11 Eggs

11.1 Foreword

Eggs have been a human food since ancient times. They are one of nature's nearly perfect protein foods and have other high quality nutrients. Eggs are readily digested and can provide a significant portion of the nutrients required daily for growth and maintenance of body tissues. They are utilized in many ways both in the food industry and the home. Chicken eggs are the most important. Those of other birds (geese, ducks, plovers, seagulls, quail) are of lesser significance. Thus, the term "eggs", without a prefix, generally relates to chicken eggs and is so considered in this chapter. Table 11.1 gives some data on the production of eggs.

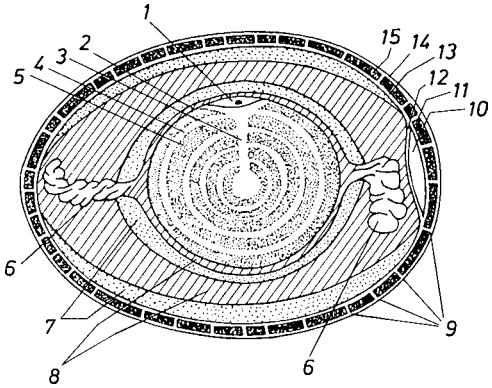


Fig. 11.1. Cross-section of a chicken egg – a schematic representation. Egg yolk: *1* germinal disc (blastoderm), *2* yolk membrane, *3* latebra, *4* a layer of light colored yolk, *5* a layer of dark colored yolk, *6* chalaza, *7* egg white (albumen) thin gel, *8* albumen thick gel, *9* pores, *10* air cell, *11* shell membrane, *12* inner egg membrane, *13* shell surface cemented to the mammillary layer, *14* cuticle, and *15* the spongy calcareous layer

11.2 Structure, Physical Properties and Composition

11.2.1 General Outline

The egg (Fig. 11.1) is surrounded by a 0.2–0.4 mm thick calcareous and porous shell. Shells of chicken eggs are white-yellow to brown, duck's are greenish to white, and those of most wild birds are characteristically spotted. The inside of the shell is lined with two closely adhering membranes (inner and outer). The two membranes separate at the large end of the egg to form an air space, the so-called air cell. The air cell is approx. 5 mm in diameter in fresh eggs and increases in size during storage, hence it can be used to determine the age of eggs. The egg white (albumen) is an aqueous, faintly straw-tinted, gel-like liquid, consisting of three fractions that differ in viscosity. The inner portion of the egg, the yolk, is surrounded by albumen. A thin but very firm layer of albumen (chalaziferous layer) closely surrounds the yolk and it branches on opposite sides of the yolk into two chalazae that extend into the thick albumen.

The chalazae resemble two twisted rope-like cords, twisted clockwise at the large end of the egg and counterclockwise at the small end. They serve as anchors to keep the yolk in the center. In an opened egg the chalazae remain with the yolk. The germinal disc (blastoderm) is located at the top of a clubshaped latebra on one side of the yolk. The yolk consists of alternate layers of dark- and light-colored material arranged concentrically.

The average weight of a chicken egg is 58 g. Its main components are water (∼74%), protein (∼12%), and lipids (∼11%). The proportions of the three main egg parts, yolk, white and shell, and the major ingredients are listed in Table 11.2. Table 11.3 gives the amino acid composition of whole egg, white and yolk.

Table 11.1. Production of eggs, 2006 (1000 t)[a]

Continent	Chicken egg	Other egg
World	61,111	5421
Africa	2224	7
America, Central-	2302	–
America, North-	5760	–
America, South- and Caribbean	5715	76
Asia	37,162	5256
Europe	10,021	79
Oceania	230	3

Country	Chicken egg	Country	Other egg
China	25,326	China	4529
USA	5360	Thailand	310
India	2604	Indonesia	202
Japan	2497	Brazil	75
Russian Fed.	2100	Philippines	72
Mexico	2014	Uzbekistan	48
Brazil	1675	Russian Federation	31
Indonesia	932	Korea, Republic of	28
France	850	Bangladesh	26
Spain	850	United Kingdom	16
Ukraine	819		
Turkey	753	∑(%)[b]	98
∑(%)[b]	75		

[a] Including egg for hatching.
[b] World production = 100%.

Table 11.2. Average composition of chicken eggs

Fraction	Percent of the total weight	Dry matter (%)	Protein (%)	Fat (%)	Carbohydrates (%)	Minerals (%)
Shell	10.3	98.4	3.3[a]			95.1
Egg white	56.9	12.1	10.6	0.03	0.9	0.6
Egg yolk	32.8	51.3	16.6	32.6	1.0	1.1

[a] A protein mucopolysaccharide complex.

11.2.2 Shell

The shell consists of calcite crystals embedded in an organic matrix or framework of interwoven protein fibers and spherical masses (protein-mucopolysaccharide complex) in a proportion of 50:1. There are also small amounts of magnesium carbonate and phosphates.

The shell structure is divided into four parts: the cuticle or bloom, the spongy layer, the mammillary layer and the pores. The outermost shell coating is an extremely thin (10 μm), transparent, mucilaginous protein layer called the cuticle, or bloom. The spongy, calcareous layer, i. e. a matrix comprising two-thirds of the shell thickness, is below the thin cuticle. The mammillary layer consists of a small layer of compressed, knob-like particles, with one side firmly cemented to the spongy layer and the other side adhering closely to the outer surface of the

Table 11.3. Amino acid composition of whole egg, egg white and yolk (g/100 g edible portion)

Amino acid	Whole egg	Egg white	Egg yolk
Ala	0.71	0.65	0.82
Arg	0.84	0.63	1.13
Asx	1.20	0.85	1.37
Cys	0.30	0.26	0.27
Glx	1.58	1.52	1.95
Gly	0.45	0.40	0.57
His	0.31	0.23	0.37
Ile	0.85	0.70	1.00
Leu	1.13	0.95	1.37
Lys	0.68	0.65	1.07
Met	0.40	0.42	0.42
Phe	0.74	0.69	0.72
Pro	0.54	0.41	0.72
Ser	0.92	0.75	1.31
Thr	0.51	0.48	0.83
Trp	0.21	0.16	0.24
Tyr	0.55	0.45	0.76
Val	0.95	0.84	1.12

shell membrane. The shell membrane is made of two layers (48 and 22 µm, respectively), each an interwoven network of protein polysaccharide fibers. The outer layer adheres closely to the mammillary layer. Tiny pore canals which extend through the shell are seen as minute pores or round openings (7000–17,000 per egg). The cuticle protein partially seals the pores, but they remain permeable to gases while restricting penetration by microorganisms.

11.2.3 Albumen (Egg White)

Albumen is a 10% aqueous solution of various proteins. Other components are present in very low amounts. The thick, gel-like albumen differs from thin albumen (cf. Fig. 11.1) only in its approx. four-fold content of ovomucin. Albumen is a pseudoplastic fluid. Its viscosity depends on shearing force (Fig. 11.2). The surface tension (12.5% solution, pH 7.8, 24 °C) is 49.9 dynes cm^{-1}. The pH of albumen of freshly laid egg is 7.6–7.9 and rises to 9.7 during storage due to diffusion of solubilized CO_2 through the shell. The rise is time and temperature dependent. For example, a pH of 9.4 was recorded after 21 days of storage at 3–35 °C.

