6

Egg products

For centuries the egg has been regarded as a high-quality food, although in the West, when we consider its nutritional value, we are basing our assessment almost exclusively on the properties of the hen's egg. The name 'egg products' includes eggs presented in ways other than in shells. After briefly summarising the biochemical characteristics of the egg, we will consider its nutritional value, functional properties and the current economic developments of this excellent raw material.

6.1 Structure and composition of the egg

6.1.1 Whole egg

The principal parts of the egg are, from the inside outwards: the yolk or vitellus, the white or albumen, the shell membranes (internal and external) and the shell. The relative proportions of each of these constituents can vary considerably. The average values applicable to a hen's egg are: shell 9.5%, white 61.5%, yolk 29.0%. A whole egg contains approximately 66% water, 11% mineral substances and 23% organic substances (12% proteins; 11% lipids).

6.1.2 Composition of the white

The white consists almost wholly of water and proteins, with a few minerals, which is very unusual for a product of animal origin (90% of the dry matter consists of proteins). It also contains free glucose (at double the concentration of blood plasma) which constitutes a primary source of energy

Table 6.1 Proteins in white of chicken eggs

Proteins	Dry matter (%)	Molecular mass (Da)	Isoelectric point	Temperature of denaturisation (°C)	Characteristics
Ovalbumin	54	46 000	4.6	84	Gelling agent
Conalbumin (ovotransferrin)	12	76 000	6.5	61	Combines with metals, bacteria inhibitor
Ovomucoid	11	28 000	4.0	70	Inhibits trypsin
Ovoglobulins	4 + 4	36 000–45 000	5.6	92	Foaming properties
Lysozyme	3.5	14 300	10.5	75	Lysis of bacteria
Ovomucin	3	$5.5–8.3 \times 10^6$	4.5–5.0		Viscosity factor
Ovoinhibitor	1.5	49 000	5.1		Inhibits serin proteases
Ovoglycoprotein	1.0	24 400	3.9		Viscosity factor
Flavoprotein	0,8	34 000	4.0		Binds vitamin B_2
Ovomacroglobulin	0.5	7.7×10^5	4.5		High antigen capacity
Ficin inhibitor	0.05	12 700	5.1		Inhibits SH proteases
Avidin	0.05	68 300	10		Complexes biotin

available to the embryo. Each protein is known for its specific properties, both functional and nutritional (Table 6.1):

- **Ovalbumin**, the most abundant protein in albumen, is a phosphoglycoprotein. It contains 3.5% carbohydrates with the number of moles of phosphate bonded to the serine residues varying from 2 to 0. The molecule contains four free sulphydryl groups and two disulphide bridges, but the number of the latter increases during storage and an '*S*-ovalbumin' is formed which is more thermostable than the native protein. The proportion of *S*-ovalbumin, which is 5% at the time of laying, can reach 80% after six months' cold storage.
- **Conalbumin** (or ovotransferrin) is a glycoprotein consisting of two sub-units. It has the capacity to bind bi- and trivalent metal cations into a complex. At its pHi one molecule can bind two cations and take on a red (Fe^{3+}) or yellow (Cu^{2+}) colour. These metal complexes are more thermostable than protein in the native state.
- **Ovomucoid** is a glycoprotein which consists of three sub-units. It is heat resistant – except in an alkaline medium – and has an anti-trypsin activity.
- **Lysozyme** is a holoprotein with a very high pH_i. It has a β-glucosaminidase enzymatic activity which allows it to lyse the wall of certain Gram-positive bacteria.
- **Ovomucin** is a glycoprotein whose carbohydrate content is almost 30%. The stretched structure of the molecule is a result of the electrostatic

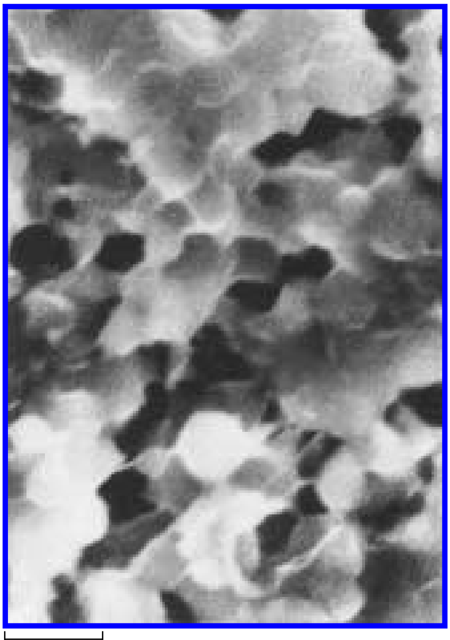

Fig. 6.1 Egg yolk granules in the native state. Observation under scanning electron microscope after freeze etching (–160 °C under vacuum) of a centrifuge residue (10 000 *g*, 45 min) of egg yolk diluted to ½. NaCl concentration: 0.085 M, 10 °C.

repulsion due to the negative charges of the residues of sialic acid which are responsible for the viscosity of the gel layer of the albumen. This protein is insoluble in water and soluble in salt solutions whose pH is higher than, or equal to, 7.

