

19

Eggs and Egg Products Processing

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19.1 Introduction

Eggs play an important role in the human diet and nutrition as an affordable nutrient-rich food commodity that contains highly digestible proteins, lipids, minerals, and vitamins (Fisinin et al., 2008). Over the past 35 years, global egg production has grown 203.2%, due to a rapidly increasing demand for proteins in the developing world (Windhorst, 2007). In 1970, the US was the greatest egg producer in the world, contributing over 20% of the global egg production (Windhorst, 2007). However, the US egg production has changed little since then, contributing 9% in 2005. During the same period, China has increased egg production over 20 times, contributing 41.1% of worldwide egg production in 2005. The major egg-producing countries are China, US, India, Japan, and Mexico. The majority of egg consumption in China is in the form of table eggs, as only about 1% of eggs are broken and further processed into egg products. In the US, however, about 30% of eggs are processed into various egg products (i.e. liquid, frozen, and dried egg products) for uses in the food service industry or as ingredients in various food applications. Examples of other egg products include hard-cooked chopped eggs, precooked scrambled eggs or omelets, quiches, precooked egg patties, scrambled egg mixes, and crepes (Froning, 2008).

In addition to food uses, eggs also contain a range of bioactive components that can be used for improving human health and other non-food applications. Extraction and fractionation of bioactive egg components such as lysozyme, avidin, ovotransferrin, ovomucin, antibody (IgY), phospholipids and sialic acid, and development of bioactive peptides from egg proteins represent great opportunities in novel applications of egg components in the future. The objectives of this chapter are to provide

an overview of egg formation, structure and chemistry, and then to introduce shell egg and broken egg processing. Perspectives on value-added egg processing for novel applications are also presented. For earlier references on egg science and processing, the reader should refer to Burley and Vadehra (1989), Stadelman and Cotterill (1995), Yamamoto et al. (1997), and Bell and Weaver (2002).

19.2 Shell egg formation

The most common breeds used for laying eggs in North America are White Leghorn (lays white-shell eggs) and Rhode Island Red (lays brown-shell eggs). Pullets (a pullet is a young hen) are first housed in a pullet barn for 19 weeks and then are transferred to another barn where they start to lay eggs for at least 12 months. While there are two sets of reproductive organs, only the left one survives and reaches maturity to produce eggs. The reproductive tract of a laying hen is composed of two parts: the ovary and oviduct (Figure 19.1). The ovary is a cluster of various sizes of developing follicles, each containing an ovum (or a yolk). The follicle contains a highly developed system of blood vessels that carry nourishment such as proteins and lipids to the developing yolk. There are about 13,000–14,000 ova in a mature ovary but most of them gradually degenerate, and only about 2000 accumulate white yolk to grow to about 6 mm in diameter and reach maturity to produce an egg. Each ovum (singular of ova) starts out as a single cell surrounded by a vitelline membrane. As the ovum develops, yolk is added for a period of 7–12 days prior to ovulation (Burley & Vadehra, 1989). Ovulation is the release of the mature ovum from the ovary into the second part of the female

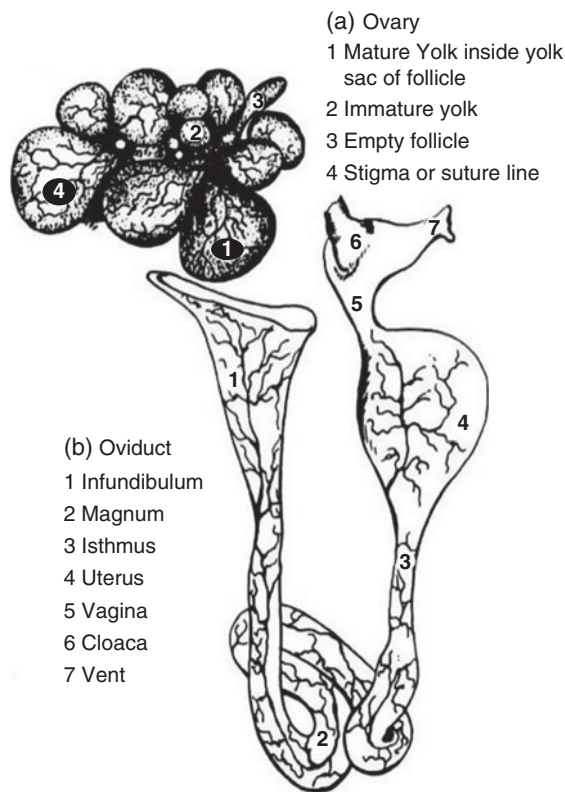


Figure 19.1 The reproductive tract of a laying hen is composed of two parts: ovary (a) and oviduct (b). Courtesy of USDA (2000).

reproductive system, the oviduct. The matured follicle is ovulated at intervals of about 24–27 h (Bell, 2002; Burley & Vadehra, 1989).

The oviduct is an organ wherein the yolk passes and the other portions of egg are secreted. In a fully developed laying hen, the oviduct is 40–80 cm long, with an average weight of 40 g, consisting of five parts: infundibulum, magnum, isthmus, uterus, and vagina (see Figure 19.1). With a funnel-shaped structure, the infundibulum is the top portion of the oviduct and opens its ampulla towards the ovary to receive the ovum after it is released from the ovary; the ovum stays approximately 15–30 min here and can become fertilized if sperm are present. The magnum is the longest portion (34 cm long) of the oviduct. The follicle is held there for about 174 min and egg albumen is secreted there to cover the egg yolk. The isthmus is about 11 cm long and is the place for the formation of inner and outer shell membranes in about 75 min. Although the uterus (or the shell gland) is only 10 cm long, the egg is held for about 16–17 h for

the completion of calcification, followed by the deposition of shell pigments and eggshell cuticle on the immobilized egg during the last 1.5 h before oviposition (Nys et al., 2004). The vagina is the last portion of the oviduct and is about 9 cm long. Its function is to carry the egg from the uterus to the cloaca. It takes about 5 min for the egg to pass through this portion (Bell, 2002; Burley & Vadehra, 1989; Stadelma, 1995).

19.3 Structure of eggs

Eggs are composed of three main parts: eggshell, including the shell membranes between the albumen and the inner shell surface, egg white and yolk, representing 9.5%, 63%, and 27.5%, respectively, of the whole egg (Cotterill & Geiger, 1977; Li-Chan et al., 1995). The yolk is located in the center of the egg, surrounded by an albumen layer, which in turn is covered by eggshell membranes and finally a hard eggshell (Hincke et al., 2012; USDA, 2000) (Figure 19.2). The eggshell provides protection against physical damage, microorganisms, and small predators (Hincke et al., 2012).