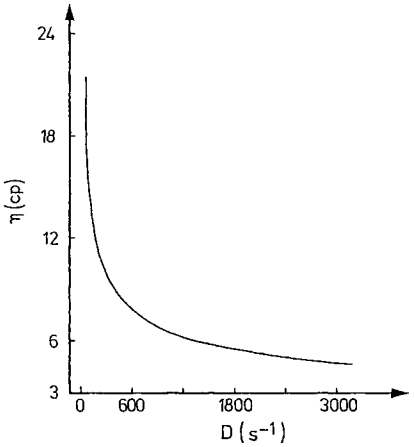


Fig. 11.2. Egg white viscosity, η, as affected by shear rate D, at 10 °C. (according to *Stadelman*, 1977)

11.2.3.1 Proteins

Table 11.4 lists the most important albumen proteins in order of their abundance in egg white. The carbohydrate moieties of the glycoprotein constituents are presented in Table 11.5. Several albumen proteins have biological activity (Table 11.4), i. e., as enzymes (e. g., lysozyme), enzyme inhibitors (e. g., ovomucoid, ovoinhibitor) and complex-forming agents for some coenzymes (e. g., flavoprotein, avidin). The biological activities may be related to protection of the egg from microbial spoilage. Egg white protein separation is relatively easy: the albumen is treated with an equal volume of saturated ammonium sulfate; the globulin fraction precipitates together with lysozyme, ovomucin and other globulins; while the major portion of the egg white remains in solution. This albumen fraction consists of ovalbumin, conalbumin and ovomucoid. Further separation of these fractions is achieved by ion-exchange chromatography.

11.2.3.1.1 Ovalbumin

This is the main albumen protein, crystallized by *Hofmeister* in 1890. It is a glycophospho-protein with 3.2% carbohydrates (Table 11.5) and 0–2 moles of serine-bound phosphoric acid per mole of protein (ovalbumin components A_3, A_2 and A_1, approx. 3, 12 and 85%, respectively).

Table 11.4. Proteins of egg white

Protein	Percent of the total protein[a]	Denaturation temperature (°C)	Molecular weight (kdal)	Isoelectric point (pH)	Comments
Ovalbumin	54	84.5	44.5	4.5	
Conalbumin (Ovotransferrin)	12	61.5	76	6.1	binds metal ions
Ovomucoid	11	70.0	28	4.1	proteinase inhibitor
Ovomucin	3.5		$5.5–8.3 \times 10^6$	4.5–5.0	inhibits viral hemagglutination
Lysozyme (Ovoglobulin G_1)	3.4	75.0	14.3	10.7	N-acetylmuramidase
Ovoglobulin G_2	4	92.5	30–45	5.5	good foam builders
Ovoglobulin G_3	4			5.8	
Flavoprotein	0.8		32	4.0	binds riboflavin
Ovoglycoprotein	1.0		24	3.9	
Ovomacroglobulin	0.5		760–900	4.5	inhibits serine and cysteine proteinases
Ovoinhibitor	1.5		49	5.1	proteinase inhibitor
Avidin	0.05		68.3[b]	9.5	binds biotin
Cystatin (ficin inhibitor)	0.05		12.7	5.1	inhibits cysteine peptidases

[a] Average values are presented.
[b] Four times 15.6 kdal + approx. 10% carbohydrate.

Table 11.5. Carbohydrate composition of some chicken egg white glycoproteins

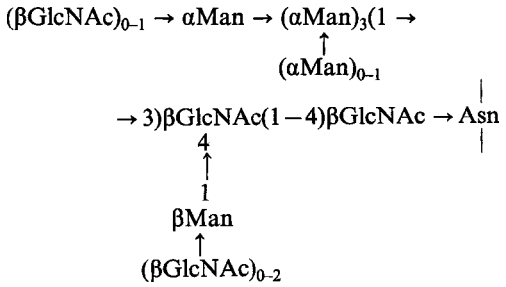
		Components (moles/mole protein)				
Protein	Carbohydrate (%)	Gal	Man	GlcN	GalN	Sialic acid
Ovalbumin	3.2		5	3		
Ovomucoid	23	2	7	23		1
α-Ovomucin[a]	13	21	46	63	6	7
Ovoglycoprotein	31	6	12	19		2
Ovoinhibitor (A)	9.2		10[b]	14		0.2
Avidin[c]	10		4(5)	3		

[a] In addition to carbohydrate, it contains 15 moles of esterified sulfuric acid per mole protein.
[b] Sum of Gal + Man.
[c] Data per subunit (16 kdal).

Ovalbumin consists of a peptide chain with 385 amino acid residues. It has a molecular weight $M_r = 42{,}699$ and contains four thiol and one disulfide group. The phosphoric acid groups are at Ser-68 and Ser-344. During the storage of eggs, the more heat-stable S-ovalbumin (coagulation temperature 92.5 °C) is formed from the native protein (coagulation temperature 84.5 °C) probably by a thiol-disulfide exchange. The content of S-ovalbumin increases from 5% in fresh eggs to 81% in eggs cold stored for 6 months. The carbohydrate moiety is bound to Asn-292 in the

sequence:

–Glu–Lys–Thr–Asn–Leu–Thr–Ser– with a probable structure as follows:



(11.1)

Ovalbumin is relatively readily denatured, for example, by shaking or whipping its aqueous solution. This is an interphase denaturation which occurs through unfolding and aggregation of protein molecules.

11.2.3.1.2 Conalbumin (Ovotransferrin)

Conalbumin and serum transferrin are identical in the chicken. This protein, unlike ovalbumin, is not denatured at the interphase but coagulates at lower temperatures. Conalbumin consists of one peptide chain and contains one oligosaccharide unit made of four mannose and eight N-acetylglucosamine residues.

Binding of metal ions (2 moles Mn^{3+}, Fe^{3+}, Cu^{2+} or Zn^{2+} per mole of protein) at pH 6 or above is a characteristic property of conalbumin. Table 11.6 lists the absorption maxima of several complexes. The occasional red discoloration of egg products during processing originates from a conalbumin-iron complex. The complex is fully dissociated at a pH less than 4. Tyrosine and histidine residues are involved in metal binding. Alkylation of 10 to 14 histidine residues with bromoacetate or nitration of tyrosine residues with tetranitromethane removes its iron-binding ability. Conalbumin has the ability to retard growth of microorganisms.