6.1.3 Composition of the yolk

The yolk is a dispersion of particles in a continuous aqueous phase or plasma (Fig. 6.1). The proteins and lipids in the yolk must be considered together, both from a chemical and a functional point of view. The yolk is actually a source of lipids which are easily dispersed in water, thus permitting emulsification of other substances. These properties are due to their high content in phospholipids and to the fact that all the lipids (including the triglycerides) are associated with at least two proteins, vitellin and vitellenin (Table 6.2). The constituents of the yolk can be separated by centrifuging into three fractions:

- A **low-density lipoprotein** (LDL) fraction (lipovitellenin) containing 90% lipids, almost all of which are triglycerides. This fraction represents approximately two-thirds of the dry matter of the yolk.

Table 6.2 Composition of chicken egg yolk

	Dry matter (%)	Proportion of yolk proteins (%)	Molecular mass	Lipid content	Phosphate content of proteins (%)	Location
Phosvitin	4	10	36 000	0	10	Granules
HDL lipovitellin	16	36	400 000	20	α = 0.5 β = 0,25	Granules
LDL lipovitellenin	68	24	3 et – 10 × 10^6	88	0.1	
Livetins	10	30	α: 80 000 β: 45 000 γ: 150 000	0	–	Continuous phase
Yolk riboflavin binding protein (YRBP)	1.5	0,4	36 000	0	0.2	Continuous phase

- A **high-density lipoprotein** (HDL) fraction which forms a granular sediment. It represents 23% of the total dry matter, contains phosvitin as well as lipovitellins (lipoproteins). These contain 18% lipids, divided more or less equally between triglycerides and phospholipids.
- A **soluble protein** fraction containing livetins and a few traces of other seric proteins.

The lipids in the yolk are represented by triglycerides (65–70%) and by phospholipids (25–30%), three-quarters of which have a phosphatidylcholine base. Phospholipids are richer in unsaturated fatty acids than the triglycerides but the fatty acid composition of these lipids can vary according to the food eaten by the hen.

The particles therefore contain three types of proteins. **Lipovitellins**, which constitute the HDL fraction, can be separated into α and β-lipovitellins. At a pH of under 7, they appear in the form of dimers. In **phosvitin**, serine represents 31% of the total number of the amino acid residues and over 90% are esterified by the phosphoric acid. This protein is capable of binding Fe^{3+} ions. The complexes formed are soluble and constitute an iron reserve.

The continuous phase contains two types of proteins. **Livetins** are globular proteins derived from proteins in the blood plasma of the hen and can be separated into three groups of different molecular mass (α, β, γ). **Lipovitellenins** can be separated into two fractions L_1 and L_2 with molecular masses of 10 and 3×10^6 Da respectively. In these lipoproteins, the proteins and the phospholipids are situated at the surface of a spherical structure whose core consists essentially of triglycerides and cholesterol.

Vitellenin has a balanced amino acid composition which is close to that

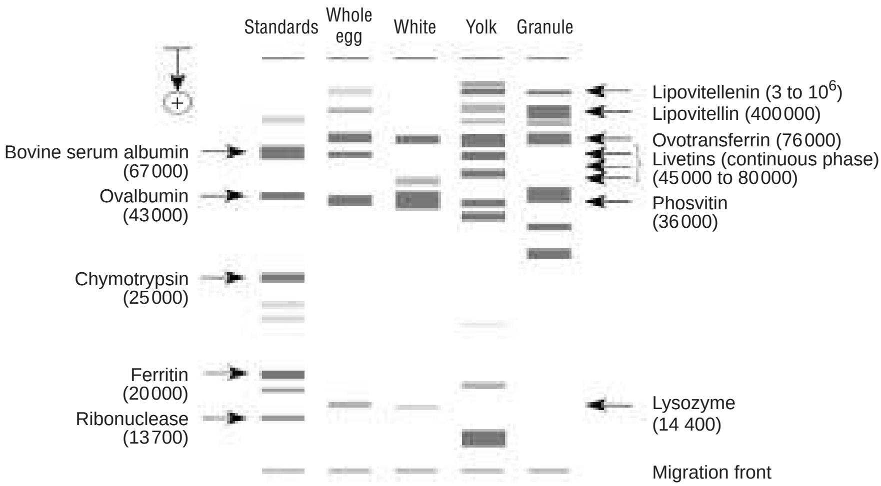

Fig. 6.2 Electrophoregram of egg proteins. Migration carried out in 7.5% polyacrylamide gel in the presence of SDS. Tris-Gly 0.04 M, pH 8.3 buffer.