An eggshell is composed of a thin film layer of cuticle, a calcium carbonate layer, and two shell membranes. There are 7000–17,000 funnel-shaped pore canals distributed unevenly on the shell surface for metabolic gases and water exchange (Dennis et al., 1996). The cuticle is the most external layer of eggs, about 10 μm thick, and it covers the pore canals. It protects the egg from moisture loss and invasion of microorganisms to a certain extent (Board & Hall, 1973; Whittow, 2000). This layer, as well as the outer portion of the calcified shell, contains the eggshell pigments, which serve as camouflage, temperature control, and possibly as factors in parental recognition (Sparks, 1994). The cuticle is a non-calcified organic layer that is deposited on the mineral surface, consisting mainly of proteins, small amount of carbohydrates, and lipids (Hincke et al., 2012). The cuticle layer can be easily removed by soaking eggs in either weak acid solutions or metal chelator-containing solutions or by washing with water (Belyavin & Boorman, 1980). Therefore, washing of eggs often leads to bacterial invasion of the egg.

The calcium carbonate layer is composed of 95% inorganic substance, mainly calcium carbonate, 3.3% protein, and 1.6% moisture (Parson, 1982). It consists of an outer vertical crystal layer, a central palisade layer, and an inner mammillary knob layer (see Figure 19.2). The vertical layer consists of short, thin crystals running in a

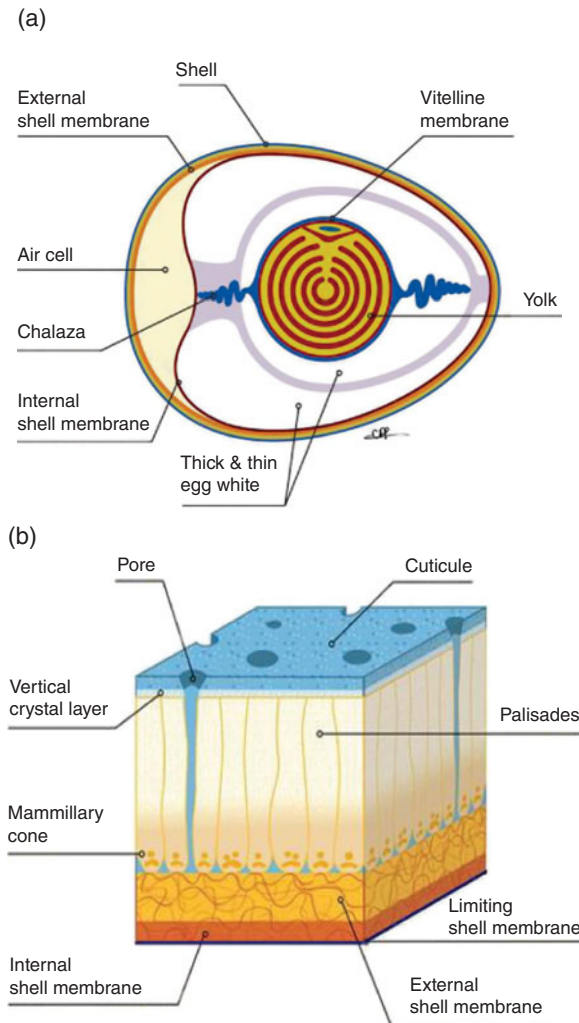


Figure 19.2 Structures of hen's eggs (a) and eggshell (b) (Hincke et al., 2012). Courtesy of Dr M. Hincke, University of Ottawa.

vertical direction of the shell. The palisade layer, often called the spongy layer, is the thickest layer of eggshell. This layer is made up of groups of columns that are perpendicular to the eggshell surface and extend outward from the mammillary cones, where its crystalline structure is constructed with collagen to form a spongy matrix (Hincke et al., 2012). The mammillary knob layer is composed of a regular array of cones or knobs that are interconnected to the fibers of the outer shell membrane to harden the shell (Parson, 1982). Within the mammillary cone layer, microcrystals of calcite are

arranged with a spherulitic texture, which facilitates the propagation of cracks during pipping as well as the mobilization of calcium to nourish the embryo by dissolution of highly reactive calcite microcrystals (Nye et al., 2004).

The eggshell membrane is composed of inner and outer membranes with a structure like entangled threads or randomly knitted nets. This structure is important in obstructing invading microorganisms by catching them in the meshwork. The eggshell is critically important in determining egg quality and forms the first line of defense against pathogens.

The albumen or egg white is composed of four distinct layers: an outer thin white next to the shell membrane, an outer thick white layer, an inner thin white, and a chalaziferous or inner thick layer, representing about 23.3%, 57.3%, 16.8%, and 2.7%, respectively, of the egg white (Burley & Vadehra, 1995). The proportions of each layer depend on breed, environmental conditions, size of the egg, and rate of production (Li-Chan et al., 1995). The thick white layer is sandwiched between the outer and inner thin albumen. The viscosity of the thick albumen is much higher than that of thin albumen, mainly due to its high content of ovomucin. The chalaziferous layer is a fibrous layer that directly covers the entire egg yolk. In the long axis of the egg, this layer is twisted at both sides of the yolk membranes, forming a thick rope-like structure named the chalazae cord. This cord is twisted clockwise at the sharpened end of the egg and counterclockwise at the opposite end (see Figure 19.2). The chalazae cord stretches into the thick albumen layer at both sides to suspend the yolk in the center of the egg (Okubo et al., 1997).

The content of yolk, consisting mainly of yellow yolk and less than 2% white yolk, is encircled by a vitelline membrane. The vitelline membrane is composed of an inner layer, a continuous membrane, and an outer layer, with thicknesses of 1.0–3.5, 0.05–0.1, and 3–8.5 μm , respectively. Both the inner and outer layers are three-dimensional meshwork structures consisting of fibers with diameters of 200–600 and 15 nm, respectively, while the continuous membrane is a piled, sheet-like structure consisting of granules with an estimated diameter of 7 nm (Okubo et al., 1997). Yellow yolk consists of deep yellow yolk and light yellow yolk, appearing alternatively and circularly (Romanoff & Romanoff, 1949). The deep yellow yolk is formed in the daytime while the light yellow yolk is formed at night when the protein concentration in the bloodstream is lower than in the daytime.

19.4 Chemical composition of eggs

Avian eggs are an excellent source of nutrients, particularly high-quality proteins, lipids, minerals, and vitamins (Herron & Fernandez, 2004; Kovacs-Nolan et al., 2005a; Li-Chan & Kim, 2008). An egg is composed of approximately 75% water, 12% each proteins and lipids, ~1% carbohydrates and minerals (Burley & Vadehra, 1989; Li-Chan et al., 1995). Most of the proteins are present in the egg white and the egg yolk, amounting to 50% and 44%, respectively; eggshell contains the rest of the proteins. Lipid presents exclusively in egg yolk while albumen has a very low (0.03%, w/w) lipid content. Though not generally part of the human diet, the eggshell forms a rich source of inorganic salts, mainly calcium carbonate and traces of magnesium carbonate and tricalcium phosphate (Li-Chan et al., 1995; Mine, 2002). The presence of novel matrix proteins has been recently characterized (Hincke et al., 2012; Li-Chan & Kim, 2008). The nutritional profile of egg in egg yolk can be modified through diet, leading to “designer eggs” such as “omega-3 eggs” and “vitamin-enriched eggs” with additional health attributes (Fraeye et al., 2012; Surai & Sparks, 2001). Designer eggs continue to grow to meet the demands of health-conscious consumers.