Table 11.6. Metal complexes of conalbumin

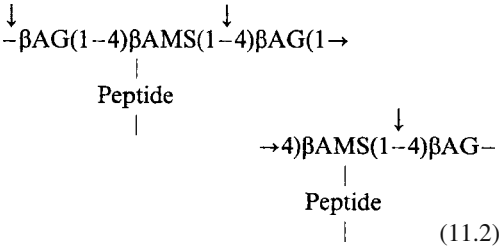
Metal ion	λ max (nm)	ε ($l\,mol^{-1}\,cm^{-1}$)	Complex color
Fe^{3+}	470	3280	pinkish
Cu^{2+}	440	2500	yellow
	670	350	
Mn^{3+}	429	4000	yellow

11.2.3.1.3 Ovomucoid

Ion-exchange chromatography or electrophoresis reveals 2 or 3 forms of this protein, which apparently differ in their sialic acid contents. The carbohydrate moiety (Table 11.5) consists of three oligosaccharide units bound to protein through asparagine residues. The protein has 9 disulfide bonds and, therefore, stability against heat coagulation. Hence, it can be isolated from the supernatants of heatcoagulated albumen solutions, and then precipitated by ethanol or acetone. Ovomucoid inhibits bovine but not human trypsin activities. The proportion of regular structural elements is high (26% of α-helix, 46% of β-structure, and 10% of β-turn).

11.2.3.1.4 Lysozyme (Ovoglobulin G1)

Lysozyme is widely distributed and is found not only in egg white but in many animal tissues and secretions, in latex exudates of some plants and in some fungi. This protein, with three known components, is an N-acetylmuramidase enzyme that hydrolyzes the cell walls of Gram-positive bacteria (murein; AG = N-acetyl-glucosamine; AMA = N-acetylmuramic acid; → = lysozyme attack):



(11.2)

Lysozyme consists of a peptide chain with 129 amino acid residues and four disulfide bonds, Its primary (Table 11.7) and tertiary structures have been elucidated (Fig. 11.3).

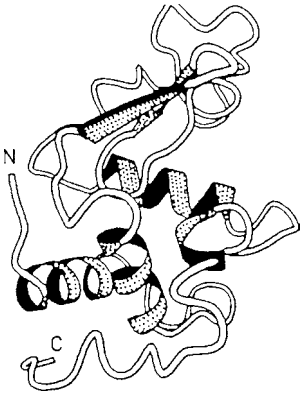


Fig. 11.3. Tertiary structure of lysozyme from chicken egg white (according to *McKenzie* and *White*, 1991)

11.2.3.1.5 Ovoglobulins G2 and G3

These proteins are good foam builders.

11.2.3.1.6 Ovomucin

This protein, of which three components are known, can apparently form fibrillar structures and so contribute to a rise in viscosity of albumen, particularly of the thick, gel-like egg white (see egg structure, Fig. 11.1), where it occurs in a four-fold higher concentration than in fractions of thin albumen.
Ovomucin has been separated into a low-carbohydrate (carbohydrate content ca. 15%) α-fraction and a high-carbohydrate (carbohydrate content ca. 50%) β-fraction. It appears to be associated with polysaccharides. The compositions of its carbohydrate moieties are given in Table 11.5. Ovomucin is heat stable. It forms a water-insoluble complex with lysozyme. The dissociation of the complex is pH dependent. Presumably it is of importance in connection with the thinning of egg white during storage of eggs.

11.2.3.1.7 Flavoprotein

This protein binds firmly with riboflavin and probably functions to facilitate transfer of this coenzyme from blood serum to egg.

11.2.3.1.8 Ovoinhibitor

This protein is, like ovomucoid, a proteinase inhibitor. It inhibits the activities of trypsin, chymotrypsin and some proteinases of microbial origin. Its carbohydrate composition is given in Table 11.5.

11.2.3.1.9 Avidin

Avidin is a basic glycoprotein (Table 11.5). Its amino acid sequence has been determined. Noteworthy is the finding that 15 positions (12% of the total sequence, Table 11.7) are identical with those of lysozyme. Avidin is a tetramer consisting of four identical subunits, each of which binds one mole of biotin. The dissociation constant of the avidin-biotin complex at pH 5.0 is $k_{-1}/k_1 = 1.3 \times 10^{-15}$ mol/l, i. e., it is extremely low. The free energy and free enthalpy of complex formation are $\Delta G = -85$ kJ/mole and $\Delta H = -90$ kJ/mole, respectively. Avidin, in its form in egg white, is practically free of biotin, and presumably fulfills an antibacterial role. Of interest is the occurrence of a related biotin-binding protein (streptavidin) in *Streptomyces* spp., which has antibiotic properties.

11.2.3.1.10 Cystatin (Ficin Inhibitor)

Chicken egg cystatin C consists of one peptide chain with a ca. 120 amino acid residues (M_r 12,700). The two isomers known differ in their isoelectric point (pI 5.6 and pI 6.5) and their immunological properties. This inhibitor inhibits cysteine endopeptidases such as ficin and papain. In fact, cathepsins B, H, and L and dipeptidyl peptidase I are also inhibited.

11.2.3.2 Other Constituents

11.2.3.2.1 Lipids

The lipid content of albumen is negligible (0.03%).

Table 11.7. Amino acid sequences of avidin (1) and lysozyme (2)[a]

1)		Ala	Arg	Lys	*Cys*	Ser	*Leu*	Thr	Gly	Lys	Trp
2)	Lys Val	Phe	Gly	Arg	*Cys*	Glu	*Leu*	Ala	Ala	Ala	Met
1)		Thr	Asn	Asp	Leu	Gly	Ser	*Asn*[b]	Met	Thr	Ile
2)		Lys	Arg	His	Gly	Leu	Asp	*Asn*[b]	Tyr	Arg	Gly
1)		Gly	Ala	Val	Asn	Ser	Arg	Gly	Glu	Phe	Thr
2)		Tyr	Ser	Leu	Gly	Asn	Trp	Val	Cys	Ala	Ala
1)		Gly	Thr	Tyr	Ile	Thr	Ala	Val	*Thr*	Ala	Thr
2)		Lys	Phe	Glu	Ser	Asn	Phe	Asn	*Thr*	Glu	Ala
1)		Ser	*Asn*	Glu	Ile	Lys	Glu	Ser	Pro	Leu	His
2)		Thr	*Asn*	Arg	Asn	Thr	Asp	Gly	Ser	Thr	Asp
1)		Gly	Thr	Glu	Asn	Thr	*Ile*	*Asn*	Lys	*Arg*	Thr
2)		Tyr	Gly	Ile	Leu	Glu	*Ile*	*Asn*	Ser	*Arg*	Trp
1)		Gln	Pro	Thr	Phe	*Gly*	Phe	*Thr*	Val	Asn	Trp
2)		Trp	Cys	Asn	Asp	*Gly*	Arg	*Thr*	Pro	Gly	Ser
1)		Lys	Phe	Ser	Glu	Ser	Thr	Thr	Val	Phe	Thr
2)		Arg	Asn	Leu	Cys	Asp	Ile	Pro	Cys	Ser	Ala
1)		Gly	Gln	Cys	Phe	Ile	Asp	Arg	Asn	Gly	Lys
2)		Leu	Leu	Ser	Ser	Asp	Ile	Thr	Ala	Ser	Val
1)		Glu	Val	Leu	*Lys*	Thr	Met	Trp	Leu	Leu	Arg
2)		Asn	Cys	Ala	*Lys*	Lys	Ile	Val	Ser	Asp	Gly
1)		Ser	Ser	Val	*Asn*	Asp	Ile	Gly	Asp	Asp	*Trp*
2)		Asp	Glu	Met	*Asn*	Ala	Trp		Val	Ala	*Trp*
1)		Lys	Ala	Thr	*Arg*	Val	*Gly*	Ile	Asn	Ile	Phe
2)		Arg	Asn	Arg	*Cys*	Lys	*Gly*	Thr	Asp	Val	Gln
1)		Thr	Arg	Leu	*Arg*	Thr	Gln	Lys	Glu		
2)		Ala	Trp	Ile	*Arg*	Gly	Cys	Arg	Leu		

[a] Italics: Identical amino acid in 1 and 2.
[b] Binding site for carbohydrates.

