CHAPTER 2: LITERATURE REVIEW

2.1 Egg composition

A schematic side view of an egg is shown in Figure 1. Eggs mainly consist of shell, albumen (egg white), yolk, chalazae, an air cell and shell membranes.

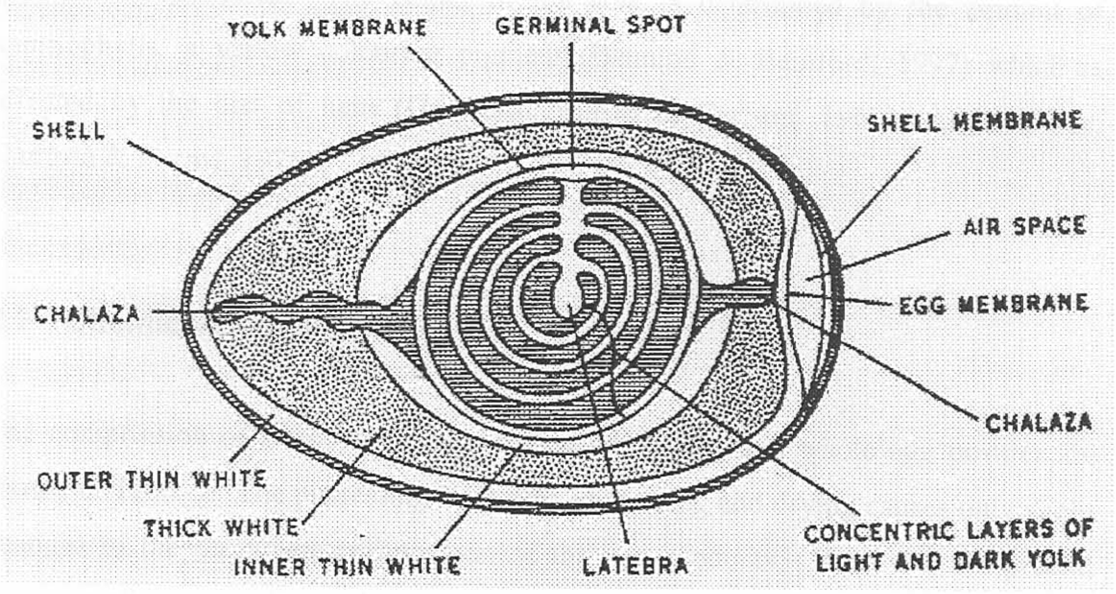

Figure 1 Schematic drawing of the internal structure of a hen's egg (Forsythe, 1957)

Egg albumen is made up of four distinct layers: outer thin white, viscous or thick white, inner thin white, and a chalaziferous layer (Almquist & Lorenz, 1933). It contains about 85% (in dry matter) of the total protein content of an egg (Bennion & Bamford, 1997). The major proteins of albumen are ovalbumin, conalbumin (ovotransferrin), ovomucoid, lysozyme and ovomucin (Parkinson, 1966). The whites are viscous and have a high pH (pH 8.2 - 9) (Toney & Bergquist, 1983) in a fresh egg. The pH changes to a maximum value of about 9.7 (Heath, 1977) during storage due to the loss of carbon dioxide. At this pH, the function of lysozyme, which forms a chemical protection against microorganisms is lost (Cotterill & Winter, 1955;

Bennion & Bamford, 1997). The egg albumen thinning during storage is also affected by pH (Cotterill & Winter, 1955).

Egg yolk can be regarded as a mixture of particles and plasma. The plasma includes low-density globules which are rich in fat (Parkinson, 1966). The egg yolk protein (livetin) consists of lipoproteins. The pH of egg yolk is pH 6.0 for fresh eggs whereas the pH changes to between pH 6.4 – 6.9 during storage (Li-Chan *et al.*, 1995). Egg yolk contains a high capacity for pigmentation and has a high proportion of yellow yolk globules. The colour of the yolk is determined by the amount of xanthophylls, a yellow colouring pigment (Bennion & Bamford, 1997) which is affected by the diet of hens (Deethardt, Burrill & Carlson, 1965b; Angalet, Fry, Damron & Harms, 1976).