19.4.1 Chemical composition of egg albumen

The major constituents of albumen are water (92%) and protein (~10%), followed by carbohydrates (0.4–0.9%) that exist in free form, usually as glucose, or forming complexes with proteins such as glycoproteins that contain mannose and galactose units. The albumen is also composed of lipid (0.03%) and ash (0.5–0.6%) (Sugino et al., 1997).

Egg albumen can also be considered as a protein system that contains ovomucin fiber in an aqueous solution of globular proteins (Li-Chan & Kim, 2008). Ovalbumin, a phosphoglycoprotein with a molecular weight of 45 kDa and an isoelectric point (pI) of 4.5, is the most abundant protein in egg white (54–58%) (Huntington & Stein, 2001; Li-Chan et al., 1995; López-Expósito et al., 2008). It is the only protein in albumen that contains free sulfhydryl groups and is a major source of amino acids for the embryo. Ovotransferrin, accounting for about 12% of egg white proteins, is a glycoprotein with a molecular weight of 75 kDa and a pI of 6. It is a disulfide-rich single-chain glycoprotein and belongs to the transferrin family (Li-Chan et al., 1995; Williams et al., 1982). As a member of the transferrin family, it is

able to bind iron, and is known for antimicrobial, antifungal and antiviral activities (Wu & Acero, 2012). Ovomuroid, representing 11% of total albumen proteins, is a thermostable glycoprotein and the dominant egg allergen. It belongs to the Kazal family of protease inhibitors, with a molecular weight of 28 kDa and a pI of 4.1 (Kato et al., 1987). Ovomucin is a sulfated glycoprotein that contributes to the gel-like structure of the thick white layer, forming flexible fibers. It is composed of two subunits: α -ovomucin, with a molecular weight of 254 kDa, and β -ovomucin, with a molecular weight of 400–610 kDa (Robinson & Monsey, 1971). Ovomucin represents 2–4% of total egg albumen and its pI is about 4.5–5.0. Lysozyme is an enzyme with a molecular weight of 14.3 kDa and a pI of 5.5; it accounts for 3.5% of total egg white and possesses bacteriostatic, bacteriolytic and bacteriocidal activity (Cunningham et al., 1991). Oviglobulins consist of two proteins, G2 and G3, with molecular weights between 30 and 45 kDa and a pI of 4.0; these proteins are known for their excellent foaming and beating properties. Ovoinhibitor possesses a molecular weight of 49 kDa and a pI of 1.5; it is capable of inhibiting trypsin and chymotrypsin as well as fungal and bacterial proteases (Huopalahti et al., 2007; Li-Chan & Kim, 2008; Li-Chan et al., 1995).

Other components, including avidin, cystatin, ovoinhibitor, ovostatin, ovoglycoprotein, ovoflavoprotein, and G2 and G3 globulin, are found in the egg white and contain minor levels of carbohydrates, minerals, and lipids (Li-Chan et al., 1995; Mine, 2002).

19.4.2 Chemical composition of egg yolk

Egg yolk represents 36% of the total egg weight. It is composed mainly of 51% water, 16% proteins, 32.6% lipids, 1.7% minerals, and 0.6% carbohydrates. In dry matter, egg yolk is composed of 68% low-density lipoprotein (LDL), 16% high-density lipoprotein (HDL), 10% globular proteins (livetins), 4% phosphoprotein (phosvitin), and 2% minor proteins (Huopalahti et al., 2007); lipids represent about 65% and the lipid to protein ratio is about 2 to 1. The egg yolk protein consists of apovitellenin, phosvitin, α - and β -lipovitellin apoproteins, α -livetin (serum albumin), β -livetin (α 2-glycoprotein), γ -livetin (γ -globulin), and traces of biotin-binding protein (Li-Chan et al., 1995; Mine, 2002). Lipids are found in the form of lipoproteins and usually are composed of 62% triglycerides, 33% phospholipids and less than 5% cholesterol (Anton, 2007). Phospholipids in egg yolk are very rich in phosphatidylcholine (PC) (76%), which

has been recognized as an important nutrient for brain development, liver function, and cancer prevention (Zeisel, 1992). Other phospholipids found are phosphatidylethanolamine (PE) (22%), phosphatidylinositol (PI), phosphatidylserine (PS), sphingomyelin (SM), cardiolipins (CL), lysoPC, and lysoPE, which are present at very low amounts (Sugino et al., 1997). The yellowish color of egg yolk is due to the presence of carotenoids, representing about 1% of the lipids, mainly carotene and xanthophylls (lutein, cryptoxanthin, and zeaxanthin) (Anton, 2007). There has been increased awareness of the role of xanthophylls in human health, in particular the roles of lutein and zeaxanthin in the prevention of age-related macular degeneration (Lesson & Caston, 2004).

The presence of cholesterol in egg yolk leads to controversial public perceptions about egg, which is cholesterol enriched and possibly contributes to the risk of coronary heart diseases (Jones, 2009; Lee & Griffin, 2006; Spence et al., 2012). However, many current studies do not support this hypothesis since the cholesterol metabolism is complicated in the human system and diet is not the sole factor that decides the level of cholesterol in blood. In the largest epidemiological study conducted to date on the relationship between egg consumption and coronary heart disease, consumption of up to one egg per day did not have a substantial overall impact on the risk of coronary heart disease and stroke (Hu et al., 1999, 2001; Qureshi et al., 2006). Although there is a potential to reduce egg yolk cholesterol by genetic selection, the extent of reduction of egg cholesterol by genetic selection is fairly small (9–10 mg), not significant if an average daily intake of cholesterol is about 250 mg (Elkin, 2006; Hargis, 1988; Naber, 1990). If the reduced cholesterol level cannot meet the embryo requirement, the laying hen will simply cease egg production. The discovery of new antioxidants and antihypertensive peptides in eggs might provide new evidence on egg and health (Majumder et al., 2013; Nimalaratne et al., 2011).

19.5 Shell egg processing

Although recognized as the most nutritious food commodity on earth, eggs are well-known source of *Salmonella* that may be present on both the outer surface and in the contents of the egg (Arvanitoyannis et al., 2009; Braden, 2006). The outbreak of more than 1900 illnesses in 11 states in 2010, which led to a voluntary market recall of over 500 million shell eggs nationwide, suggests that *S. enteritidis* is still an important cause of human illness

in the United States (CDC, 2010). *Salmonella enteritidis* (SE) was identified as the cause of infection in 62.5% cases and *S. typhimurium* in 12.9% while other serotypes are responsible for <2% of human infections (EFSA, 2007). Eggs can be contaminated by penetration through the eggshell from the colonized gut or from contaminated faeces during or after oviposition (horizontal transmission), or by direct contamination of the yolk, albumen, eggshell membranes or eggshells before oviposition, originating from the infection of reproductive organs with SE, although it is not yet clear which route is most important for SE to contaminate the egg contents (Gantois et al., 2009).

