21-3] is preferred, but other approved whipping aids include triethyl citrate, triacetin [102-76-1], and sodium desoxycholate [302-95-4]. These additives are effective at levels of less than 0.02% on a solids basis.

The yolk content of good quality egg white products is very low, less than 0.03% on a liquid basis (24). Fat content on a dry basis is then 0.06%.

Dispersibility of egg white powders into water is relatively poor. The powders tend to clump and form balls that are difficult to disperse. Instant dispersing product is made by mixing the whites with sugar and then agglomerating the particles (25).

*Dried Whole Egg and Yolk.* Dried plain whole egg and yolk products are either dried as is, or have the glucose removed to improve stability and shelf life of the product. Glucose is removed before drying by use of glucose oxidase or by yeast fermentation. Bacterial fermentation is not used because of off-flavor and off-odor development.

Dried whole egg and yolk products with glucose are less stable, and are usually held under refrigeration until used. The whole egg product has more glucose than the egg yolk and therefore is less stable.

Dried whole egg and yolk products should be spray-dried so that a minimum amount of heat is imparted to the product during drying. Sodium silicoaluminate [1344-00-9] or silicon dioxide [7631-86-9] is added at a level of less than 2.0% to give free-flowing and noncaking characteristics.

Dried blends of whole egg and yolk with carbohydrates have sucrose or corn syrup added to the liquids before spray-drying. Such carbohydrates preserve the whipping properties of whole egg and yolk by keeping the fat in an emulsified state. Corn syrup also gives anticaking characteristics, better flowability, and improved dispersibility in water. Dried blends of egg and carbohydrate function well in emulsified, as well as unemulsified, sponge cakes.

*Specialty Dried Egg Products.* A dried scrambled egg mix purchased for the U.S. military by USDA is a product having 51% whole egg, 30% skim milk, 15% vegetable oil, 2.5% salt, and 2.5% moisture.

Imitation whole egg having a low cholesterol content contains egg white as a base; nonfat milk and vegetable oil, substituting for egg yolk, are added to give a composition similar to whole egg. These are in frozen, liquid, or dried forms.

Low cholesterol egg products are formed by extraction of cholesterol from the egg. Attempts have been made to extract cholesterol by using hexane or by supercritical $CO_2$ extraction methods (26,27). A whole egg product in which 80%

of the cholesterol is removed by a process using beta-cyclodextrin, a starch derivative, added to egg yolks has been introduced. The cyclodextrin binds up to 80% of the cholesterol, the mixture is centrifuged, and the liquid separated. The cholesterol-reduced yolk is then blended with egg white, pasteurized, and packed in asceptic containers to give a liquid whole egg product having a shelf life of 60 days under refrigeration.

Hard-cooked eggs are usually packed in acid solution, such as vinegar, which contains spice.

**4.6. Specifications.** Typical specifications are indicated in Table 9 for liquid, frozen, and dried egg products. Every lot of egg product is tested for moisture, pH, total bacteria count, coliform, yeast and mold, and *Salmonella*.

Special tests are run for certain customers. Such tests reflect how the product performs in a particular application.

## 5. Economic Aspects

In the United States in 2004, a total of 257.3 eggs were consumed per person, compared to 236.4 in 1994; 76.5 of those 257.3 eggs were consumed as egg products in 2004 as compared to 60.2 eggs in 1994. See Table 10 for data covering the period 1994–2004 (28).

**5.1. Imports.** Currently, Canada is the only active exporter of egg products to the United States. The Egg Products Inspection Act (EPIA) specifies that egg products may not be imported into the United States except from countries that have an egg products inspection system equivalent to the U.S. (14).

**5.2. Organic Egg Market.** Organic egg sales were $161 million in 2005, up from $140 million in 2004, with an average annual growth rate of 19 percent between 2000 and 2005 (29). Estimated annual growth rates through the end of the decade range from 8 to 13 percent, with annual sales reaching $263 million (30).