11.2.3.2.2 Carbohydrates

Carbohydrates (approx. 1%) are partly bound to protein (approx. 0.5%) and partly free (0.4–0.5%). Free carbohydrates include glucose (98%) and mannose, galactose, arabi-nose, xylose, ribose and deoxyribose, totaling 0.2–2.0 mg/100 g egg white. There are no free oligosaccharides or polysaccharides. Bound carbohydrates were covered previously with proteins (cf. 11.2.3.1 Table 11.5). Mannose, galactose and glucosamine are predominant, and sialic acid and galactosamine are also present.

11.2.3.2.3 Minerals

The mineral content of egg white is 0.6%. Its composition is listed in Table 11.8.

Table 11.8. Mineral composition of eggs

	Egg white (%)	Egg yolk (%)
Sulfur	0.195	0.016
Phosphorus	0.015–0.03	0.543–0.980
Sodium	0.161–0.169	0.026–0.086
Potassium	0.145–0.167	0.112–0.360
Magnesium	0.009	0.016
Calcium	0.008–0.02	0.121–0.262
Iron	0.0001–0.0002	0.0053–0.011

11.2.3.2.4 Vitamins

Data on vitamins found in egg white are summarized in Table 11.12.

11.2.4 Egg Yolk

Yolk is a fat-in-water emulsion with about 50% dry weight. It consists of 65% lipids, 31% proteins and 4% carbohydrates, vitamins and minerals. The main components of egg yolk are LDL (68%; cf. 3.5.1.2), HDL (16%), livetins (10%) and phosvitins (4%). Water transfer from egg white drops the solid content of the yolk by 2–4% during storage for 1–2 weeks. Egg yolk is a pseudoplastic non-*Newtonian* fluid with a viscosity which depends on the shear forces applied. Its surface tension is $0.044\ Nm^{-1}$ (25 °C), while its pH is 6.0 and, unlike egg white, increases only slightly (to 6.4–6.9) even after prolonged storage. Yolk contains particles of differing size that can be classified into two groups:

- *Yolk droplets* of highly variable size, with a diameter range of 20–40 µm. They resemble fat droplets, consist mostly of lipids, and some have protein membranes. They are a mixture of lipoproteins with a low density (LDL, cf. 3.5.1.2).
- *Granules* that have a diameter of 1.0–1.3 µm, i. e., they are substantially smaller than yolk droplets, and are more uniform in size but less uniform in shape. They have a substructure and consist of proteins but also contain lipids and minerals.

The first steps in the analysis of the proteins present in egg yolk are orientated towards the method used to classify lipoproteins (cf. 3.5.1.2). First, the granules are separated by the centrifugation of the diluted yolk (Fig. 11.4). They consist of 70% HDL, 12% LDL, which is very similar to the plasma LDL, and 16% phosvitin. After raising the density by adding salt, as shown in Fig. 11.4, the plasma is separated by ultracentrifugation into floating LDL (85% of the plasma), sedimenting γ-livetin and the α- und β-livetins remaining in solution, which are then precipitated with alginate.

Electrophoretic analyses of the lipid-free samples provide an insight into the proteins and apoproteins (lipoproteins after removal of the lipids, e. g., by extraction with acetone) present in egg yolk and its fractions. A relevant experiment, the results of which are presented in Table 11.9, shows 20 protein zones in the molecular weight

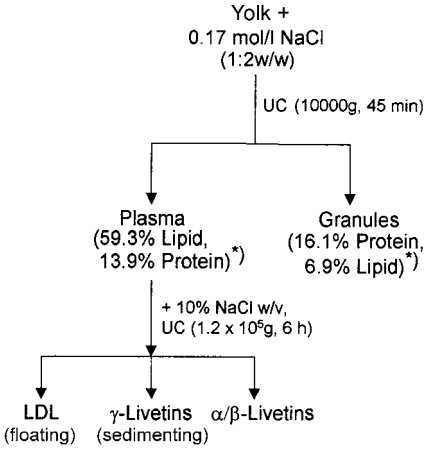


Fig. 11.4. A schematic representation of the fractionation of egg yolk.
UC: ultracentrifuge
*) Numbers: proportions of the yolk dry weight

Table 11.9. Proteins and apoproteins[a] identified in egg yolk, plasma (P) and granules (G) after electrophoretic separation (SDS-PAGE)

MW (kdal)	P/G	RV	S	Protein/Apoprotein
221	P	2.9	2	Apovitellenin VIa
203	P	8.7	1	γ-Livetin + Apovitellenin VI
122	P	7.7	2	Apovitellenin Va
110	G	21.4	1	Apovitellin 3 + 4
93	P	0.6	2	Apovitellenin Vb
85	P	1.6	2	Apovitellenin V
78	G	4.5	1	Apovitellin 5 + 6
73	P	1.5	2	α-Livetin
68	P	3.6	1	Apovitellenin IV
62	P	0.4	1	Apovitellenin IIIa
59	G	1.3		Phosvitin
55	P	10.7	1	α-Livetin/Apovitellenin III
47	G	4.8	2	Apovitellin 7
36	P	2.9	0	β-Livetin
33	P	4.8	0	β-Livetin
31	G	7.6	1	Apovitellin 8
21	P	0.3	2	Apovitellenin IIa
20	P	1.2	2	Apovitellenin II
17	P	9.6	1	Apovitellenin I
5	P	3.3	1	Apolipoprotein CII

[a] The samples were defatted before SDS-PAGE
MW: molecular weight; RV: relative volume of the protein zone; S: stability on heating (egg yolk diluted 1:5 (w/w) with 1% (v/v) NaCl solution was heated at 74 °C for 15 min): 0, thermostable; 1, partial damage; 2, thermolabile

range of 5 to 221 kdal. Fifteen zones which are mainly due to the apovitellins come from the plasma (Table 11.9). The granules are separated into phosvitin and four apovitellins, which appear at the molecular weights 31, 47, 78 and 110 kdal. However, it should be taken into account that the molecular weights of proteins determined using physical methods (e. g., electrophoresis, chromatography) represent only approximate values. The exact values can be calculated only after the amino acid sequence has been determined. The apovitellins 3 and 4 are quantitatively conspicuous. However, the quantities stated in Table 11.9 are only rough estimations because when the electropherogram is dyed, the proteins do not react with the same color yield, e. g., phosvitin is greatly undervalued in Table 11.9. Table 11.9 also indicates the differences in the thermostability of the proteins. On heating, most of the apovitellenins and α-livetin become insoluble and are, consequently, no longer visible in the electropherogram. Some lipoproteins and proteins will now be characterized more closely.