Salmonella enteritidis can survive in the albumen, but it is effectively inhibited from growing for an extended period of time due to an increased pH from 7.2 to over 9.0 during the initial days after laying, and the presence of a viscous ovomucin also hampers the movement of invading bacteria from egg albumen to egg yolk, as well as several antimicrobial proteins such as ovotransferrin (binding of iron and making iron unavailable for bacteria), avidin (binding of biotin), and lysozyme (disruption of bacterial membranes) (Humphrey, 1994). However, storage of eggs at ambient temperature (above 7.2 °C) for extended periods of time could promote growth and multiplication of SE; therefore, the Food and Drug Administration (FDA) published a final rule in the Federal Register (65 FR 76092), which states that a proposed maximum ambient temperature of 7.2 °C (45 °F), during storage and transportation, would extend the effectiveness of the egg's natural defense against SE and slow the growth rate of this food-borne pathogen (FDA, 2009). However, EU Commission Regulation 589/2008 specifies that "egg should be stored and transported at a constant temperature, and should in general not be refrigerated before sale to the final consumers" (EU, 2008), due mainly to the perception that eggs kept in cold storage are no longer regarded as "fresh." Although this is under debate, all eggs in the US have to be washed, cleaned, sanitized, oiled, dried, refrigerated, stored and transported, before marketing as table eggs or further processing (USDA, 2000, 2006, 2011).

The United States Department of Health and Human Services (HHS) and Department of Agriculture (USDA) and its related agencies have historically led the federal government's efforts to ensure the safety of shell eggs. The HHS, through its authority under the Federal Food, Drug and Cosmetic Act (FFDCA) and the Public Health Service Act (PHSA), has provided oversight of shell egg safety at egg-laying barns (USDA, 2011).

19.5.1 Egg washing

It is assumed that a chicken egg is at its highest quality at the time of laying (Stadelman, 1995a). Therefore, it is critical to properly handle eggs to maintain their highest quality.

Since it is not possible to produce entirely clean eggs, in the US eggs are washed and cleaned to remove stains, dirt, and other surface contaminants to reduce bacterial contamination and prevent the penetration of bacteria into the egg contents, as well as to enhance the appearance to the consumer. In off-line production sites, eggs are transported from farms to a central facility for processing. These center facilities have shell-egg storage rooms to hold eggs for a few days between 10 °C and 16 °C, or below 7.2 °C if over 1 week. The storage room should be adjacent to the empty case storage and transfer rooms for easy transferring of eggs to the washers. In the 1990s, farms with millions of birds made in-line production system more economical and efficient. In the in-line system, eggs are processed the same day that they are laid (Stadelman, 1995b; Zeidler, 2002a). In the Code of Federal Regulations (CFR) Title 7, section 56.76, minimum facility and operating requirements for shell egg grading and packing plants, as well as shell egg cleaning operations, are specified.

During washing, eggs should not be allowed to soak in water to avoid the possibility of bacterial penetration of the shells. Modern egg washers are designed to spray the eggs with water containing a sanitizer along with a detergent (USDA, 2000). Washing water temperature should be maintained at 32.2 °C (90 °F) or higher, and needs to be at least 11 °C (20 °F) warmer than the internal temperature of eggs to prevent the wash water from being drawn into the eggs. As shown in Figure 19.3a, egg loading is separated from egg washing and incoming eggs are conveyed to the washer machine, which is equipped with a series of spray jets and brushes (Figure 19.3b). Rotating of eggs during washing using oscillating brushes provides the scrubbing action. The washing operation must be continuous and fresh water should also maintain continuous overflow. For safety reasons, the wash water has to be changed approximately every 4 h or more often if needed, in order to maintain sanitary conditions, and is mandatory at the end of each shift (Galiş et al., 2013). It is mandatory to use only potable water with an iron content of less than 2 ppm for washing as water high in iron can support bacterial spoilage. The detergents chosen must be listed as approved for use on eggs in the current *Lists of Proprietary and New Food Compounds* (USDA FSIS, Miscellaneous Publication Number 1419); alkaline detergents at amounts sufficient to maintain a pH of 11 are most effective. Water

pH should range between 10 and 11 since *Salmonella* sensitivity to heat increases as pH increases above 10 (Zeidler, 2002a).

Following washing, eggs are then rinsed with water at a temperature at least equal to or warmer than the wash water to remove any adhering dirt and chemicals; the rinsing water contains a sanitizer, usually chlorine-based compounds such as sodium hypochlorite (not less than 50 ppm or more than 200 ppm of available chlorine or its equivalent) (USDA, 2000).

The main disadvantage of egg washing is the removal of the cuticle layer, the first defense against bacterial contamination (Board & Halls, 1973). To prevent the potential of microbial penetration into the eggs, shell eggs must be sufficiently dried directly after rinsing. Eggs are air dried using electric fans and transported in the conveyors for the oiling process, where they are sprayed with mineral oil, which should be tasteless and colorless. An oiling process is introduced to seal the shell pores to prevent weight loss by evaporation and the escape of carbon dioxide, which slows down the increase in pH and air cell size, preserving egg quality (Stadelman, 1995b; Zeidler, 2002a). Plant personnel segregate broken and dirty eggs after the washing cycle and prior to the candling operation (USDA, 2000). Egg washing, sanitizing, and oiling should be conducted according to the procedures outlined in the current Regulations Governing the Voluntary Grading of Shell Eggs (7 CFR Part 56). All equipment and processing rooms should be thoroughly cleaned at the end of each processing day and should remain reasonably clean throughout the processing shift.

In-shell pasteurized eggs are gaining popularity due to recent incidences of SE contamination. The technology was developed in the late 1980s and commercialized by National Pasteurized Eggs, Inc. (<http://www.safeeggs.com/>). The key to the technology is to pasteurize eggs without cooking them. Eggs are locked in place in transfer baskets, dipped in two warm water baths with temperatures of 130 °F and 140 °F (54.4 °C and 60 °C) for about 5 h and in a 45 °F (7.2 °C) cold-water bath for about an hour. At the end of the pasteurization process, eggs are dried, coated with food-grade wax to prevent moisture and microbial penetration, and moved to the candling booth for grading and packaging (Zeidler, 2002a). Other methods, such as electrolyzed water, ozone, irradiation, microwave technology, ultraviolet light technology, pulsed light technology, gas plasma technology, ultrasounds, etc. are under development to decontaminate shell eggs (Galiş et al., 2013). The FDA approved irradiation of shell eggs with doses up to 3 kGy (FSIS, 2000).

(a)



(b)



(c)

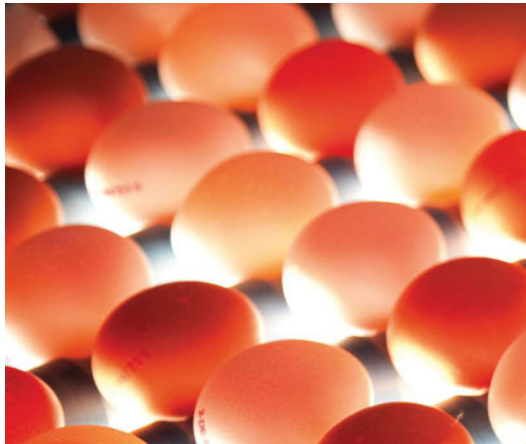


Figure 19.3 Overview of egg washing machine. Incoming eggs are conveyed to the egg washer (a), eggs are sprayed with washing water and rotated using oscillating brushes to remove dirt without damaging eggshell (b), and egg candling (c). Images (a) and (b), courtesy of Dr Vincent Guyonnet of Burnbrae Farm Ltd., Canada. Image (c), courtesy of Sanovo Technology Group.