2.2 Chemical composition

The composition of fresh whole egg, frozen whole egg and whole egg powder are shown in Table 1. The processing by means of freezing and drying causes only slight changes to the proximate composition of the egg products. However, the protein structure of egg ingredients change and the liberation of free fat may occur (Powrie & Nakai, 1985).

Table 1 Proximate composition of fresh whole egg, frozen whole egg and whole egg powder on dry base (Adapted from Watkins, 1995)

Composition	Shell egg	Frozen egg pulp	Whole egg powder
Protein (%)	49.00	48.98	48.97
Lipid (%)	44.54	44.49	44.52
Carbohydrate (%)	2.38	2.45	2.38
Ash (%)	4.08	4.08	4.13

2.3 Egg processing

Improved technology and the development of mechanical equipment were responsible for small-scale egg processing lines to become large commercial operations (American Egg Board, 2001). Egg products for commercial usage include liquid, frozen and dried whole egg, albumen and yolk. Various blends of whole egg and yolk are also included (Stadelman *et al.*, 1988). The processing steps of whole egg products are shown in Figure 2.

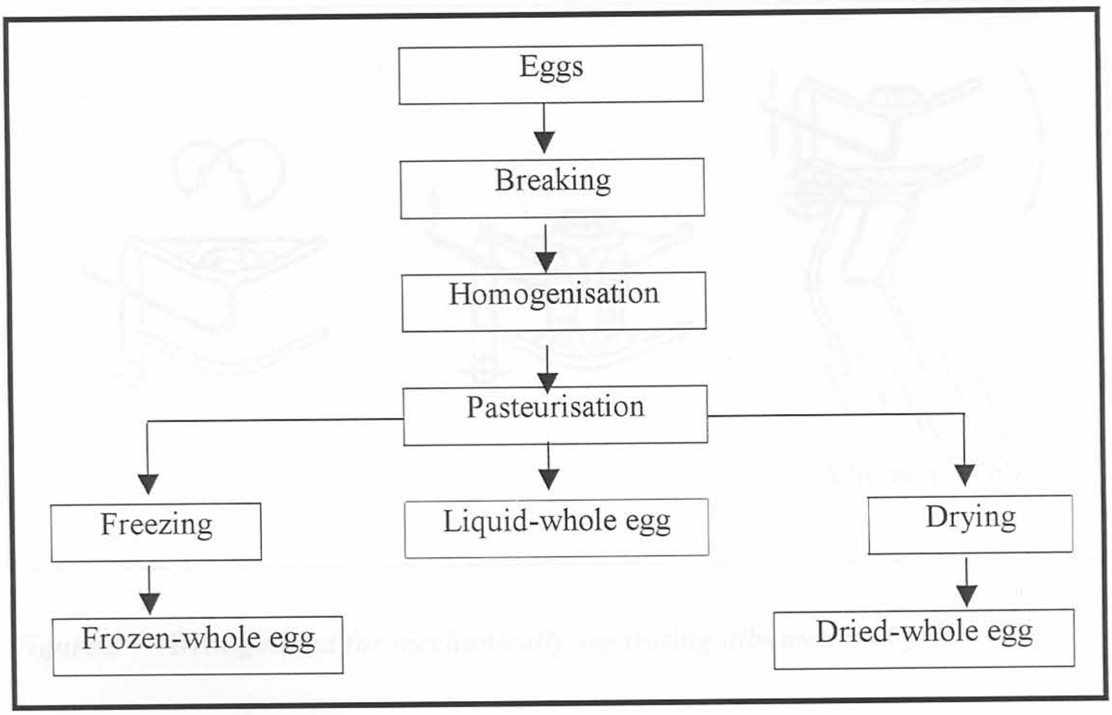

Figure 2 The processing steps of whole egg products (Adapted from Linden & Lorient, 1999)

Ultra-pasteurisation and irradiation have also been used to process whole egg products.

2.3.1 Breaking

This operation (Figure 3) is to break the eggs and separate the yolk, albumin and shells. The egg is placed automatically on a type of egg-cup, is struck by two blades which thus break the egg into two halves. When the egg reaches a receiving spatula, the white will separate from the yolk (Linden & Lorient, 1999). For efficiency and product quality, the breaking plant should be as close to the site of shell-egg production as possible (Watkins, 1995). The broken egg is very easily contaminated by bacteria. Thus, the sanitation system and handling practices in the plant must be very well organized (Galyean, Cotterill & Cunningham, 1972).