Table 11.10. Amino acid composition of phosvitin and α- and β-lipovitellins (mole %)

Amino acid	Phosvitin[a]	α-Lipovitellin	β-Lipovitellin
Gly	2.7	5.0	4.6
Ala	3.6	8.0	7.5
Val	1.3	6.2	6.6
Leu	1.3	9.2	9.0
Ile	0.9	5.6	6.2
Pro	1.3	5.5	5.5
Phe	0.9	3.2	3.3
Tyr	0.5	3.3	3.0
Trp	0.5	0.8	0.8
Ser	54.5	9.0	9.0
Thr	2.2	5.2	5.6
Cys	0.0	2.1	1.9
Met	0.5	2.6	2.6
Asx	6.2	9.6	9.3
Glx	5.8	11.4	11.6
His	4.9	2.2	2.0
Lys	7.6	5.7	5.9
Arg	5.3	5.4	5.6

11.2.4.1 Proteins of Granules

11.2.4.1.1 Lipovitellins

The lipovitellin fraction represents high density lipoproteins (HDL). Its lipid moiety is 22% of dry matter and consists of 35% triglycerides, approx. 60% phospholipids and close to 5% cholesterol and cholesterol esters (cf. 3.5.1). The lipovitellins can be separated by electrophoretic and chromatographic methods into their α- and β-components, which differ in their protein-bound phosphorus content (0.39 and 0.19% P, respectively). α-Lipovitellin consists of two polypeptide chains (M_r 111,000 and 85,000), but β-lipovitellin has only one chain (M_r 110,000). The vitellins are covalently bound to oligosaccharides made up of mannose, galactose, glucosamine and sialic acid. The stronger acidic character of α-lipovitellin is based not only on the higher phosphoric acid content, but also on the higher content of sialic acid. The two lipovitellins form a quaternary structure (M_r 420,000), which decomposes into subunits above pH 9. The amino acid composition is shown in Table 11.10. In the yolk, lipovitellins are present as a complex with phosvitin, with about two phosvitin molecules (M_r 32,000) for each lipovitellin molecule (M_r 420,000). The lipovitellins are heat stable. However, they lose this property if the lipids are separated.

11.2.4.1.2 Phosvitin

Phosvitin is a glycophosphoprotein with an exceptionally high amount of phosphoric acid bound to serine residues. For this reason, it behaves like a polyelectrolyte (polyanion) in aqueous solution. On electrophoresis, two components are obtained, α- and β-phosvitin, which are protein aggregates with molecular weights of 160,000 and 190,000. In the presence of sodium dodecyl sulfate, α-phosvitin dissociates into three different subunits (M_r = 37,500, 42,500 and 45,000) and β-phosvitin into only one subunit (M_r = 45,000). Its amino acid composition is given in Table 11.10. The partial specific volume of 0.545 ml/g is very low, probably due to the large repulsive charges of the molecule. The frictional ratio suggests the presence of a long, mostly stretched molecular form.
A partial review of its amino acid sequence shows that sequences of 6–8 phosphoserine residues, in-

terrupted by basic and other amino acid residues, are typical of this protein:

$$\cdots Asp—(Pse)_6—Arg—Asp\cdots$$
$$\cdots His—His—Arg—(Pse)_6—Arg—His—Lys\cdots \quad (11.3)$$

The carbohydrate moiety is a branched oligosaccharide, consisting of mannose (3 residues), galactose (also 3 residues), N-acetylglucosamine (5) and N-acetylneuraminic acid (2). The oligosaccharide is bound by an N-glycosidic linkage to asparagine. The amino acid sequence in the vicinity of the linkage position is shown in Formula 11.4.

$$\cdots Ser—Asn^{169}—Ser—Gly—(Pse)_8—Arg—Ser—$$
|
Carbohydrate
$$—Val—Ser—His—His\cdots \quad (11.4)$$

Phosvitin is relatively heat stable. In fact, no changes can be electrophoretically detected after 10 minutes at 110 °C. Phosphate is eliminated at 140 °C. Coagulating egg yolk is frequently enclosed in coagulates of other proteins.
Phosvitin very strongly binds multivalent cations, the type of metal and the pH being of importance. The iron in eggs, present as $Fe^{3\oplus}$, is bound to an extent of 95% to phosvitin and so strongly that its availability for nutrition is greatly limited. The $Fe^{3\oplus}$ complex is monomeric and phosvitin is saturated with iron at a molar ratio of Fe/P = 0.5; this strongly suggests formation of a chelate complex involving two phosphate groups from the same peptide chain per iron. Since phosvitin traps iron and other heavy metal ions, it can synergistically support antioxidants.

11.2.4.2 Plasma Proteins

11.2.4.2.1 Lipovitellenin

Lipovitellenin is obtained as a floating, low density lipoprotein (LDL) by ultracentrifugation of diluted yolk. Several components with varying densities can be separated by fractional centrifugation. The lipid moiety represents 84–90% of the dry matter and consists of 74% triglycerides and 26% phospholipids. The latter contain predominantly phosphatidyl choline (approx. 75%), phosphatidyl ethanolamine (approx. 18%) as well as sphingomyelin and lysophospholipids (approx. 8%). Eleven bands appear on electrophoresis of the apoproteins (Table 11.9).

11.2.4.2.2 Livetin

The water-soluble globular protein fraction can be separated electrophoretically into α-, β- and γ-livetins (Table 11.9). These have been proven to correspond to chicken blood serum proteins, i. e. serum albumin, α_2-glycoprotein and γ-globulin.

11.2.4.3 Lipids

Egg yolk contains 32.6% of lipid whose composition is given in Table 11.11. These lipids occur as the lipoproteins described above and, as such, are closely associated with the proteins occurring in yolk.
The fatty acid composition of the lipids depends on that of the feed (Table 11.12). However, the extent to which individual fatty acids are incorporated varies greatly. The addition of fats rich in linoleic acid to the feed, e. g., soy oil, leads to a great increase in this fatty acid. In comparison, only traces of the main fatty acid 10:0 of coconut oil is recovered (Table 11.12). Highly unsaturated ω-3-fatty acids (20:5, 22:6) from fish oils do appear in egg lipids, but not in proportion to their

Table 11.11. Egg yolk lipids

Lipid fraction	a	b
Triacylglycerols	66	
Phospholipids	28	
Phosphatidyl choline		73
Phosphatidyl ethanolamine		15.5
Lysophosphatidyl choline		5.8
Sphingomyelin		2.5
Lysophosphatidyl ethanolamine		2.1
Plasmalogen		0.9
Phosphatidyl inositol		0.6
Cholesterol, cholesterol esters and other compounds	6	

[a] As percent of total lipids.
[b] As percent of phospholipid fraction.