of vitellin, but it contains very little cysteine. The YRBP (yolk riboflavin binding protein) is a flavoprotein which binds one mole of riboflavin (vitamin B_2) per mole of apoprotein. This glycoprotein whose pH_i is equal to 4.1 is immunologically identical to the flavoprotein in egg white. All the proteins in the white and the yolk are easily identifiable by electrophoresis in a dissociating sodium dodecyl sulphate (SDS) medium (Fig. 6.2).

6.2 Nutritional value of the egg

The egg is a fairly low-energy source of perfectly balanced proteins and easily digestible lipids. It is also an important source of phosphorus, iron and vitamins. On the other hand it is a food lacking in carbohydrates, calcium and vitamin C.

6.2.1 Biological value of the proteins

Egg proteins are well known for their very high biological value which results from the complementarity between the proteins in the yolk and those in the white, and from the balance between the amino acid residues in these proteins. The net protein utilisation (coefficient of digestive utilisation × biological value) of the proteins in the whole cooked egg reaches 94%, which is an indication of their excellent efficiency. In the raw state, proteins from the white eaten alone are only approximately 50% digestible because of the presence of anti-trypsin factors (ovomucoid) and in particular because the raw egg white is a poor stimulator of secretions of gastric and pancreatic juices. Cooking, by coagulating the proteins, facilitates the work of the digestive enzymes, and allows a 92% digestive utilisation to be reached, especially if the egg is accompanied by other foods. In addition, cooking destroys the biotin–avidin bond.

On the other hand, egg yolk is very easily digested in the raw state and any excessive cooking tends to reduce its digestive utilisation. In practice this effect is relatively weak and we can accept that all normal culinary preparations improve the digestibility of the white without adversely affecting that of the yolk. What is more, albumin proteins possess direct or indirect anti-bacterial biological properties (anti-protease activities, complexing vitamins or metals) which contribute to satisfactory egg storage. In this respect, we should stress that washing eggs encourages the penetration of bacteria, because it may eliminate the protective protein cuticle. Water penetration can then allow bacteria to enter. Eggs must therefore be dried quickly after washing.

6.2.2 Lipid digestibility

Egg yolk lipids are highly digestible by humans (between 94 and 96%) thanks to their emulsified state. This digestibility is higher in relation to the triglycerides (98%), the fraction that has the highest content in saturated fatty acids; but still reaches 90% for phospholipids. The egg yolk content in unsaturated fatty acids (approximately two-thirds that of total fatty acids), and particularly in linoleic acid, is moreover an important nutritional element for humans.

As far as the fairly high content of cholesterol (250–300 mg/egg) is concerned, several points should be made. When the daily ingestion level of cholesterol is reasonable, there is no direct relationship between this level and that of blood cholesterol. Eating an egg seems to fall below this threshold. In addition, the level of blood cholesterol depends on the other sterines ingested (plant sterine in particular) and on other dietary characteristics (caloric rate, fibre content, etc.).

6.2.3 Minerals and vitamins

Together with milk, the egg is the food richest in assimilable phosphorus whereas it supplies only a small amount of calcium in relation to human requirements. Another interesting nutritional characteristic of egg yolk is its high iron content, as an egg can meet 30% of a person's daily requirements in this element. If hens have received a balanced diet, the egg is an important source of vitamins. An egg meets between 10 and 15% of a person's daily requirement in vitamins A and D. This food can also supply approximately 5–10% of vitamin B_1 requirements, approximately 20% of vitamins B_2 and B_5 requirements and almost all the requirements in biotin (B_8). Cooking eggs for longer than 5 min can result in certain losses

– of vitamin A (up to 30%), vitamin B_1 and above all folic acid (B_9) (up to 50%).

6.3 Functional properties

Eggs and egg products are obviously used in the food industry for their nutritional value, but also for their functional properties which make them indispensable in numerous manufacturing processes. These properties, and their uses, are summarised in Table 6.3.

6.3.1 Aromatic and colourant capacity

The whole egg, and more particularly the yolk, has a characteristic and very highly valued flavour. The flavours are bound on the lipids of the yolk which contains over a hundred volatile compounds. The colour of the yolk determines the attraction and acceptability of the egg for the consumer. The colour of the vitellus depends on how rich it is in xanthophyll and carotenoid pigments, which come from the hen's diet.