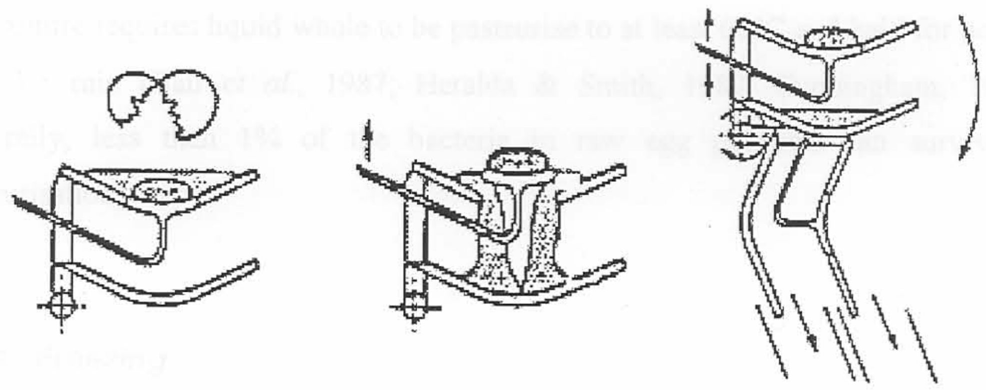

Figure 3 Arrangement for mechanically separating albumen and yolk

2.3.2 Homogenisation

This processing step is to blend the egg white and yolk. The whole egg product's solid level must be standardized to 24.0% -24.5% whereas the solid level of shell egg solids may range between 21% and 25% (Du Preez, 2000). The homogenisation can reduce the severity of heat processing such as pasteurisation and drying (Kincal, 1987).

2.3.3 Pasteurisation

Pasteurisation was first practiced by the egg product industry in the 1930s (Moore, Warren, Davis & Johnson, 1988). The main purpose of pasteurising is to create a wholesome product by eliminating pathogenic bacteria, such as salmonellae. This pathogenic bacteria has been the primary concern for eggs and egg products (Cunningham, 1995). The conditions of pasteurisation depend on the composition of the egg products, and it is closely related to the pH of the egg products. Since *Salmonellae* are most heat resistant at pH 5 to 6, therefore, the pasteurisation conditions are different between the whole egg, egg yolk and egg albumin. In addition, the solid and nature of constituents of the final egg product are also a factor of concern to decide the pasteurisation condition. The United States Department of Agriculture requires liquid whole to be pasteurise to at least 60°C and held for no less than 3.5 min (Ball *et al.*, 1987; Heralda & Smith, 1989; Cunningham, 1995). Generally, less than 1% of the bacteria in raw egg products can survive in pasteurisation.

2.3.4 Freezing

Freezing is an operation step to eliminate the growth of most microbial populations (Heldman & Hertel, 1997). This is carried out in cells or by passing the whole egg products through a tunnel at –45°C (Linden & Lorient, 1999). The freezing and thawing rate, storage temperature and time are very important for the quality of the product. Fast freezing and thawing resulted in less yolk gelation than slow freezing and thawing (Cotterill, 1995). In addition, smaller ice crystals are formed and less dehydration of the proteins occurs (Powrie, Little & Lopez, 1963). The functional properties of whole egg products are only slightly affected. However, the texture is changed by freezing (Cotterill, 1995). Frozen egg has a higher proportion of poly-unsaturated fatty acid than egg powder samples (Guardiola, Codony, Manich, Rafecas & Boatella, 1995a). Most frozen-egg products are marketed as ingredients for use in other food products.

2.3.5 Dehydration

Drying or dehydration of foods is an extremely important food processing operation used to preserve foods for extended periods of time by stopping the growth of microorganisms due to water activity of the food (Heldman & Hertel, 1997). For drying, the quality of eggs, handling methods, sanitation practices, pasteurisation procedures, drying, and storage are all may affect the quality of final dehydrated product (Bergquist, 1995).