Growth in the specialty egg market is rapid, and organic eggs are the fastest growing part of this sector (31). Factors boosting demand for organic eggs include consumer concerns for health and animal welfare. In addition, demand for organic eggs is high among consumers who regularly purchase organic items.

Although conventional eggs are the second biggest private label, or house brand, item in the supermarket, organic eggs have historically been sold as branded items (31). Private labeling of organic eggs, however, seems to be growing. In addition, the egg sector seems to be increasing its use of the "natural" label, which in this case typically refers to eggs from hens that are fed a vegetarian diet.

**5.3. Production Issues.** An important aspect of economic consideration is the prevention of egg and egg product loss to the drain or the atmosphere, eg, a checked or cracked egg may be broken in the washer, and the contents go down the drain with the wash water. Other measurable losses during egg product production are listed in Table 6.

Spray dryers may lose dried egg products out of the stack. Cyclone-type collectors, usually used as the secondary collector, are not properly designed to collect products efficiently. A well-designed cyclone collector recovers only 85–90%

of spray-dried egg white, with 10–15% lost out of the stack, and 94–95% of egg products co-dried with carbohydrates. Bag-type collectors are needed for 100% recovery of both these products. Plain whole egg and plain egg yolk products are capable of being collected almost 100% with a cyclone collector, but a bag collector is advised.

## 6. Labeling of Eggs Products

With the implementation of the Nutrition Labeling and Education Act in 1994, egg products sold at retail are required to bear nutrition labeling. The Nutrition Facts panel gives data on the nutrient composition per serving and contribution to one's overall diet.

In addition, all egg products must be labeled with;

The common or usual name and, if the product is comprised of two or more ingredients, the ingredients listed in the order of descending proportions.

The name and address of the packer or distributor.

The date of the pack which may be shown as a lot number or production code number

The net contents

The official USDA inspection mark and establishment number.

All packages of raw, shell eggs not treated to destroy *Salmonella* must carry safe handling instructions in regard to safe cooking and refrigeration procedures (14).

Organic eggs must be produced to comply with the Organic Food Production Act and labeled accordingly. The USDA organic seal (the words "100% organic" or "organic" inside a circle) may be used on products that are 100% organic or products that contain 95% organic ingredients (29).

## 7. Health and Safety Factors

The interior of shell eggs is mostly sterile at the time of lay. A few eggs may be contaminated inside the shell because of infection of the birds at the time the egg is being formed. However, contamination of the outside of the shell occurs after lay from fecal matter, nesting material, floor litter, dust, etc. Although shell eggs have several physical and chemical barriers that protect the contents from bacterial contamination, eg, shell membrane and antibacterial factors in egg whites, eggs have been implicated in food poisoning outbreaks.

**7.1. Salmonella.** *Salmonella Enteriditis* is the microorganism that has caused most of the problems in shell eggs. Evidence from the Southeastern Poultry and Egg Association (Decatur, Georgia) suggests that this bacteria is contained within the contents of the shell, a result of the bacteria colonizing within the bird. Only a very few birds are contaminated in this way. In 1990, the incidence of *S. enteriditis* was relatively low. One egg in 250,000 was found to be contaminated. Additionally only 7% of the producers had contaminated eggs. In the case of these producers, one egg in 15,000 was found to be positive. However, because one contaminated egg can contaminate the entire batch of eggs mixed with it, it is recommended that all eggs be cooked thoroughly before serving.

Egg products are relatively free of *Salmonella* because pasteurization and testing for *Salmonella* is required. Since July 1, 1971, the USDA has been responsible for mandatory inspection of all egg products in the United States. These regulations specify the minimum standards for sanitary conditions of plant facilities and equipment, pasteurizing conditions, etc. All egg products must be *Salmonella*-negative using a specified sampling and testing program.