6.3.2 Coagulation and gelling

Egg proteins are responsible for the coagulation which takes place as a result of the action of physical or chemical agents. The egg moves from a fluid state to a solid state called the coagulum. Thermal coagulation takes place from 62 °C upwards in the case of the white and from 65 °C upwards in the case of the yolk. The principal proteins of the white (ovalbumin and conalbumin) have good gelling properties. Ovomucoid alone does not coagulate. The proteins in the yolk are also subjected to thermal coagulation with the exception of livetins and phosvitin.

Salt and sucrose protect against heat denaturation and allow the temperature of pasteurisation to increase by 6 and 3 °C respectively. However, they also increase the resistance of micro-organisms. This protective effect can be explained by a reduction in the quantity of free water available in the soluble phase. Modifying the structure of the protein bound water improves the heat stability of the mixture and delays denaturation.

On the other hand, at the pH of egg yolk, sodium chloride reduces the protein load, affects the hydrogen bonds and increases the role of the hydrophobic bonds. Proteins can therefore aggregate with each other if the temperature is sufficiently high for denaturation to occur. The gelling properties of the yolk proteins are associated with the lipoproteins. LDLs are denatured from 60 °C upwards, lose their fluidity at 65 °C and form a gel at 85 °C. The gel obtained is more stable than bovine ovalbumin or serumalbumin gel prepared under the same conditions. Unlike these two proteins, the lipovitellenins (LDL) produce gels that are stable between pH 4 and 9.

Table 6.3 Functional characteristics of eggs and ovoproducts and their uses within the food industry

Capacities	Agents responsible	Variation factors	Products of substitution	Industrial applications
Aromatic (entire)	Numerous volatile compounds	Chicken diet Storage conditions Technological processes		All food industries
Colourant (yellow)	Xanthophylls Carotenoids	Chicken diet Light Presence of salt Drying	Colourants	Biscuit industry Baking industry Desserts Pasta
Coagulant (entire)	Coagulatable proteins	Time/ temperature pH, ionic strength Presence of sugars Dilution Technological processes	Carrageenan Alginates Modified starches	Biscuit industry Baking industry Processed meats
Binder (entire)	Proteins	Additives increasing viscosity Technological processes	Polysaccharides Pectins Gelatins Gums Proteins	Ice-cream Pasta Processed meat
Anti-crystalliser (white)	Proteins	Presence of yolk Presence of cations Technological processes	Polysaccharides	Confectionery
Foamer (white)	Globulins Lysozyme Ovomucin Ovalbumin	Age of egg Homogenisation Beating conditions pH Dilution Presence of salt or sugars Presence of yolk Technological processes	Caseins and caseinates Whey proteins	Biscuit industry Baking industry Confectionery Ready-made meals
Emulsifier (yellow)	Lecithins Lipoproteins Cholesterol	Beating conditions pH	Soya lecithins, dairy proteins	Biscuit industry Baking industry Processed

Table 6.3 *Continued*

Capacities	Agents responsible	Variation factors	Products of substitution	Industrial applications
		Dilution Presence of salt or sugars Presence of white Technological processes		meats (croquettes) Emulsified sauces

Modifications to functional properties after freezing–thawing are small and essentially associated with an increase in viscosity. The first constituents of the yolk to be affected by freezing are the LDLs and the gelling of the yolk in cold conditions is due to the protein–protein interactions following the rupture of the lipoproteins. In addition, the concentration of salts in the non-frozen phase will also be responsible for particle degradation.

6.3.3 Emulsifying properties

The high emulsifying properties of egg yolk are attributed to the phospholipids and in particular to the lecithins present in the form of lipoprotein complexes. Livetins and lipovitellins help to reduce surface tension and facilitate the formation of the emulsion, but do not influence stability. The LDLs contribute most to emulsion stability.

The hydrophobicity of the LDLs is higher than that of bovine serumalbumin or that of β-lactoglobulin. The lipid constituents that surround the apoprotein on the surface of the micelle produce a hydrophobic environment which facilitates the adsorption of the apoprotein at the interface while the emulsion is being formed. Denaturing the LDLs by heat processing reduces emulsifying activity and capacity, as well as the emulsion stability.

The high viscosity of egg yolk provides the emulsions with good stability. There is a linear relationship between the stability of the emulsion and the square root of the viscosity. Adding egg white to the yolk reduces the stability of the emulsions formed and this effect is essentially linked to a drop in viscosity. This observation is important, since industrial egg yolk can sometimes contain up to 20% egg white.