19.5.2 Candling and grading

After oiling, eggs are conveyed to the candling area where defective eggs are removed (Vaclavik & Christian, 2008). Candling is a technique that allows the shell and inside of eggs to be viewed without breaking the shell; candling was once used to check incoming eggs for freshness by viewing their internal contents by candlelight, where egg contents could be seen when held up to a candle while being rapidly rotated. Today, commercial eggs may be scanned *en masse*, with bright lights under trays of eggs (Mountney & Parkhurst, 1995; Vaclavik & Christian, 2008) (see Figure 19.3c). During candling, a wand-type pointer electronically marks eggs that are dirty or cracked, or that contain blood spots. New equipment is capable of automatically removing these eggs with minimal oversight. Modern egg washers are able to perform automatic loading, washing, drying, oiling, candling, weighing, and packaging (see Figure 19.3).

After candling, eggs are weighed and then segregated by weight classes and conveyed to the applicable size packing line. In the US there are six weight classes for eggs, differing by 3.0 oz per dozen intervals. Peewee is the smallest category, weighing 15 oz and less per dozen, while jumbo represents the largest category, weighing 30 oz or more per dozen. Each category has a minimum weight for individual cartons as well as for individual eggs in the carton. All peewees, small eggs and many medium eggs are directed to breaking operations, leaving mainly medium, large, extra large, and jumbo categories on the market.

Grading generally involves the sorting of products according to quality, size, weight, and other factors that determine the relative value of the product. Egg grading is the grouping of eggs into lots having similar quality and weight characteristics (USDA, 2000). US standards for quality of individual eggs have been developed on the basis of such interior quality factors as condition of the white and yolk, size of the air cell, and exterior quality factors of cleanliness and soundness of the shell as shown in Table 19.1 (USDA, 2000). Eggs that achieve the quality standards are conveyed to the weighing scales and packed according to their weight in automatic packaging units and then stored in cool rooms before shipping.

19.5.3 Packaging and storage

Packaging and packing are normally carried out in conjunction with the grading operation. After grading, eggs are conveyed to the packaging machine, where they are separated by weight and classified into different categories,

Table 19.1 Summary of US standards for quality of shell eggs

Quality	Remarks
AA	Unbroken shell Air cell less than 1/8" in depth and clear Firm whites and yolk with no apparent defect
A	Unbroken shell Air cell 3/16" in depth Egg white clear and reasonably firm and yolk free from apparent defects
B	Slightly abnormal shell Air cell should not exceed 3/8" in depth Clear egg white but slightly weak Yolk slightly flattened

Courtesy of USDA (2000), non-copyright material.

transported to the automatic packer and packed in cartons (6, 12 or 18 eggs) or filler flats (20 or 30 eggs), and then placed in cardboard cases or wire baskets and moved to the cold storage room for cooling prior to shipment. Packages should be marked with the date of packing, sell-by date codes and plant identification, although some companies choose to ink-jet print the individual eggs as well. Cartons are usually made from recyclable corrugated fiberboard material, which is the most common packing material. Other materials include rigid plastic cases, polystyrene foam cartons, and molded clear plastics; the design and material used are important factors in reducing egg damage during storage and distribution. It is mandatory in the US to keep shell eggs at or below 45°F (7.2°C) after processing (during storage, transportation, and marketing) to effectively control SE inside the egg (minimizing the risk of microbial multiplication and reducing the heat resistance of SE) (USDA, 2000); therefore rapid cooling techniques or extended cold storage times are required to meet these refrigeration regulations.

19.6 Further processing of eggs and egg products

Of the 76.2 billion eggs consumed in 2009, 30% were in the form of egg products (eggs removed from their shells) (USDA, 2011). Liquid, frozen, and dried egg products are widely used by the food service industry such as scrambled or made into omelets, or as ingredients in other foods, such as prepared mayonnaise, ice cream, salad dressings, frozen desserts, cream puff, cakes, confections,

etc. (FSIS, 2013; Yang & Baldwin, 1995). The term “egg products” refers to eggs that are removed from their shells for processing at facilities called “breaker plants.” The processing of egg products includes breaking eggs, filtering, mixing, stabilizing, blending, pasteurizing, cooling, freezing or drying, and packaging. This is done at USDA-inspected plants. The USDA’s Food Safety and Inspection Service (FSIS), through its authority under the Egg Products Inspection Act (EPIA), provides oversight of shell eggs after they have left the barn to either be placed in cartons for consumers or sent to an egg product processor (FSIS, 2011).

Shell eggs must be washed and completely dried prior to breaking. Eggs with broken shell membrane are not permitted for human consumption. The egg breaking room should be separate from the egg washing room. The development of highly automatic, computer-controlled egg breaking and separating machines is a key achievement in the production of egg products. The basic egg breaking unit is composed of a cracker and a



Figure 19.4 Eggs are first cracked and egg contents fall into a yolk-albumen separator where the top cup retains only yolk while whites slide to the bottom cup. Courtesy of Dr Vincent Guyonnet of Burnbrae Farm Ltd., Canada.

yolk-albumen separator. The crack head cracks the shells at the center and pulls the two shells apart. The yolk-albumen separator has two cups positioned one above the other. After cracking, the egg content falls into the top cup to retain only yolk while the white slides to the bottom cup (Figure 19.4). Many of these units are attached to a round or oval rotating table which provides great processing capacity, as many as 188,000 eggs per hour in modern egg breaking machines. Breaking machines are cleaned and sanitized after 4 h of operation, and at the end of the final shift of operation. Holding tanks and pipes are made of stainless steel and are cooled by ice water running between the inner and outer walls, keeping the liquid eggs as cold as possible. Strict sanitation and temperature control are the key factors in maintaining low microbial load. After breaking, the edible liquid products are filtered, ingredients (salt, sugar, etc.) are added, blended, standardized, and pasteurized prior to packaging in a separate room or further frozen or dried.

19.7 Liquid egg products

Liquid egg white usually has a total solids content of ~12%. The solids content can be affected slightly (usually within 1%) by loss of moisture and egg stocks (smaller eggs have higher solids level while larger eggs from older birds have lower solids level). The pH of liquid whites ranges from 7.6 to 9.3, depending on the amount of carbon dioxide lost from the egg. Liquid egg whites obtained from stored eggs usually have higher pH; as the eggs are stored, the pH will increase due to carbon dioxide loss through the shell during storage. The amount of carbon dioxide loss is the only factor that can affect the pH of liquid egg whites, which depends on the egg temperature, the amount of carbon dioxide in the environment and the degree of egg sealing or oiling (Cotterill & McBee, 1995).