Government agencies have implemented an Egg Safety Action Plan to eliminate *Salmonella Enteritidis* illnesses due to eggs. The Action Plan identifies the systems and practices that must be carried out in order to meet the goal of eliminating SE Illnesses associated with the consumption of eggs by 2010.

Federal and state governments, the egg industry, and the scientific community are working together to solve the problem. Involved government agencies include: USDA'S Food Safety and Inspection Service (FSIS), Agricultural Marketing Service (AMS), and the Animal and Plant Health Inspection Service (APHIS); the U.S. Food and Drug Administration (FDA); and State departments of agriculture.

**7.2. Allergies.** Certain individuals are allergic to eggs and egg products. Most allergies occur as a result of the egg processing plants' transfer rooms where shell eggs are presented to the egg washing machine before the breaking machine. Dust from cases and incidental contact with egg material may cause problems, which are mostly respiratory. Respiratory problems can also occur as a result of the spray-drying of egg white; the finished product is fairly dusty, and can cause problems for those individuals who are allergic to egg white powder. When using egg white powder in large quantities, a dumping station with an exhaust system having a bag collector to facilitate the removal of dust from the air is recommended. Whole egg and yolk products are nondusty and usually do not cause a problem.

**7.3. Safe Cooking and Storage Procedures.** Many cooking methods can be used to cook eggs safely. Eggs must be cooked thoroughly until the yokes are firm. Eggs in other food products should be cooked to 160°F.

Table 11 gives data on how to store eggs safely (14).

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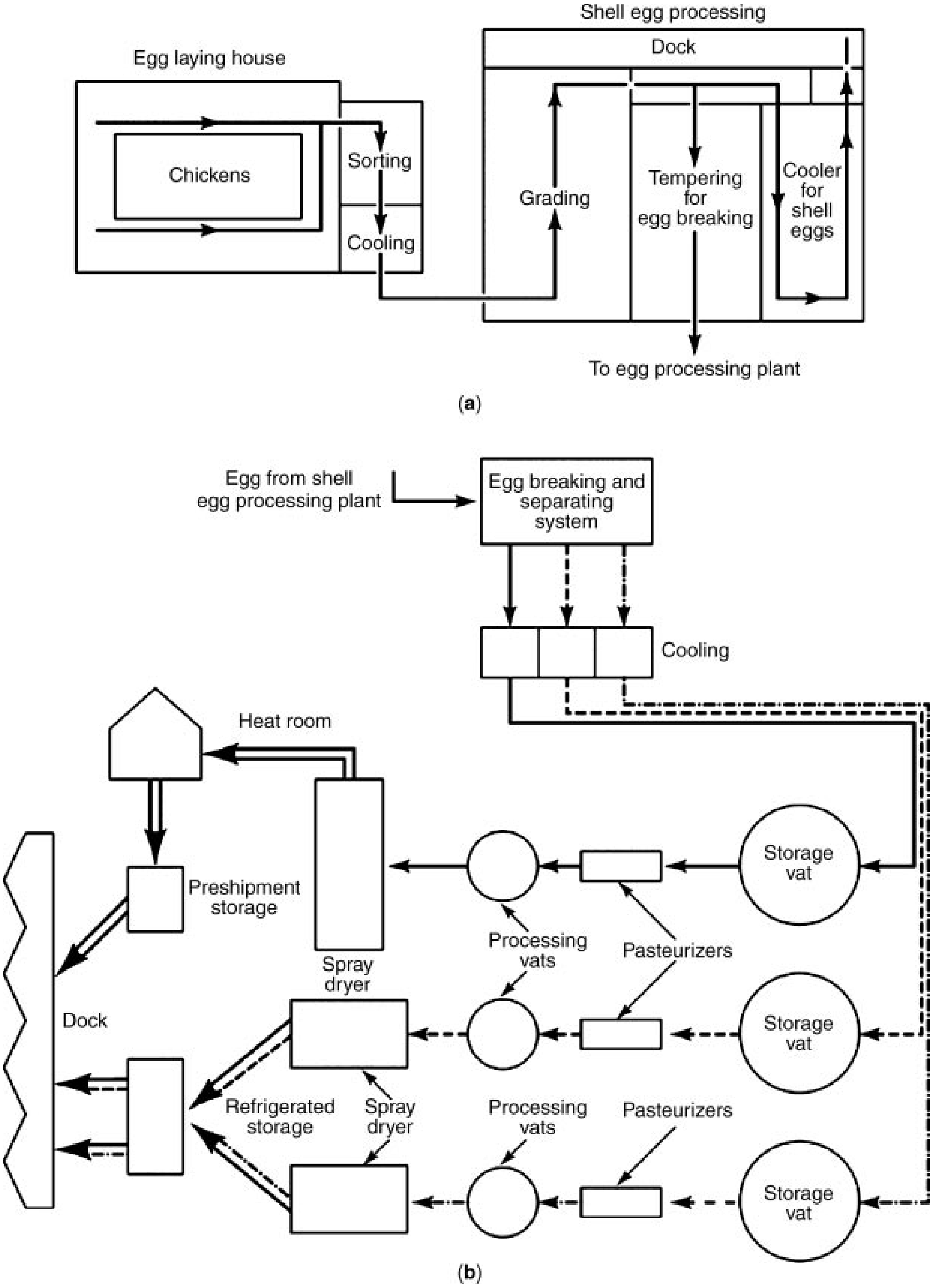