The viscosity of the yolk increases when sodium chloride is added as this improves the stability of the emulsions but results in a significant reduction in the emulsifying capacity of the constituents of the yolk. Salt causes the protein and lipoprotein complexes of the yolk to dehydrate, with the sodium chloride using some of the water to dissolve it. Dehydrated proteins would tend to group together, thus resulting in increased viscosity, but this would make migration and adsorption at the interface more difficult. In addition, salting allows functional properties to be retained more effectively following heat processing. Finally pasteurisation, freezing and concentration make little difference to the emulsifying properties.

6.3.4 Foaming capacity

Foaming capacity is a very valuable property of the white, and involves the ovomucin, the globulins and the ovalbumin. The proteins in the egg white show maximum foaming performances both at their 'native' pH (pH 8–9) and in the region of their isoelectric pH (4–5).

Sodium chloride increases bulking and reduces foam stability. This is probably the result of a drop in viscosity of the protein solution. The Ca^{2+} ions can improve stability by forming bridges between the carboxylic groups of the protein.

Carbohydrates depress the foam expansion but improve its stability. So, when manufacturing meringues or other products that need to swell, it is better to add the sucrose towards the end of the operation when the foam has already expanded. In this way, the foam-stabilising role played by the glycoproteins of the egg white (ovomucoid, ovalbumin) is linked to their capacity to retain water in the lamellae.

It is well known that low concentrations of contaminating lipids (less than 0.1%) seriously damage the foaming properties of proteins by placing themselves at the air/water interface, thus preventing, through competitive adsorption, the most favourable conformation of protein films.

Egg white is particularly sensitive to excessive beating. Beating egg white or ovalbumin for more than 6–8 min causes a partial aggregation–coagulation of proteins at the air/water interface. These proteins, which cannot be dissolved, are not properly adsorbed at the interface and do not form a coherent interfacial film, hence the viscosity of the liquid lamellae is not sufficient to create good foam stability.

Moderate heat processing used prior to foam formation improves the foaming properties of numerous proteins, one of which is egg white. These foams also have the property of retaining their structure during heating. However, severe drying processes seriously damage their swelling properties, because they reduce solubility.

6.3.5 Other functional properties

Egg white and, to a certain extent, the yolk possess excellent **binding properties**, with the latter involving the water-holding, lipid retention and adhesion properties. In addition, egg white possesses an **anti-crystallisation**

capacity; for example it delays the crystallisation of sucrose in a saturated solution and improves the homogeneity and the texture of confectionery products. Whereas the coagulating and emulsifying properties of the yolk are functional properties which are extensively involved in the physical behaviour of foods and their characteristics of taste, the binding capacity of the mineral elements is a property which is rarely brought to the fore.

However, the remarkable ability of the constituents of egg yolk to bind minerals could be used for nutritional purposes. The proteins responsible for this would actually allow the essential mineral elements to be conveyed in a form the organism can assimilate. Phosvitin has moreover been described as the protein which conveys iron for the embryo. It is possible to isolate two phosvitin–Fe^{3+} complexes of different colours, with their stoichiometric ratio equal to 2. In one case the iron is linked by a tetrahedric bond, and in the second case by an octahedric bond.

In the case of egg yolk, all the proteins, with the exception of the livetins, are phosphorylated and capable of binding minerals, but the phosvitin possesses by far the greatest chelating capacity. The Scatchard diagram shows 140 sites for binding magnesium and 160 for calcium with similar affinity constants. These values can be similar to the number of phosphate groups of the phosvitin.

6.3.6 Modifications to functional properties

When eggs are stored, the conversion of ovalbumin into *S*-ovalbumin, and the dissociation of the ovomucin–lysozyme complex, with destruction of the ovomucin gel, are important reactions from a technological point of view, since they result in at least partial loss of gelling and foaming properties and liquefaction of the egg white. These reactions are essentially due to a rise in pH. In fact, eggs permanently lose CO_2 which migrates through the membranes and the shell. This phenomenon, which can be accelerated by a rise in temperature, results in an increase of the pH of the albumen from 7.6 to a maximum value of 9.7. Several processes allow the rise in pH and its detrimental consequences to be reduced. It is thus possible to maintain an egg's quality for approximately 6 months at –1 °C (temperature slightly higher than its freezing point) and 90% relative humidity, in order to reduce loss of water by evaporation. Another solution consists of storing the eggs in an atmosphere that contains 2.5% CO_2. The reduction in the porosity of eggs, either by soaking in oil, or by briefly heating in water in order to coagulate a thin layer of proteins under the shell, or by using impermeable packaging, has also been tested. In all cases refrigeration is favourable. Later we will see that the whole liquid egg, the yolk or the white can also be stored by adding sucrose and/or salt, with or without prior concentration by ultrafiltration or even after dehydration.