The solids content of pure egg yolk from fresh eggs is about $51.9 \pm 0.1\%$ and the pH of pure egg yolk is about 6.0. During storage, water migrating from the white is the major factor affecting the initial egg yolk solids. The total solids range from 44% to 48% from breaking facilities, depending on the amount of egg white adhering to the yolk and moisture migration. The presence of egg whites in egg yolk will also increase the pH. Usually the solids level is standardized to 43–44% solids level by addition of egg white (Cunningham, 1972).

Liquid whole egg is a blend of egg white and egg yolk. The solids level of a blend of egg whites and egg yolk in natural proportions is about 23–25%. Under USDA

regulations, the solids level of blended liquid whole egg is standardized to 24.2% (FDA, 2012a); this may require the addition of more yolk than is present in natural proportions in the liquid from shell eggs. The pH of liquid whole egg can vary from 7.0 to 7.6, usually 7.2 (Cotterill & McBee, 1995).

19.8 Pasteurization

After breaking, the liquid eggs should be pasteurized as soon as possible to reduce the possibility of food-borne pathogen contamination or proliferation. The bacterial quality of liquid products depends on the quality of the eggs being broken, the sanitation conditions in the plant, and handling practices. Under the EPIA, egg products must be pasteurized to eliminate *Salmonella* (FSIS, 2013); pasteurization of egg products in the US has been mandatory since 1966 (Cunningham, 1995). The pasteurization process involves a combination of time and temperature in order to reduce the number of viable pathogens, especially *Salmonella*. The USDA now requires that liquid whole egg be heated to at least 60°C (140°F) and held for no less than 3.5 min, or at least (134°F) and held for no less than 3.5 min, or at least 55.6°C (132°F) but held for 6.5 min for egg white. Liquid egg products, especially egg whites, are very susceptible to heat treatment, resulting in protein damage and impaired functionality. Adding additives, including carbohydrates such as sucrose, glucose or fructose, or salt at 10% levels can protect susceptible egg proteins from damage and therefore allow higher temperatures, of approximately 3–6°C before heat damage occurs (Cunningham, 1995). The compositional differences of liquid egg products such as solids level, fat content, and pH, affect the heat resistance of salmonellae and account for the wide range of pasteurization conditions recommended. A higher temperature (60°C or higher) is needed for pasteurization of egg yolk, as salmonellae are more heat resistant in yolk than in whole egg or egg white. The increased heat resistance in egg yolk is due to the lower pH and higher solid content of egg yolk.

Facilities for pasteurization of egg products must be adequate and of approved construction so that all products are processed as approved. Pasteurization equipment for liquid egg product must include a holding tube, an automatic flow diversion valve, thermal controls, and recording devices to determine compliance with pasteurization standards as set forth by the USDA. The temperature of the heated liquid egg product must



Figure 19.5 Liquid egg products are pasteurized using tubular-type high-temperature-short-time (HTST) systems. Courtesy of Dr Vincent Guyonnet of Burnbrae Farm Ltd., Canada.

be continuously and automatically recorded during the process (FDA, 2012b). The most widely adopted systems for pasteurization in liquid egg products are plate-type or tubular-type high-temperature, short-time (HTST) systems (Figure 19.5). HTST is a continuous method that can process large volumes in a short time; it is composed of a steel plate heat exchanger that heats and cools the egg liquid in a short time. Table 19.2 lists current USDA pasteurization requirements for various egg products. The temperatures and holding times listed in Table 19.2 are minima; the product may be heated to higher temperatures and held for longer periods of time. Pasteurization procedures must insure complete pasteurization, and holding, packaging, facilities, and operations shall be such as to prevent contamination of the product.

After pasteurization, liquid products are cooled and packaged, often shipped in bulk tankers to other plants for various applications, or frozen. Over one-fourth of the total liquid production is frozen (Stadelman & Cotterill, 1995). Freezing causes only minor changes in raw egg white while the formation of gelation upon freezing and storing raw egg yolk below –6°C is a well-known phenomenon. The extent of gelation in whole egg is less

Table 19.2 Pasteurization requirements

Liquid egg product	Minimum temperature requirements (°F)	Minimum holding time requirements (minutes)
Albumen (without use of chemicals)	134	3.5
	132	6.2
Whole egg	140	3.5
Whole egg blends (less than 2% added non-egg ingredients)	142	3.5
	140	6.2
Fortified whole egg and blends (24–38% egg solids, 2–12% added non-egg ingredients)	144	3.5
	142	6.2
Salt whole egg (with 2% or more salt added)	146	3.5
	144	6.2
Sugar whole egg (2–12% sugar added)	142	3.5
	140	6.2
Plain yolk	142	3.5
	140	6.2
Sugar yolk (2% or more sugar added)	146	3.5
	144	6.2
Salt yolk (2–12% salt added)	146	3.5
	144	6.2

Courtesy of USDA (2000), non-copyright material.

drastic than in yolk. The loss of fluidity makes the gelled product hard to use and hard to mix with ingredients and produces an undesirable appearance. Heating thawed yolk at 45–55 °C for 1 h partially reverses this gelation (Palmer et al., 1970). It is thought that LDL is the primary egg yolk component altered by freezing (Wakamatu et al., 1983). Gelation is easily controlled by adding 10% salt or sugar to egg yolk.

19.8.1 Alternative methods of pasteurization

Other methods of pasteurization may be approved when they give equivalent effects to those specified above.

Ultra-heat treatment (UHT) requires the use of high temperature for a short time. In the case of liquid eggs, this type of pasteurization requires more attention, as egg proteins are more susceptible to temperature denaturation; usually the liquid eggs are heated at temperatures of 70 °C for 1.5 min and then packed in aseptic packages, which increase the shelf life for up to 24 weeks, although the final product still needs to be refrigerated (Cunningham, 1995; Zeidler, 2002b).

Another alternative method is the lactic acid-aluminum sulfate method, which allows pasteurization at temperatures similar to whole egg (62 °C for 3.5–4 min). The maximum stability of most egg white proteins occurs at near neutral pH, with the exception of ovotransferrin (Nakamura & Omori, 1979). To overcome this, aluminum salts such as aluminum sulfate solution are added prior to treatment to stabilize the protein, by forming complexes that are more heat stable than the protein itself. The addition of aluminum salt should be made slowly, with rapid stirring of the whites, to avoid protein coagulation by local high concentrations of acid and aluminum. The pH of the egg white before pasteurization should be 6.6–7.0. This method produces low foaming products so a foaming or whipping aid may be incorporated into the stabilizing solution (Cunningham, 1995).

Another method used is the heat plus hydrogen peroxide method that was developed by Armour and Company. This process combines heat treatment and hydroxide peroxide. Hydrogen peroxide is used as a bactericidal agent, and the egg white can be pasteurized at its normal pH (9.0) at lower temperatures. Egg white is first heated to around 52–53 °C and held for 1.5 min to inactivate natural catalase (thereby eliminating the problem of excessive foam formation); hydrogen peroxide is then added to a final concentration of 0.075–0.1%, and allowed to react for 2 min at the elevated temperature. The egg whites are cooled to 7 °C and catalase is added to remove residual hydroxide peroxide. The advantage of this method is that egg whites can be pasteurized at relatively lower temperatures and therefore the foaming properties of egg white are not affected (Cunningham, 1995). This method is widely used for pasteurization of egg whites.