**Fig. 1.** (**a**) Shell egg treatment, (**b**) egg processing plant: (—), egg white liquids; (– – –), whole egg liquid; (–·–), yolk liquid; (=), spray-dried egg white; (=–), spray-dried whole egg; (=·–), spray-dried yolk.

**Fig. 2.** Double-tier egg breaking and separating system. Egg loader, left; washer and inspection, center; and two-tier egg breaking and separating, right. (Courtesy of Sanovo Engineering.)

Table 1. **Physical Properties of Liquid Egg Products**[a]

| Property | Whites | Yolks | Whole |
|---|---|---|---|
| solids, % | 12.1 | 44.0 | 24.5 |
| specific gravity | 1.035 | 1.035 | 1.035 |
| specific heat | 0.940 | 0.780 | 0.880 |
| freezing point, °C | −0.4 | −0.4 | −0.4 |
| specific heat below freezing | 0.500 | 0.500 | 0.500 |
| latent heat of freezing, kJ/kg[b] | 531.4 | 338.9 | 451.9 |
| viscosity, mPa(=cP) | | | |
| 5°C | 12 | 260 | 20 |
| 50°C | 5 | | |
| 60°C | | 45 | 7 |

[a]Ref. 4.
[b]To convert kJ to kcal, divide by 4.184.

Table 2. **Proteins in Egg White**[a]

| Protein | Amount of albumen, % | pH[b] | Mol wt | Denaturation, °C | Characteristics |
|---|---|---|---|---|---|
| ovalbumin | 54 | 4.5 | 45,000 | 84.0 | phosphoglyco-protein |
| ovotransferrin[c] | 12 | 6.1 | 76,000 | 61.0 | binds metallic ions |
| ovomucoid | 11 | 4.1 | 28,000 | 70.0 | inhibits trypsin |
| ovomucin | 3.5 | 4.5–5.0 | $5.5–8.3 \times 10^6$ | | sialoprotein, viscous |
| lysozyme[d] | 3.4 | 10.7 | 14,300 | 75.0 | lyses some bacteria |
| $G_2$ globulin | 4.0 | 5.5 | $3.0–4.5 \times 10^4$ | 92.5 | |
| $G_3$ globulin | 4.0 | 4.8 | | | |
| ovoinhibitor | 1.5 | 5.1 | 49,000 | | inhibits serine proteases |
| ficin inhibitor | 0.05 | 5.1 | 12,700 | | inhibits thioproteases |
| ovoglycoprotein | 1.0 | 3.9 | 24,400 | | sialoprotein |
| ovoflavoprotein | 0.8 | 4.0 | 32,000 | | binds riboflavin |
| ovomacroglubulin | 0.5 | 4.5 | $7.6–9.0 \times 10^5$ | | strongly antigenic |
| avidin | 0.05 | 10.0 | 68,300 | | binds biotin |

[a]Refs. 5 and 6.
[b]Isoelectric point.
[c]Also known as conalbumin.
[d]CAS Registry Number is [901-63-2].