6.4 Current economic developments

6.4.1 Technologies implemented

The principal operations involved in the technology of producing egg products are summarised in Fig. 6.3.

6.4.1.1 Breaking

This operation consists of breaking the eggs individually, as bulk-breaking is prohibited. The egg, placed automatically on a type of egg-cup, is struck by two blades which thus separate the egg into two half shells, with the white being separated from the yolk when it reaches a receiving spatula. Certain breaking machines are now equipped with a scanner to detect the presence of yolk in the whites.

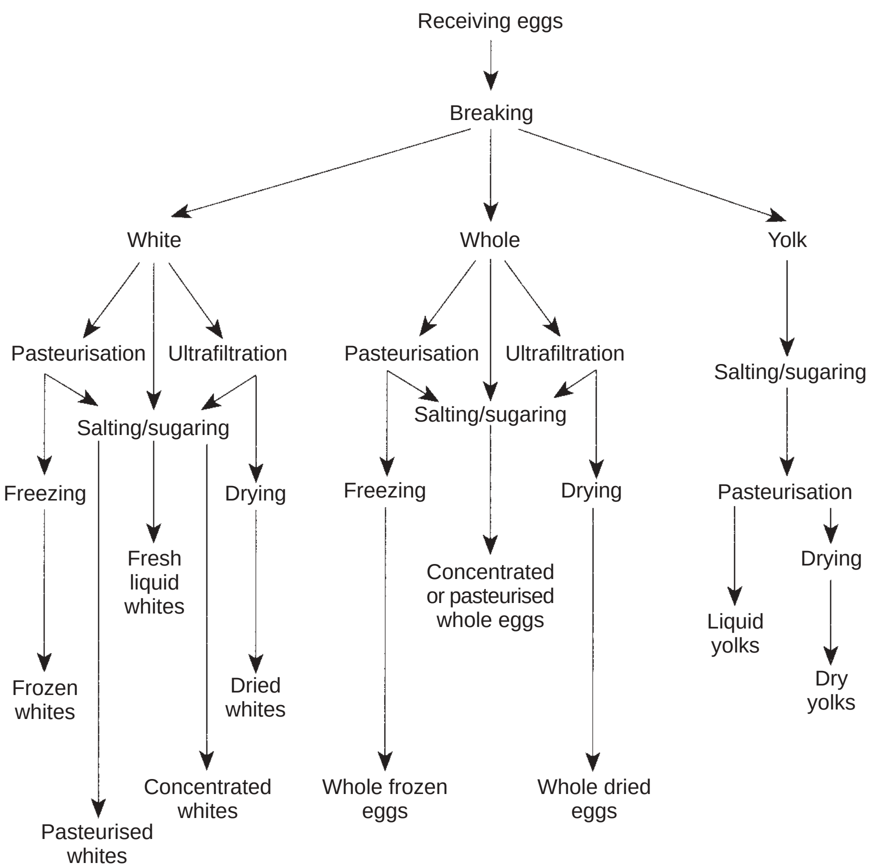

Fig. 6.3 Principal operations in the technology of egg products.

6.4.1.2 Separation and fractionation operations

Separation

The quality of white–yolk separation greatly depends on the state of freshness, and the storage conditions of the eggs, and therefore influences the subsequent functional properties of the egg products obtained. For example, migration of yolk into the white impairs the foaming capacity of the egg white. Further to this operation, it is possible to obtain liquid egg products in the form of yolks, whites or whole eggs, which are then strained in order to eliminate shell debris and to ensure the homogeneity of the products.

Fractionation techniques

The main techniques used to extract egg proteins for commercial use are as follows:

- Chromatography techniques:
  - by ion exchange in order to extract avidin, flavoproteins, ovoglobulins and lysozyme;
  - affinity chromatography used to extract the proteins which exhibit biological activity, such as avidin, flavoprotein, conalbumin;
  - gel-filtration used as a preparatory stage in the separation of ovomucin and as a method of effecting quantitative analysis of the lysozyme.
- Techniques of precipitation by means of:
  - reduction or increase in ionic strength, for example in order to prepare ovomucin, or to precipitate lysozyme using NaCl;
  - ammonium sulphate, in order to separate the proteins in the mixture: separation of ovalbumin and ovomucoid.