Table 11.12. Fatty acid composition of the lipids in egg yolk – Influence of feed[a]

	Fish oil (3%)[b]		Soy oil (12%)		Coconut oil (10%)	
Fatty acid	I	II	I	II	I	II
10:0	–	–	–	–	7.9	–
12:0	–	–	–	–	40.0	1.0
14:0	–	–	0.1	0.2	18.5	7.5
16:0	23.0	26.8	11.4	24.0	12.5	25.5
16:1	7.9	4.9	–	1.6	–	4.6
18:0	7.0	18.2	5.0	8.6	3.6	8.1
18:1	15.8	31.7	24.5	38.1	10.9	39.3
18:2	4.9	11.3	50.3	33.1	4.9	9.0
18:3	4.4	0.4	7.5	1.4	0.3	0.2
20:4	4.9	1.3	–	1.2	–	–
20:5	9.5	0.4	–	–	–	–
20:1	–	–	0.6	0.2	–	–
22:4	6.2	0.2	–	–	–	–
22:5	7.5	0.5	–	–	–	–
22:6	8.0	4.1	–	0.5	–	–

[a] Fatty acid distribution (weight %) in the lipids of the feed (I) and in the yolk (II).
[b] Fat content in the feed.

content in the feed. This also applies to 22:5 (Table 11.12). Furthermore, it has been observed that the fatty acid pattern of the feed is reflected more clearly in the triglyceride fraction of egg lipids than in the polar lipids.

About 4% of the egg lipids consists of sterols. The main component is cholesterol (96%), ca. 15% of which is esterified with fatty acids. The cholesterol content is 2.5%, based on the egg yolk solids. Disregarding mammalian brain, this level exceeds by far that in all other foods (cf. 3.8.2.2.1) and, therefore, serves as an indicator of the addition of eggs. Cholestanol, 7-cholestenol, campesterol, β-sitosterol, 24-methylene cholesterol and lanosterol are other components of the sterol fraction. The quality of egg products is endangered by autoxidation of cholesterol (cf. 3.8.2.2.1).

11.2.4.4 Other Constituents

11.2.4.4.1 Carbohydrates

Egg yolk carbohydrates are about 1% of the dry matter, with 0.2% bound to proteins. The free carbohydrates present in addition to glucose are the same monosaccharides identified in egg white (cf. 11.2.3.2.2).

11.2.4.4.2 Minerals

The minerals in egg yolk are listed in Table 11.8.

11.2.4.4.3 Vitamins

The vitamins in egg yolk are presented in Table 11.13.

Table 11.13. Vitamin content of whole egg, egg white and yolk (mg/100 g edible portion)

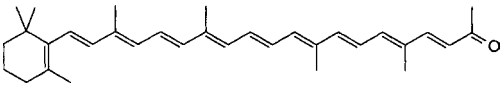
Vitamin	Whole egg	Egg white	Egg yolk
Retinol (A)	0.22	0	1.12
Thiamine	0.11	0.022	0.29
Riboflavin	0.30	0.27	0.44
Niacin	0.1	0.1	0.065
Pyridoxine (B_6)	0.08	0.012	0.3
Pantothenic acid	1.59	0.14	3.72
Biotin	0.025	0.007	0.053
Folic acid	0.051	0.009	0.15
Tocopherols	2.3	0	6.5
α-Tocopherol	1.9		5.4
Vitamin D	0.003		0.0056
Vitamin K	0.009		

11.2.4.4.4 Aroma Substances

The typical aroma substances of egg white and egg yolk are still unknown. The "fishy" aroma defect that can occur in eggs is caused by trimethylamine TMA, which has an odor threshold that depends on the pH (25 µg/kg, pH 7.9) because only the undissociated form is odor active. TMA is formed by the microbial degradation of choline, e. g., on feeding fish meal or soy meal. Normally, TMA does not interfere because it is enzymatically oxidized to odorless TMA oxide. However, in feed, e. g., soy meal, substances exist which could inhibit this reaction.

11.2.4.4.5 Colorants

The color of the yolk, which is produced by carotenoids in the feed, is considered to be a quality characteristic. Normally, xanthophylls (cf. 3.8.4.1.2) are absorbed from the feed, preferably lutein, followed by luteinmono- and diester, 3′-oxolutein and zeaxanthin. The color of the yolk can be intensified by the appropriate feed composition. The substances available dissolved in an oil are, e. g., β-*apo*-8′-carotene ethyl ester, citranaxanthin (5′,6′-dihydro-5′-*apo*-β-carotene-6′-one, Formula 11.5) and canthaxanthin.



(11.5)

11.3 Storage of Eggs

A series of changes occurs in eggs during storage. The diffusion of CO_2 through the pores of the shell, which starts soon after the egg is laid, causes a sharp rise in pH, especially in egg white. The gradual evaporation of water through the shell causes a decrease in density (initially approx. 1.086 g/cm^3; the daily reduction coefficient is about 0.0017 g/cm^3) and the air cell enlarges. The viscosity of the egg white drops. The yolk is compact and upright in a fresh egg, but it flattens during storage. After the egg is cracked and the contents are released onto a level surface, this flattening is expressed as yolk index, the ratio of yolk height to diameter. Furthermore, the vitellin membrane of the yolk becomes rigid and tears readily once the egg is opened. Of importance for egg processing is the fact that several properties change, such as egg white whipping behavior and foam stability. In addition, a "stale" flavor develops.

These changes are used for determination of the age of an egg, e. g., in the floating test (change in egg density), flash candling (egg yolk form and position), egg white viscosity test, measurement of air cell size, refractive index, and sensory assay of the "stale" flavor (performed mostly with softboiled eggs). The lower the storage temperature and the lower the losses of CO_2 and water, the lower the quality loss during storage of eggs. Therefore, cold storage is an important part of egg preservation. A temperature of 0 to −1.5 °C (common chilled storage or subcooling at −1.5 °C) and a relative humidity of 85–90% are generally used. A coating (oiling) of the shell surface with light paraffin-base mineral oil quite efficiently retards CO_2 and vapor escape, but a tangible benefit is derived only if oil is applied soon (1 h) after laying, since at this time the CO_2 loss is the highest. Controlled atmosphere storage of eggs (air or nitrogen with up to 45% CO_2) has been shown to be a beneficial form of egg preservation. Cold storage preserves eggs for 6–9 months, with a particularly increased shelf life with subcooled storage at −1.5 °C. Egg weight loss is 3.0–6.5% during storage.

Microbial spoilage is indicated by an increase in lactic acid and succinic acid to values above 1 g/kg and 25 mg/kg of dry matter respectively. 3-Hydroxybutyric acid serves as an indicator of fertilized eggs (>10 mg/kg of egg mass).