Table 3. **Nutritional Composition of Eggs**[a]

| Nutrient | Shell,[b] whole | Liquid/frozen[c] | | |
|---|---|---|---|---|
| | | Whole | White | Yolk |
| | | *Essential constituents* | | |
| solids, g | 13.47 | 24.5 | 12.1 | 44.0 |
| calories | 84 | 152 | 50 | 313 |
| protein[d] | 6.60 | 12.0 | 10.2 | 114.9 |
| total lipids, g | 6.00 | 10.9 | | 27.5 |
| ash, g | 0.55 | 1.00 | 0.68 | 1.49 |
| | | *Lipids* | | |
| fatty acids, g | | | | |
| saturated, total | *2.01* | *3.67* | | *9.16* |
| 8:0 | 0.027 | 0.05 | | 0.13 |
| 10:0 | 0.082 | 0.15 | | 0.38 |
| 12:0 | 0.027 | 0.05 | | 0.12 |
| 14:0 | 0.022 | 0.04 | | 0.09 |
| 16:0 | 0.137 | 2.5 | | 6.2 |
| 18:0 | 0.462 | 0.84 | | 2.14 |
| 20:0 | 0.022 | 0.04 | | 0.10 |
| monounsaturated, total | *2.53* | *4.60* | | *11.80* |
| 14:1 | 0.005 | 0.01 | | 0.03 |
| 16:1 | 0.214 | 0.39 | | 0.97 |
| 18:1 | 2.31 | 4.2 | | 10.8 |
| polyunsaturated, total | *0.73* | *1.32* | | *3.37* |
| 18:2 | 0.660 | 1.20 | | 3.07 |
| 18:3 | 0.011 | 0.02 | | 0.06 |
| 20:4 | 0.055 | 0.10 | | 0.24 |
| cholesterol, g[e] | 0.205 | 0.36 | | 0.96 |
| lecithin, g | 1.27 | 2.32 | | 5.81 |
| cephalin, g | 0.253 | 0.46 | | 1.15 |
| | | *Vitamins* | | |
| A, IU | 264 | 480 | | 1240 |
| D, IU | 27 | 50 | | 129 |
| E, mg | 0.88 | 1.6 | | 4.1 |
| $B_{12}$, μg | 0.48 | 0.88 | | 2.27 |
| biotin, μg | 11.0 | 20.0 | 6.8 | 40.8 |
| choline, mg | 237 | 430 | 1.2 | 1130 |
| folic acid, mg | 0.023 | 0.060 | 0.016 | 0.128 |
| inositol, mg | 5.94 | 10.8 | 4.0 | 21.4 |
| niacin, mg | 0.045 | 0.082 | 0.092 | 0.067 |
| pantothenic acid, mg | 0.83 | 1.52 | 0.24 | 3.5 |
| pyridoxine, mg | 0.065 | 0.119 | 0.021 | 0.273 |
| riboflavin, mg | 0.18 | 0.33 | 0.28 | 0.41 |
| thiamine, mg | 0.05 | 0.09 | 0.011 | 0.22 |
| | | *Minerals* | | |
| calcium, mg | 29.2 | 53 | 10 | 121 |
| chlorine, mg | 96.0 | 175 | 174 | 176 |
| copper, mg | 0.033 | 0.061 | 0.023 | 0.121 |
| iodine, mg | 0.026 | 0.047 | 0.003 | 0.114 |
| iron, mg | 1.08 | 1.97 | 0.14 | 4.83 |
| magnesium, mg | 6.33 | 11.5 | 10.8 | 12.5 |
| manganese, mg | 0.021 | 0.038 | 0.007 | 0.09 |