6.4.1.3 Pasteurisation

The purpose of this process is to eliminate pathogenic micro-organisms such as the salmonella present in liquid egg products, by applying time scales of 2.5 min at 58 or 64.4 °C, depending on whether this involves whole eggs, yolks or whites.

The treatments employed require plate exchangers, with a corrugated surface, tubular ones or those with hot incubators in order to pasteurise dehydrated whites (six days at 52 °C). Generally speaking, high pasteurisation reduces the foaming capacity of egg whites and has no effect on the emulsifying capacity of the yolks, if these are salted in advance.

6.4.1.4 Salting and sugaring

These operations are used to prepare the egg products for subsequent treatments, so as to retain their functional properties and improve storage. Salting is an operation employed prior to extracting lysozyme from the egg white, as a means of increasing the coagulation temperature with a view to using more severe heat treatments applied to the whole eggs and yolks. Sugaring is used for the same reasons.

6.4.1.5 De-sugaring

This is applied to egg whites in order to eliminate glucose and avoid the phenomena associated with the Maillard reaction during heat processing. It operates either by means of fermentation, by incorporating bacteria or yeasts, or by means of an enzyme (prohibited in France) using glucose-oxidase and catalase. Generally speaking, foaming capacity is improved in egg whites that have had their sugar removed.

6.4.1.6 Concentration

Ultrafiltration is the technique most frequently used for concentrating egg products which have between 11 and 33% dry matter for the white, from 24 to 48% for the whole egg and 46% for the yolk. It is used either to obtain products to be marketed in a concentrated form, or as a preliminary stage before dehydration. The advantage of this procedure is that it does not involve heat and is therefore practically non-denaturing for egg products, apart from the whites whose foaming properties reduce slightly. In addition, these egg products, which are liquid at intermediate moisture contents, can be kept from between six months and one year at ambient temperature.

6.4.1.7 Freezing

This is applied to liquid egg products which need to be stored. They need to be pasteurised no later than 12 hours after breaking. This is carried out in cells or in tunnels at –45 °C or on shelling cylinders which permit products in the form of straws to be obtained. These are easy to measure out and quickly defrost. From the point of view of functional properties, the viscosity of the yolks and the whole eggs increases after rapid thawing, whereas it is almost stable for the whites. Retaining these qualities is directly associated with the rate of freezing.

6.4.1.8 Drying

This allows the water content of the various egg products to be lowered by means of various processes:

- **Spray drying:** this is applied to previously concentrated egg products, with sucrose removed from the whites, salted or sugared to limit denaturation. Centrifugal spraying is generally preferred to spraying by pressure (nozzle) which is not as easy to use.
- **Freeze drying:** this permits products of excellent quality to be obtained from the frozen egg product, but it is still very costly for industrial use. Emulsifying and foaming properties are affected since after rehydration the yolks are more viscous and protein solubility reduces during storage.

6.4.1.9 *Irradiation*

To date this technique has not received authorisation, but trials carried out reveal its advantages in reducing pathogenic flora and in improving egg product storage. Doses applied using electron accelerators or X-rays vary from 2 to 4 kGy. Problems with taste and smell are encountered in connection with egg products which have been frozen in the absence of oxygen. The foaming capacity of the whites tends to increase.

6.4.2 Industrial uses

Egg products are widely used within the food industry for their first class functional properties (Table 6.4). Although their cost remains high in comparison with other protein binders (milk, blood, soya proteins, for example), the excellent foaming or coagulating properties of the white, and the emulsifying properties of the yolk, give them unquestionable advantages.

6.4.2.1 *Functional qualities of some egg products*

A comparative study has allowed us to understand certain functional properties of some spray-dried egg powders, by comparing the results between

Table 6.4 Advantages and limitations of using the principal types of egg products

Type	Advantages	Limiting factors
Liquid egg products	Functional properties similar to eggs in shells Great flexibility of use Preparation of à la carte products varying the dry extract, salt, sugar Depending on salt or sugar concentrations → sale limit at 3 °C varies from 5 days to to 1 month	Must be used immediately before knowing the results of the microbiological checks
Frozen egg products	Increased viscosity and return to normal value possible by adding salt and/or sugar Bacteriological quality identical to the fresh product if used immediately after thawing	Storage at –20 °C and mastery of thawing Not very flexible to use Modified functional properties and sample heterogeneous after thawing
Powdered egg	Cheap transport and storage costs Storage over 1 year at 20 °C Stable bacteriological quality Increased viscosity of rehydrated eggs	Functional properties reduced (in particular swelling capacity, coloration) Removal of sugar from whites for successful storage Rehydration operation not yet mastered

these and other egg products (fresh, frozen, etc.). As far as the results obtained for the whole egg are concerned, this study showed that the temperature and gelling time were very close, no matter what product was tested, and that in particular there were very few differences at this level between powders and fresh eggs; the gelling strength depended more on the pH than on the form of the whole egg (powder, fresh, etc.).