Spray-drying, freeze-drying, pan-drying, belt-drying as well as foam-drying and foam-spray-drying have been used. Spray-drying (Figure 4) is the most common drying method for commercial egg product in South Africa. The quality of dried egg products changes the least with freeze-drying. However, the cost of freeze-drying is relatively high. Nevertheless, it has been used for producing a dried whole-egg product containing emulsifier primarily for baker use in England (Spicer, 1969) or mostly used as research tool (Guardiola, Codony, Miskin, Rafecas & Boatella, 1995a). Satyanarayana Rao (1993) found that the spray-drying, foam mat drying and freeze drying methods had no significant effect on the palatability and acceptability during one year storage.

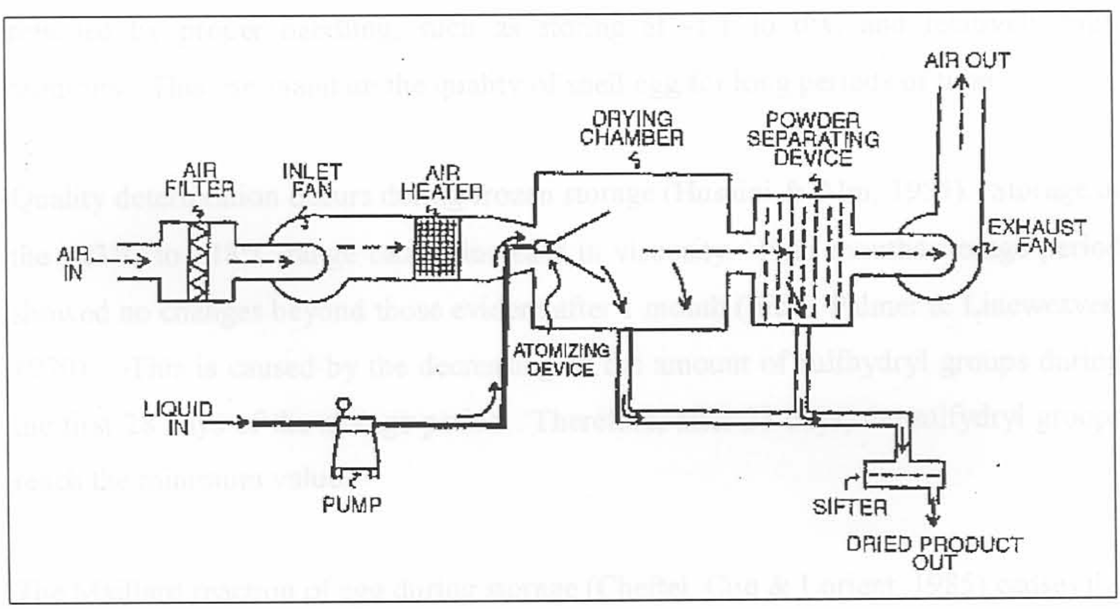

Figure 4 Schematic diagram of spray-drying system (Bergquist, 1995)

2.3.6 Storage

The storage of shell egg, frozen egg and dried egg will all be discussed under this section. Some deterioration in odour and flavour occurs during storage of eggs. Unpleasant flavours are absorbed by eggs if care is not taken to prevent odours in storage areas. In addition, characteristic stale odours and flavours develop in eggs during long storage periods (Campbell, Penfield & Griswold, 1987).

As soon as the egg is laid, changes begin to take place that lower its quality and eventually cause spoilage (Campbell *et al.*, 1987). During the storage, CO_2 losses through the shell cause the pH of albumen to rise, and this changes the structure of the albumen protein (Clinger, Young, Prudent & Winter, 1951). After 3 days the pH may rise to 9.3 or more and render the egg less susceptible to bacterial infection. In addition, evaporation of moisture and movement of water within the egg occur during the storage period. This movement results in enlargement and decreased viscosity of the yolk, weakening of the vitelline membrane, and consequent flattening of the yolk when the egg is broken (Campbell *et al.*, 1987). The thinning of egg white occurs due to changes that take place in the internal molecular structure. These changes can be retarded by proper handling, such as storing at -1.1 to 0°C and relatively high humidity. This can maintain the quality of shell egg for long periods of time.

Quality deterioration occurs during frozen storage (Husaini & Alm, 1955). Storage in the –23°C to –18°C range causes increase in viscosity. Four months storage period showed no changes beyond those evident after 1 month (Ijichi, Palmer & Lineweaver, 1970). This is caused by the decreasing of the amount of sulfhydryl groups during the first 28 days of the storage period. Therefore, after 28 days, the sulfydryl groups reach the minimum value.