Table 3. (*Continued*)

| Nutrient | Shell,[b] whole | Liquid/frozen[c] | | |
|---|---|---|---|---|
| | | Whole | White | Yolk |
| phosphorus, mg | 111 | 202 | 22 | 485 |
| potassium, mg | 74 | 135 | 150 | 110 |
| sodium, mg | 71 | 129 | 165 | 74 |
| sulfur, mg | 90 | 164 | 163 | 165 |
| zinc, mg | 0.72 | 1.30 | 0.12 | 3.15 |

[a]Refs. 1, 7–10.
[b]Per egg; based on 60.9 g shell egg weight with 55.1 g total liquid whole egg, ie, 38.4 g white and 16.7 g yolk.
[c]Per 100 g; based on 24.5% and 12.1% solids, respectively, for whole and white liquid. Yolk contains 44% egg solids, diluted with egg white only.
[d]Protein based on total nitrogen multiplied by 6.25.
[e]Reflects USDA figures for cholesterol in egg and egg products, 22% less than earlier figures.

Table 4. **USDA Size or Weight Standards**[a]

| Size or weight class | Minimum net weight per dozen, kg (oz) |
|---|---|
| jumbo | 0.86 (30) |
| extra large | 0.77 (27) |
| large | 0.68 (24) |
| medium | 0.60 (21) |
| small | 0.51 (18) |
| peewee | 0.42 (15) |

[a]Ref. 14.

Table 5. **United States Standards for Quality of Individual Shell Eggs**[a]

| Factor | AA | A | B |
|---|---|---|---|
| shell | clean, unbroken, practically normal | clean, unbroken, practically normal | clean to slightly stained,[b] unbroken, abnormal |
| air cell white | 3.2 mm or less in depth, unlimited movement, and free or bubbly clear, firm | 4.8 mm or less in depth, unlimited movement, and free or bubbly clear, reasonably firm | over 4.8 mm in depth, unlimited movement, and free or bubbly weak and watery, small blood and meat spots present[c] |
| yolk | outline slightly defined, practically free from defects | outline fairly well defined, practically free from defects | outline plainly visible, enlarged and flattened, clearly visible germ development but no blood, other serious defects |

[a]Ref. 8.
[b]Moderately stained areas permitted, ie, 1/32 of surface if localized, or 1/16 if scattered.
[c]If they are small, ie, aggregating not more than 3.2 mm in diameter.

Table 6. **Effect of Egg Quality on Products**[a]

| Property | Shell egg quality | | |
|---|---|---|---|
| | Excellent | Average | Poor |
| | *Incoming* | | |
| shell eggs, kg/case | 21.75 | 21.79 | 21.68 |
| quality of shell | | | |
| checks, % | 2.0 | 5.0 | 6.5 |
| leakers, % | 0.0 | 1.0 | 4.0 |
| stucks, % | 0.0 | 1.5 | 5.2 |
| dirt, % | 0.0 | 3.6 | 4.2 |
| | *Outgoing* | | |
| edible liquid, kg/case | | | |
| egg whites | 10.92 | 10.35 | 9.45 |
| yolk std. to 43.5%[b] | 7.27 | 6.86 | 5.93 |
| mix std. to 24.5%[c] | 0.0 | 0.79 | 1.72 |
| *total edible* | *18.19* | *18.00* | *17.10* |
| inedible yield, kg/case | | | |
| shells | 2.62 | 2.53 | 2.47 |
| liquid and shell wringings | .91 | 1.06 | 1.74 |
| measured losses, kgcase | | | |
| transfer room floor | 0.0045 | 0.0181 | 0.0363 |
| breaking room floor | 0.0045 | 0.0045 | 0.0091 |
| egg wash water | 0.0091 | 0.1406 | 0.2177 |
| breaking machine wash water | 0.0091 | 0.0227 | 0.0544 |
| *Total* | *21.75* | *21.79* | *21.64* |
| | *Unaccounted for losses* | | |
| machine set speed, case/h | 90 | 80 | 74 |
| effective machine speed, case/h | 90 | 75.5 | 58.0 |
| egg white solids, % | 11.1 | 11.2 | 11.72 |
| yolk contents of whites, % | 0.008 | 0.026 | 0.046 |
| mix solids,[d] % | 24.5 | 24.5 | 24.5 |
| yolk solids[d] % | 43.5 | 43.5 | 43.5 |