11.4 Egg Products

11.4.1 General Outline

Egg products, in liquid, frozen or dried forms, are made from whole eggs, white or yolk. They are utilized further as semi-end products in the manufacturing of baked goods, noodles, confectionery, pastry products, mayonnaise and other salad dressings, soup powders, margarine, meat products, ice creams and egg liqueurs. Figure 11.5 gives an overview of the main

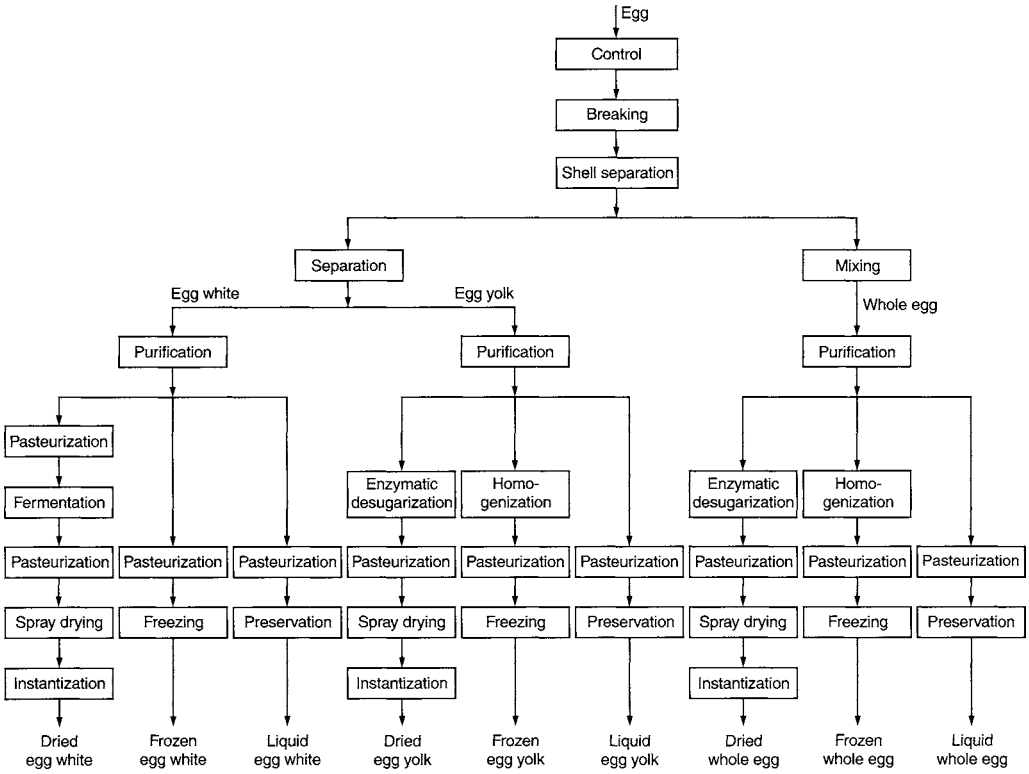


Fig. 11.5. Schematic presentation of the production of egg products

processing steps involved in manufacturing of egg products.

11.4.2 Technically-Important Properties

The many uses of egg products are basically a result of three properties of eggs: coagulation when heated; foaming ability (whippability); and emulsifying properties. The coloring ability and aroma of egg should also be mentioned.

11.4.2.1 Thermal Coagulation

Egg white begins to coagulate at 62 °C and egg yolk at 65 °C. The coagulation temperature is influenced by pH. At a pH at or above 11.9 egg white gels or sets even at room temperature, though after a while the gel liquiefies. All egg proteins coagulate, except ovomucoid and phosvitin. Conalbumin is particularly sensitive, but can be stabilized by complexing it with metal ions. Due to their ability to coagulate, egg products are important food-binding agents.

11.4.2.2 Foaming Ability

11.4.2.2.1 Egg White

Whipping of egg white builds a foam which entraps air and hence is used as a leavening agent in many food products (baked goods, angel cakes, biscuits, soufflés, etc.).
Due to a large surface area increase in the liquid/air interphase, proteins denature and aggregate during whipping. In particular, ovomucin forms a film of insoluble material between the liquid lamella and air bubble, thereby stabilizing the foam. Egg globulin also contributes to this effect by increasing the fluid viscosity and by decreasing the surface tension, both

effects of importance in the initial stage of the whipping process. In angel cake, egg white without ovomucin and globulins leads to long whipping times and cakes with reduced volumes. An excessive ovomucin content decreases the elasticity of the ovomucin film and thus decreases the thermal stability (expansion of air bubbles) of the foam. The stability of the foam is increased by polymers of conalbumin and ovalbumin, which are stable to sodium dodecyl sulfate and 2-mercaptoethanol.

The whipping properties of dried egg white can be improved by the addition of whey proteins, casein and bovine serum albumin. The foaming ability is also increased by weak proteolysis and partial hydrolysis of the oligosaccharides in the glycoproteins by treatment with amylases.

The whippability of egg white can be assayed by measurement of foam volume and foam stability (amount of liquid released from the foam in a given time).

Small amounts of yolk (0.1%) considerably reduce the foam formation.

11.4.2.2.2 Egg Yolk

Egg yolk can be whipped into stable foam only at higher temperatures (optimum 72 °C), the volume increasing about six fold in the process. Above the critical temperature, the volume falls and the proteins coagulate. The protein coagulation is prevented by reducing the pH value, e. g., by the addition of acetic acid. This effect is used in the production of highly stable sauces.

11.4.2.3 Emulsifying Effect

The emulsifying effect of whole egg or egg yolk alone is utilized, for example, in the production of mayonnaise and of creamy salad dressings (cf. 14.4.6). Phospholipids, LDLs and proteins are responsible for the emulsifying action of eggs.

11.4.3 Dried Products

The eggs are stored at 15 °C for up to 2 days because the content of the egg can be easily separated from the shell at this temperature. In some countries, eggs are disinfected with an aqueous chlorine solution (200 mg/l) before they are broken open.

The liquid content of eggs is mixed or churned either immediately or only after egg white and yolk separation. This homogenization is followed by a purification step using centrifuges (separators), and then by a pasteurization step (Fig. 11.5).

Since the egg white coagulates at 55 °C and the yolk and the whole egg coagulate between 62 °C and 65 °C, pasteurization requires lower temperatures than those used for milk (cf. 10.1.3.3), e. g., 52 °C/7 min for the egg white, 62 °C/6 min for the yolk and 64.5 °C/6 min for the whole egg.

The sugars are removed prior to egg drying to prevent reaction between amino compoents (proteins, phosphatidyl ethanolamines) and reducing sugars (glucose), thereby avoiding undesired brown discoloration and faulty aroma.

Glucose is removed from egg white after pasteurization (cf. 11.4.5), usually by microbiological sugar fermentation. The pH of the pasteurized egg liquid is shifted from 9.0–9.3 to pH 7.0–7.5 using citric or lactic acid, and then is incubated at 30–33 °C with suitable microorganisms (*Streptococcus* spp., *Aerobacter* spp.). The sugar in whole egg homogenate or yolk is removed in part by yeasts (e. g. *Saccharomyces cerevisiae*) or mainly by glucoseoxidase/catalase enzymes (cf. 2.7.2.1.1 and 2.7.2.1.2), which oxidize glucose to gluconic acid. Addition of hydrogen peroxide releases oxygen and accelerates the process.