The Maillard reaction of egg during storage (Cheftel, Cuq & Lorient, 1985) causes the off-flavours, discolouration, loss of solubility and loss of nutritive value. This non-enzymatic browning can be retarded by desugarisation of egg product before drying

(Satyanarayana Rao, 1991). However, some workers reported that the Maillard reaction effectively improved functional properties of food proteins (Handa & Kuroda, 1999). Kato, Minaki & Kobayashi (1993) found that the emulsifying properties of dried egg white improved through the Maillard reaction. In addition, the myofibrillar protein of eggs conjugated with glucose through the Maillard reaction resulted in the improvement of the solubility of protein (Saeki, 1997).

2.4 Functional properties

According to Hall (1996), Pour defined functionality as "any property of a food or food ingredient, except its nutritional ones, that influences its utilization". Most functional properties affect the sensory characteristics of food products which may be influenced by processing, and storage (Ahmedna, Prinyawiwatkul & Rao, 1999). The functional properties of eggs are not only affected by the diet, age, breed of laying hens as well as environment and seasons of the year (Angalet *et al.*, 1976) but also affected by the concentration of protein, pH, time, temperature, ionic strength and presence of other components like salt (Heralda & Smith, 1989; Akintayo, Oshodi & Esuoso, 1999). In addition, the sequence and distribution of amino acids affect the solubility, surface hydrophobicity and ability to stabilize foams and emulsions (Hall, 1996).

Protein solubility has significant influence on the functional properties of egg proteins (Kato, Fujimoto, Matsudomi & Kobayashi, 1986). Generally speaking, a good emulsion, foam, gelation and whipping properties require high protein solubility. In addition, the flexibility of proteins closely related to functional properties. The flexibility means slight protein is structure changes which are too small to detect by observation. However, Kato, Takahashi, Matsudomi & Kobayashi (1983) reported that protein flexibility can be detected by the protease digestion method. Furthermore, protein flexibility is an important structural factor governing the foaming and emulsifying properties, as well as the hydrophobicity of protein. In addition, Townsend & Nakai (1983) found a high correlation between foaming capacity and molecular flexibility (R^2 = 0.806). This relationship indicates that it is important for protein molecules to be flexible enough to spread out at the air/water interface to stabilize fresh air cells, thus preventing the collapsing of foams.

For sponge cakes, the main functions of eggs are foaming, coagulation, water-holding capacity, colour and flavour. Hence, the literature review on functional properties of egg will concentrate on these properties.

2.4.1 Foaming

Eggs play a major role in foaming capacity of cake batter. The typical foam structure is shown in Fig 5. They produce large volume of stable foams which coagulate during heating. This adds particular value to the production of cakes, such as sponge cakes (Du Preez, 2000). Foams can be produced by whipping/ stirring, bubbling/sparging and shaking (Hammershøj, Prins & Qvist, 1999). The rate and motion of beaters can influence the incorporation of air, while pre-treatments like blending, homogenising and temperature, and the addition of ingredients will also influence egg foams (Du Preez, 2000). Protein molecules contain both hydrophilic and hydrophobic sites on their surfaces. During the whipping process the hydrophobic regions facilitate adsorption at the interface, a protein surface tension facilitates the creation of new interfaces and more bubbles (Poole, 1989). As egg is beaten, air is incorporated into the liquid to form foams with bubbles that decrease in size and increase in number (Kim & Setser, 1982). The smaller bubbles will have a higher gas pressure and therefore higher gas concentration, which causes diffusion of gas from small to large bubbles (Hammershøj *et al.*, 1999). The partly unfolded molecules then combine to form stabilizing films around the bubbles (Poole, West & Walters, 1984; Yang & Baldwin, 1995). Whole egg and yolk products will also form foams, but they are not as efficient as egg white (Toney & Bergquist, 1983).

Foaming capacity is a very valuable property of the egg white, and involves the ovomucin, the globulins and the ovalbumin (Linden & Lorient, 1999). The globulins facilitate foam formation, the ovomucin-lysozyme complex (Cotterill & Winter, 1955) confers foam stability, and ovalbumin and conalbumin provide heat-setting properties.