[a]From data supplied by Henningsen Foods, Inc.
[b]Yolk comes from breaking machines at 45% or greater, and this is standardized to 43.5% solids by adding mix and whites to the liquid. USDA standards do not allow going below 43.0% solids for yolk. Solids to which product is standardized depends on customer specifications.
[c]Mix comes off the machines at less than 24% solids and is standardized to 24.5% solids by adding yolk.
[d]After standardizing.

Table 7. **Minimum Pasteurization Requirements for Liquid Egg Products**[a]

| Product type | Temperature, °C | Holding time, min |
|---|---|---|
| albumen[b] | 56.7 | 3.5 |
| | 55.5 | 6.2 |
| whole egg | 60 | 3.5 |
| whole egg blends[c] | 61.1 | 3.5 |
| | 60 | 6.2 |
| fortified whole egg and blends[d] | 62.2 | 3.5 |
| | 61.1 | 6.2 |
| salt whole egg[e] | 63.3 | 3.5 |
| | 62.2 | 6.2 |
| sugar whole egg[f] | 61.1 | 3.5 |
| | 60 | 6.2 |
| plain yolk | 61.1 | 3.5 |
| | 60 | 6.2 |
| sugar yolk[g] | 63.3 | 3.5 |
| | 62.2 | 6.2 |
| salt yolk[h] | 63.3 | 3.5 |
| | 62.2 | 6.2 |

[a]Ref. 18.
[b]No additives.
[c]Less than 2% added nonegg ingredients.
[d]24–38% egg solids, 2–12% added nonegg ingredients.
[e]2% or more salt added.
[f]2–12% sugar added.
[g]2% or more sugar added.
[h]2–12% salt added.

Table 8. **Dried Egg Products**

| Egg white | Whole egg | Egg yolk |
|---|---|---|
| spray-dried egg white solids (whipping and nonwhipping) | standard whole egg solids | standard egg yolk solids |
| flake albumen (pan-dried) | stabilized (glucose-free) whole egg solids | stabilized (glucose-free) egg yolk solids |
| instant egg white with sugar | blends of whole egg with sugar | free-flowing egg yolk solids |
| | blends of whole egg with corn syrup | blends of egg yolk with sugar |
| | free-flowing whole egg solids | blends of egg yolk with corn syrup |

Table 9. **Specifications for Egg Products**[a]

| | Liquid or frozen | | | Solids | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | Yolk | |
| Specification | White | Yolk[b] | Whole | Whites, spray-dried | Whole, plain | Plain | Free[c]-flowing |
| moisture, % | | | | <8.0 | <5.0 | <5.0 | <3.0 |
| total solids, % | >11.0 | >43.0 | >24.2[c] | | | | |
| crude protein, % | >10.0 | >14.0 | >12.0 | >80.0 | >45.0 | >30.0 | >30.0 |
| total lipids, % | <0.01% | >28.0 | >10.5 | <0.06 | >40.0 | >56.0 | >56.0 |
| pH | $8.9 \pm 0.3$ | $6.2 \pm 0.1$ | $7.3 \pm 0.3$ | $7.0 \pm 0.5$ | $8.3 \pm 0.3$ | $6.4 \pm 0.3$ | $6.4 \pm 0.3$ |
| carbohydrates[d], % | | | | glu.free | SOP | SOP | SOP |
| total microbial count, gm[e] | <5,000 | <5,000 | <5,000 | <10,000 | <10,000 | <10,000 | <10,000 |
| granulation[f] | | | | USBS-60 | USBS-16 | USBS-16 | USBS-16 |