The heat plus vacuum process is another method used for pasteurization. The use of a vacuum to remove air from egg whites achieves the same microbiological results at lower temperature. The system uses a typical HTST plate pasteurizer equipped with a vacuum chamber. Egg whites are first vacuumed for 17–20 min to eliminate air, and then heated to 57 °C for 3.5 min (Cunningham, 1995).

Non-thermal preservation processes, such as irradiation, high-pressure processing (HPP) and pulsed electric field (PEF) processing, are claimed to result in better quality retention, energy efficiency, and/or longer shelf life, compared to traditional heat processing (Cullen et al., 2012). Proctor et al. (1953) used irradiation for the first time in liquid whole egg and reported that the use of a high voltage of cathode rays could reduce viable *Salmonella*. Irradiation produces free radicals, which increase the oxidation of polyunsaturated fatty acids and cholesterol, change color, and destroy carotenoids in dehydrated egg products (Du & Ahn, 2000). Irradiation has been used in the treatment of liquid egg and can be used in frozen egg products due to its penetration power. Consumer acceptance of irradiated foods primarily dictates the future use of this process in the pasteurization of egg products (Min et al., 2005; Sheldon, 2005).

The PEF technique uses short, high-voltage pulses to break the cell membranes of vegetative microorganisms in liquid media by expanding existing pores (electroporation) or creating new ones (Cullen et al., 2012). The membranes of PEF-treated cells become permeable to small molecules; permeation causes swelling and eventual rupture of the cell membrane. During processing, the product is subjected to the application of short, high-intensity electric fields (in the order of 20–80 kV) by passing through a chamber that consists of two electrodes that deliver pulses for a few milliseconds. Fresh liquid whole egg can have a shelf life of 28 day at 4–6 °C when it has been treated with 10 pulses (2 microseconds per pulse), but changes in viscosity and color were observed (Qin et al., 1995). One of the main advantages of using PEF is that the temperature is not higher than 55 °C (Sheldon, 2005).

High-pressure processing (HPP) treatment generally maintains better taste, appearance, and texture as well as nutrition of the food product (Cruz-Romero et al., 2004). The effect of HPP on eggs was first studied by Bridgman (1914) who observed egg albumen coagulation while pressurized at 600 MPa. Other changes in egg components have been reported, such as improvement of the foaming capacity of egg white due to exposure of SH groups that favors foaming stability (van der Plancken et al., 2007; Yang et al., 2010). HPP reduced *Salmonella enteritidis* when applied to liquid whole egg at 350 MPa and 50 °C at 2-min pulses for four cycles, which indicates that it can be used as a pasteurization method (Bari et al., 2008). Its potential in processing egg products has been extensively reviewed (Juliano et al., 2012). Coagulation of egg albumen can be avoided by adding

7–10% NaCl or sucrose even at pressures of 800 MPa (Iametti et al., 1999).

19.9 Desugarization

Demand for dried egg products for military use was high at the outbreak of World War II. During the 1930s, the US was unable to produce dried egg albumen with satisfactory storage stability and functionality. It was known that the Chinese process involved fermentation of the albumen prior to drying (Sebring, 1995) and that removal of glucose from egg liquids is essential to prevent the Maillard reaction between glucose and protein in producing undesirable color and the glucose-cephalin reaction (a reaction between a cephalin amino group and aldehydes of glucose), responsible for off-flavor development (Sebring, 1995).

The traditional Chinese process uses spontaneous microbial fermentation but is not acceptable due to the health hazard resulting from the growth of pathogenic bacteria. Therefore, controlled bacterial fermentation is preferred to eliminate pathogens and also to reduce the time required for fermentation. A number of strains, including acid-producing organisms such as *Lactobacillus* species, *Streptococcus diacetilactis*, *Klebsiella pneumoniae*, etc., are used for removal of sugar. This method is widely accepted for desugarization of egg whites. The albumen is first pasteurized and then acidified to pH 7.0–7.5 with food-grade citric or lactic acid. The liquid is then inoculated with the proper culture and held at 30–33 °C to prepare inocula. The culture is then frozen for future use as inocula in the fermentation of large batches of egg white. The level of inoculum is usually 10–15% of the total batch weight (Sebring, 1995). Yeast fermentation is also used to desugar whole egg, egg white, and egg yolk. The pH of the liquid egg is adjusted to the range 6.0–7.0, by addition of dilute hydrochloric acid, and controlled fermentation is maintained by adding food-grade baker's yeast (*Saccharomyces cerevisiae*) (FDA, 2012a). Fermentation of whole egg with 0.2–0.4% by weight of moist baker's yeast at 22–23 °C depleted the sugar within 2–4 h (Sebring, 1995).

The glucose oxidase-catalase enzyme system is used exclusively for desugarization of whole egg, other yolk-containing egg products, and egg white. The reaction can be carried out at an elevated temperature of 30–33 °C or at a low temperature of 10 °C. The lower temperature requires a longer reaction time. The optimum pH for glucose oxidase is 6.0; therefore adjustment of pH is not

necessary in yolk while pH adjustment with citric or lactic acid may be required for egg white or whole egg. The dose of enzyme is determined by the rate of reaction desired, temperature of egg, activity of enzyme, and the amount of glucose to be removed. Considerable caution is required in adding hydrogen peroxide to the egg because of foaming from evolved oxygen (Stadelman & Cotterill, 1995).

19.10 Dehydration

Dried egg products are used for the production of bakery goods, mayonnaise, salad dressing, pasta, etc. Use of dried eggs facilitates storage and transportation, as they are easy to handle and to formulate. The drying process is mainly performed by spray drying, pan drying, or belt drying. Concentration of liquid egg products before drying is a means of improving thermal efficiency, increasing the capacity of a dryer, and changing product characteristics such as lighter bulk density; liquid eggs can be concentrated using vacuum-type evaporation or ultrafiltration. Spray drying is the most common method used. In this method the liquid egg is atomized by high-pressure nozzles (500–6000 psi) into a stream of hot air for instant removal of water. Flowability can be achieved by adding a free-flowing agent such as sodium silicoaluminate or silicon dioxide, at levels of 2% to 1%, respectively (Bergquist, 1995). The finished dried product must contain not less than 95% total egg solids by weight (FDA, 2012a). The air used for drying is filtered to remove undesirable dust and other contaminants and then is heated to an inlet temperature of 121–232 °C; the hot air is then moved to the spray-drying chamber by an inlet fan. The powder separates from the drying air in the drying chamber and also in a separating device; the air is then removed from the system by an exhaust fan. The dried product removed from the dryer is sometimes cooled and is usually sifted before packaging.