The emulsifying capacity of the whole eggs did, however, depend on the form of the product; it was significantly higher in the case of the fresh egg than in the case of a powder. With regard to the results obtained with egg whites, the gelling times of the white are comparable, whether these are fresh, frozen or powdered. The gelling temperatures of these different products are also very close, but slightly lower in the case of the fresh egg. However, gels of egg whites obtained from powders are firmer than those obtained using other forms of white.

The emulsifying properties of egg white powders are closely linked with the pH of the product. The emulsifying properties of fresh egg whites are consistently higher than those of powdered ones. The foaming capacity of powdered egg whites are, on the other hand, consistently higher than those of fresh or frozen egg whites. This might seem surprising because, generally speaking, drying damages the foaming properties of proteins; however, powdered egg whites undergo pre-treatment (de-sugaring) and above all post-treatment (oven-drying) which increases the foaming capacity and the gelling capacity. The various stabilities of foams from powdered whites seem, on the other hand, to be very close, at a given pH, to those of fresh and frozen egg whites. We should also point out that the emulsifying capacity of powdered yolks is clearly lower than that of fresh egg yolks. On the other hand, the stability of egg yolk emulsions obtained from powders is higher than that obtained with fresh eggs.

Measurements of viscosity carried out on egg yolks have shown that egg yolk from powder possesses a viscosity which is approximately ten times higher than the fresh yolk between 25 and 60 °C. On the other hand, at a temperature of 70 °C, the viscosities are more or less the same.

6.4.2.2 Using egg products as food ingredients

Because of their functional and nutritional properties, and in their various forms (liquids, dehydrated, frozen), egg ingredients allow the manufacture of the following types of products:

- Shelled hard-boiled eggs.
- Frozen or dehydrated omelettes.
- Hard-boiled egg cubes for egg salads and aperitifs.
- Egg sausage.
- Egg ketchup – flavoured sauce based on egg yolk.

- Drinks – orange juice mixed with whole liquid eggs, egg liqueurs, eggnog.
- Scotch eggs – hard-boiled eggs covered with sausage meat.
- Egg white yoghurts.
- Ready-to-use mixes.

Work has been carried out using dehydrated egg products, with a view to modifying them for ready-to-use mixes: powdered pancake mix, powdered flavoured omelettes, cooked meat mixes, vegetable pâtés, poundcakes, etc.

6.4.2.3 Molecules of technological and pharmaceutical use

As a result of using and developing fractionation techniques, certain egg white and yolk proteins with useful biological properties can be used and purified, such as the following.

Extracts of the white

- Lysozyme: this is well known for its anti-trypsic and anti-bacterial qualities especially in relation to the vegetative cells of *Clostridium butyricum*, hence its potential use in the dairy and pharmaceutical industries.
- Conalbumin: its chelating properties allow it to transport mineral substances within the organism.
- Ovomucoid, the ovoinhibitor: these proteins are essentially used for their anti-trypsic properties.
- Avidin and flavoprotein: these have nutritional advantages because they transport biotin and riboflavin respectively.

Extracts of the yolk

- Lecithin is used in cosmetic and food products, but for economic reasons it is extracted from soya.
- Phosvitin: on the one hand this protein provides a higher and more easily assimilated source of phosphorus than casein, and on the other it possesses antioxidant properties.

Extracts of the shell

These are hardly ever exploited commercially, firstly because of problems of collection, and secondly because of the relatively low tonnages which limits such uses as:

- incorporation in metals;
- use as fertiliser;
- use of the keratin present in the cuticle with a view to extracting cysteine, which is already carried out using poultry feathers.

6.4.3 Future prospects

The development of egg products and processed products based on eggs on the market shows how dynamic the industry is in finding solutions for the need to improve added value and increase consumption, which is an essential condition for improved commercial use.

However, although numerous investigations carried out to date have made an effective contribution to this development, efforts in terms of research must be intensified. Among the priority routes to take, we could cite the following:

- Developing products that have been adapted to changes in consumer habits (semi-processed, processed products).
- Adjusting egg products adapted for industrial use which consist of either egg proteins only, or mixtures that combine them with proteins of other origins (milk, gluten, legumes, etc.).
- The search for new fractionation techniques capable of extracting certain constituents of eggs having a high added value at a competitive price.
- Looking for new storage techniques capable of retaining functional qualities more successfully.