[a]Ref. 8.
[b]Egg yolk contains approximately 17% egg white; natural egg yolk contains about 52% solids.
[c]Free-flowing products contain less than 2% sodium silicoaluminate.
[d]Most egg white solids are desugared. Whole egg and yolk products are desugared if specified on purchase (SOP).
[e]Includes 10 gm maximum each of yeast, mold, and coliform; all products must be *Salmonellae* negative.
[f]USBS-60 corresponds to 60-mesh ($\sim$ 0.25 mm) screen size; USBS-16 corresponds to 16-mesh ($\sim$1.19 mm) screen size.

Table 10. **United States Egg Production and Consumption[a]**

| Year | Average population* $\times 10^6$ | Cases produced $\times 10^6$ | Cases broken $\times 10^6$ | Per capita consumption | | |
|---|---|---|---|---|---|---|
| | | | | Shell and product | Shell | Egg product |
| 1994 | 263 | 174.9 | 46.7 | 236.4 | 176.2 | 60.2 |
| 1995 | 266 | 174.4 | 47.6 | 233.5 | 175.5 | 58.0 |
| 1996 | 269 | 179.8 | 50.4 | 234.6 | 173.4 | 61.2 |
| 1997 | 273 | 182.5 | 52.7 | 235.7 | 174.4 | 61.4 |
| 1998 | 276 | 187.1 | 54.7 | 240.1 | 177.4 | 62.7 |
| 1999 | 279 | 193.0 | 58.0 | 250.7 | 178.5 | 72.2 |
| 2000 | 282 | 198.4 | 61.6 | 253.0 | 179.1 | 73.8 |
| 2001 | 285 | 203.0 | 60.3 | 254.2 | 181.0 | 73.2 |
| 2002 | 288 | 203.3 | 62.3 | 256.0 | 180.7 | 75.3 |
| 2003 | 291 | 206.9 | 60.9 | 255.6 | 182.5 | 73.0 |
| 2004 | 294 | 210.3 | 63.6 | 257.3 | 180.8 | 76.5 |

[a] Ref. 14.

* U.S. Census Bureau.

Table 11. **Egg Storage Chart**[a]

| Product | Refrigerator | Freezer |
|---|---|---|
| raw eggs in shell | 3 to 5 weeks | do not freeze |
| raw egg whites | 2 to 4 days | 12 months |
| raw egg yolks | 2 to 4 days | yolks do not freeze well |
| raw egg accidentally frozen in shell | use immediately after thawing | keep frozen; then refrigerate to thaw |
| hard-cooked eggs | 1 week | do not freeze |
| egg substitutes, liquid unopened | 10 days | do not freeze |
| egg substitutes, liquid opened | 3 days | do not freeze |
| egg substitutes, frozen unopened | after thawing, 7 days, or refer to "Use-By" date on carton | 12 months |
| egg substitutes, frozen opened | after thawing, 3 days, or refer to "Use-By" date on carton | do not freeze |
| casseroles made with eggs | 3 to 4 days | after baking, 2 to 3 months |
| eggnog, commercial | 3 to 5 days | 6 months |
| eggnog, homemade | 2 to 4 days | do not freeze |
| pies, pumpkin or pecan | 3 to 4 days | after baking, 1 to 2 months |
| pies, custard and chiffon | 3 to 4 days | do not freeze |
| quiche with any kind of filling | 3 to 4 days | after baking, 1 to 2 months. |

[a]Ref. 14, last modified May 2006.