Pan driers are still used for making egg white. Drying on pans to a moisture level of 12–16% will produce a flake-type product with dimensions of 1.5–12.5 mm; material finer than this is sometimes called granular egg white. Pan-dried egg white can also be milled to a fine powder (Bergquist, 1995; Zeidler, 2002b). Belt drying is used in China for making dried whole egg and yolk. The liquid egg is spread as a thin film on a continuous aluminum belt moving through a hot air stream. Another form of belt drying, called “fluff” or “foam” drying, is when the product is whipped into a stable foam and

spread in a thin layer on a continuous moving belt passing through heated air. Foam spray drying, a method used for dairy products, has also been used for drying egg products. Egg products produced by this method have a lower bulk density and different particle characteristics than regular spray-dried products (Bergquist, 1995; Zeidler, 2002b).

Heat treatment of dried whites is an approved method for pasteurization (FDA, 2012d). The storage of dried egg white at elevated temperatures has been shown to be an effective means of pasteurization (Cunningham, 1995; Zeidler, 2002b). Albumen is not damaged by storage at 54 °C for as long as 60 days. The moisture content of dried egg white is important and should be around 6.5–8.0% (Froning, 2008). The product should be held in the heat treatment room in a closed container and must be spaced to assure adequate heat penetration and air circulation (FDA, 2012d). The minimum requirements for heat treatment of spray- or pan-dried albumen are as follows:

- spray-dried albumen must be heated throughout to a temperature not less than 130 °F and held continuously at such temperature for not less than 7 days and until it is salmonella negative
- pan-dried albumen must be heated throughout to a temperature of not less than 125 °F and held continuously at such temperature for not less than 5 days and until it is salmonella negative. Mine (1995) reported that this process improves whipping properties of egg white.

19.11 Egg further processing (value-added processing)

The presence of many bioactive components in eggs opens new windows for value-added processing of eggs (Hatta et al., 2008; Huopalahti et al., 2007; Kovacs-Nolan et al., 2005a; Mine, 2007; Seko et al., 1997; Zeisel, 1992). Lysozyme is produced at commercial scale using cation exchange chromatography for various applications. Lysozyme is effective against gram-positive bacteria such as *Bacillus stearothermophilus*, *Clostridium tyrobutyricum*, and *Clostridium thermosaccharolyticum* (Losso et al., 2000). It is estimated that over 100 tonnes of lysozyme are used each year for these purposes (Scott et al., 1987). Lysozyme is a generally recognized as safe (GRAS) protein that has been approved for use in cheese making to prevent the growth of *Clostridium tyrobutyricum*, which causes off-odors and late “blowing” (unwanted fermentation) in some cheeses (Cunningham et al., 1991; Proctor & Cunningham, 1988), in wine and

beer production to control lactic acid bacteria such as *Lactobacillus* spp., which is a cause of spoilage (Daeschel et al., 1999; Gerboux et al., 1997), in meat products such as sausage, salami, pork, beef, or turkey (Bolder, 1997; Hughey et al., 1989), and in oral health care products such as toothpaste, mouthwash, and chewing gum (Sava, 1996; Tenuovo, 2002).

Avidin can be easily recovered as a co-product in lysozyme separation (Durance & Nakai, 1988). Avidin is the best known for its high biotin-binding ability and shows a bacteriostatic effect on bacteria that require biotin (Charter & Lagarde, 2004; Korpela et al., 1984). Ovotransferrin acts as an antimicrobial agent toward bacteria species such as *Pseudomonas* spp., *Escherichia coli*, and *Streptococcus mutans* (Valenti et al., 1983). This activity is largely bacteriostatic, being reversed by the addition of ferric ions; if the protein is saturated with iron, the bacteriostatic effect it has on gram-negative bacteria is overcome (Florence & Rehault, 2007).

Egg yolk antibodies may find wide applications, as previously reviewed (Kovacs-Nolan et al., 2004; Sunwoo et al., 2006). Immunoglobulin Y (IgY), with a molecular weight of 21–25 kDa, is a major antibody in birds. Antibodies combat the infectivity and toxicity of pathogenic antigens by recognizing and binding with the antigen in a specific manner; therefore they are able to enhance the immune system. IgY is transferred from the hen to the embryo through a receptor localized on the surface of the yolk membrane; egg yolk contains about 100 mg IgY/yolk (Hodek & Stiborova, 2003). IgY can be extracted by diluting egg yolk 10 times with water, followed by centrifugation, then sodium sulfate is added to the supernatant and the resulting precipitate is purified by ultrafiltration, alcohol precipitation or salt precipitation. Further precipitation can be obtained by gel filtration or anion exchange chromatography (Ko & Ahn, 2007). IgY can be used in the following immunotherapeutic applications: inhibition and/or prevention of *E. coli*, *Salmonella* spp., *Streptococcus mutans*, *Helicobacter pylori*, and Crohn's disease, among others (Kovacs-Nolan et al., 2005b). Wen et al. (2012) studied the preparation of IgY against specific influenza B virus with positive results in trials with mice. In addition, IgY can be used as a food ingredient in functional food products such as yogurt or as a bactericidal agent, in sport drinks, and in pharmaceutical products like acne medication (Li-Chan et al., 1995).

Egg proteins have shown great promise as a rich source of various bioactive peptides that may improve human health and prevent diseases. Peptides with antimicrobial,

antihypertensive, antioxidative, and immunomodulatory activity have been reported (During et al., 1999; Ibrahim et al., 2000; Lee et al., 2006; Majumder & Wu, 2010; Shen et al., 2010). The identification of these peptides represents a great commercialization opportunity since they have potential as health-promoting food ingredients in different areas, such as prevention and treatment of microbial infections of the gastrointestinal tract, control of microbiological quality of foods and feeds, and extension of shelf life of foods (Korhonen & Rokka, 2011).

19.12 Sustainability

In the 1980s, the major challenge of the egg industry was probably the public perception of the presence of cholesterol in egg yolk and its controversially associated risk of heart diseases. After four decades, the challenges facing the industry are more complicated; debate on the issue of cholesterol continues, and the increasing cost of feed in competition with the use of renewable agriculture products to replace increasingly expensive fossil-based oils and chemicals, concerns about animal welfare using the conventional cage system, globalization, etc. will affect the sustainability of the egg industry. The EU banned the conventional cage system in January 2012, mainly due to animal welfare concerns, while this is the most common commercial housing system for egg-laying hens in the US and other parts of the world. Adoption of a non-cage system will have substantial effects on the cost of production, as well as increased risk for bird-to-bird transmission and internal egg contamination of *Salmonella* and *Campylobacter* (Mench et al., 2011). Sustainability of the egg industry will depend on the community, the industry, the government, international organizations, researchers, and consumers working collectively to address issues of animal welfare, cost of production, environment, food safety, animal health, and human health.

19.13 Conclusion

As the primary animal protein in many parts of the world, egg products will continue to be an important part of our daily diets; new technologies and new methods of egg processing such as non-thermal processing will see applications in the egg industry to improve nutrition, safety, shelf-life and taste of egg products, or to create new egg products. New applications of egg products as functional foods and nutraceuticals and other non-food uses

are expected to grow. The egg industry is, however, at a time of rapid change; the industry needs to understand how the change in laying hens practice (removal of conventional cages, etc.) might affect egg safety and egg processing.

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