Spray drying is the most important egg drying process. The yolk, which has a relatively high solids content, is dried directly. The egg white and the whole egg are concentrated from 11 to 18% and from 24 to 32% solids respectivey using membrane filtration, which saves energy in the drying process. The whole egg can also be concentrated by film boiling in vacuum. After heating to 45–50 °C, egg white is usually dried by high-pressure dispersion in a stream of air at 165 °C. In this process, the egg white heats up to 50–60 °C. The product is then stored in heat-maintaining rooms (post-pasteurization) for at least 7 days at 55 °C to kill pathogenic microbes.

The whole egg and egg yolk are brought to 64.5 and 63 °C respectively to reduce germs, fol-

Table 11.14. Composition of dried egg products (values in %)

Constituent	Whole egg	Egg white	Egg yolk
Moisture[a]	5.0	8.0	5.0
Fat[b]	40.0	0.12	57.0
Protein[b]	45.0	80.0	30.0
Ash	3.7	5.7	3.4

[a] Maximum values.
[b] Minimum values.

lowed by spray drying at high pressure or with a centrifugal atomizer. The temperatures of the hot air blown in are 185 °C (whole egg) or 165 °C (yolk). The temperatures of the air drop to 50–60 °C in the drying process, which results in a water content of 4–5%. The products are quickly cooled in a cold air stream to 25–30 °C to prevent lipid peroxidation. There is no post-pasteurization. Other egg drying processes, e. g., freeze drying, are hardly ever applied commercially.

Dried instant powder can be made in the usual way: rewetting and additionally drying the agglomerated particles. Egg white agglomerization is facilitated by addition of sugar (sucrose or lactose).

The shelf life of dried egg white is essentially unlimited. Whole egg powder devoid of sugar has a shelf life of approx. 1 year at room temperature, while sugarless yolk lasts 8 months at 20–24 °C and more than a year in cold storage. The shelf-life of powders containing egg yolk is limited by aroma defects which develop gradually from oxidation of yolk fat. The compositions of dried egg products are given in Table 11.14.

11.4.4 Frozen Egg Products

The eggs are pretreated as described above (cf. 11.4.3 and Fig. 11.5). The homogenate is pasteurized at 63 °C for 1 min (cf. 11.4.5) to lower the germ count and is then frozen quickly at −40 °C. The shelf-life of the frozen eggs is up to 12 months at a storage temperature of −15 to −18 °C.

Frozen egg white thickens negligibly after thawing, while the viscosity of egg yolk rises

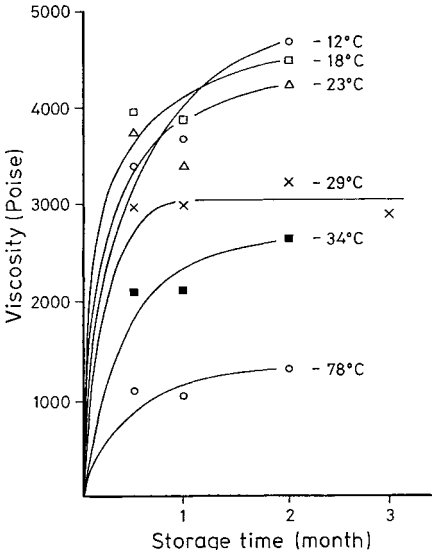


Fig. 11.6. Egg yolk viscosity after frozen storage. (According to *Palmer* et al., 1970)

irreversibly when freezing and storage temperatures are below −6 °C (Fig. 11.6). The egg yolk has a gel-like consistency after thawing, which hampers further utilization by dosage metering or mixing. Thawed whole egg gels can cause similar problems, but to a lesser extent than yolk. Pretreatment of yolk with proteolytic enzymes, such as papain, and with phospholipase A prevents gel formation. Mechanical treatments after thawing of yolk can result in a drop in viscosity. Gel formation can also be prevented by adding 2–10% common salt or 8–10% sucrose to egg yolk, cf. Fig. 11.7. Good results are also obtained with a solution containing glucose and fructose in the ratio of 45:55. The egg yolk is diluted with 70.3% and the whole egg with 45.2% of this solution. Although salted and sugar-sweetened yolk is of limited acceptability to some manufacturers, this process is of great importance.

The consistency of the frozen egg products is influenced by the temperature gradients during freezing and thawing, and also by storage duration and temperature. Rapid freezing and thawing are best.

The molecular events leading to gel formation by freezing are poorly understood. Apparently, the formation of ice crystals causes a partial dehydration of protein, coupled with a rearrangement of

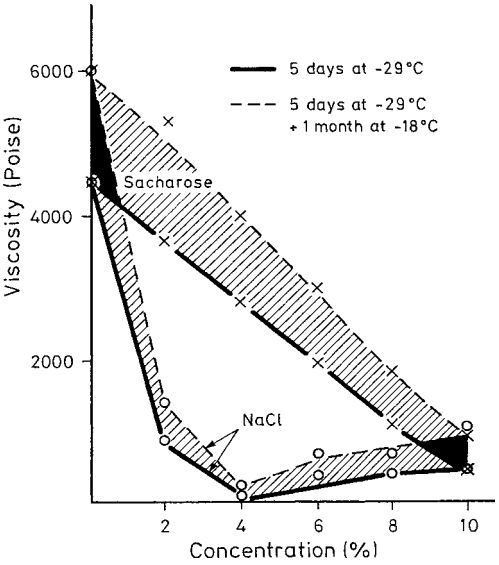


Fig. 11.7. Egg yolk viscosity on addition of NaCl or saccharose and after frozen storage. (according to *Palmer* et al., 1970)

Table 11.15. Composition of frozen and liquid egg products (values in %)

Constituent	Whole egg	Egg white	Egg yolk
Moisture	75.3	88.0	57.0
Fat	11	<0.03[a]	27.2
Protein	12	10.5	13.5
Reducing sugars	0.7	0.8	0.7

[a] Proportion of egg yolk (weight-%).

lipoprotein. This probably induces formation of entangled protein strands.

The whippability of egg white can be enhanced by various additives, such as glycerol, starch syrup and triethyl citrate. Typical compositional data for frozen egg products are provided in Table 11.15.

11.4.5 Liquid Egg Products

Eggs are pretreated as described earlier (cf. 11.4.3 and Fig. 11.5). Despite sanitary conditions at plants, eggs cannot be entirely protected from microorganisms. Pasteurization is difficult due to the heat sensitivity of egg protein and the need to kill the pathogens under specific conditions. It is especially important to eliminate *Salmonella* spp., which have varying resistances to heat. The most resistant are *S. senftenberg, S. oranienburg* and *S. paratyphi B*. Inactivation of α-amylase occurs as the temperature lethal to *S. senftenberg* is approached; hence, this enzyme can be used as an indicator to monitor the adequacy of the heat treatment. The heating conditions differ for different liquid egg products (cf. 11.4.3).

Most of the egg white proteins are relatively stable at pH 7, so normal pasteurization conditions do not negatively affect processing properties such as whippability. An exception is conalbumin, but addition of metal ions (e. g. Al-lactate) can stabilize even this protein. Addition of Na-hexametaphosphate can also improve the stability of conalbumin.

Pasteurized liquid egg products are generally also preserved by chemical means, e. g., addition of sorbic or benzoic acid.

The compositions of liquid egg products are presented in Table 11.15.

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