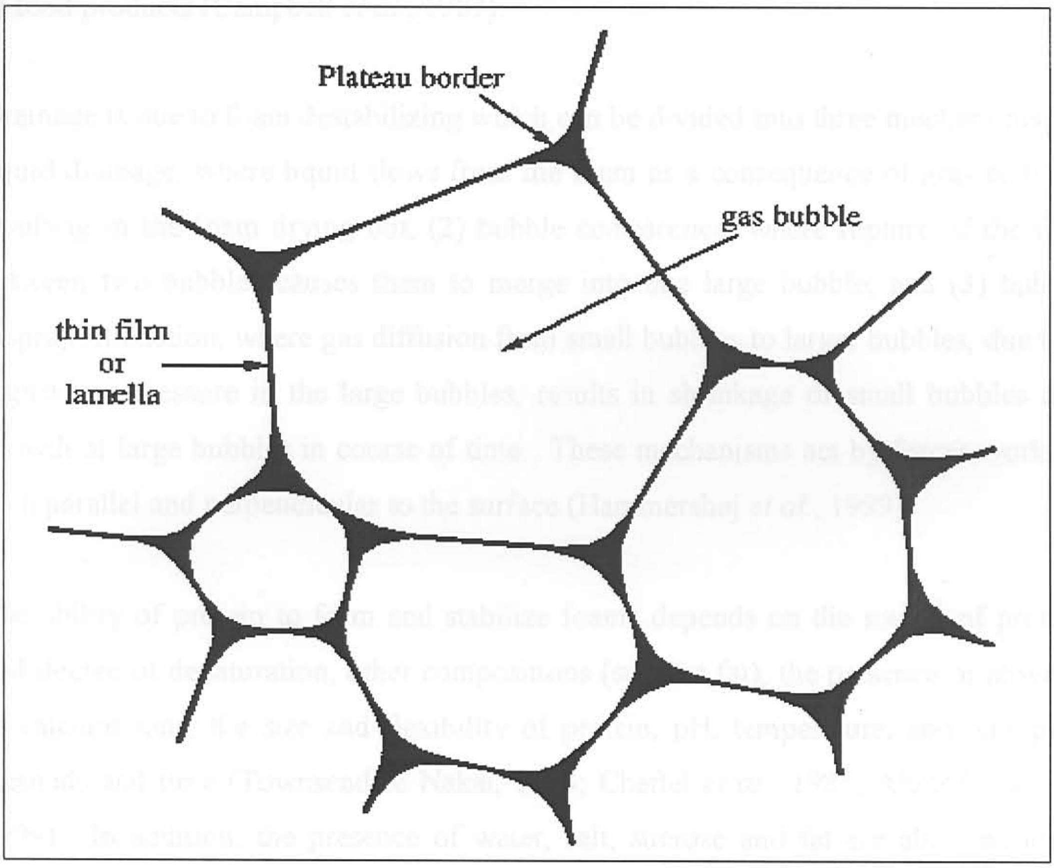

Figure 5   The structure of foam bubbles (Wilde & Clark, 1996)

Globulins contribute to high viscosity and decrease the tendency for liquid to drain away from the air bubbles of foams. It also lowers the surface tension, which is helpful especially in the initial stages of foaming. Low surface tension also enhances small bubble formation and smooth and light texture (MacDonnell, Feeney, Hanson, Campbell & Sugihara, 1955; Ahmedna *et al.*, 1999). Johnson & Zabik (1981) stated that the interaction of lysozyme and globulin, an important function of the foaming process, undergoes destruction during thermal processing (Bharti, Panda & Sahoo, 2001).

The formation of a stable foam requires high tensile strength or elasticity lamella (Yang & Baldwin, 1995). Overwhipping lead to loss of the elasticity of bubbles lost due to insolubilization of too much of the ovomucin (MacDonnell *et al.*, 1955). This is especially important for egg foams when heated. The air in the cells expands, and the albumen surrounding it must either stretch or break. This results in lower volume of food products (Campbell *et al.*, 1987).

Drainage is due to foam destabilizing which can be divided into three mechanisms; (1) liquid drainage, where liquid flows from the foam as a consequence of gravity force resulting in the foam drying out, (2) bubble coalescence, where rupture of the film between two bubbles causes them to merge into one large bubble, and (3) bubble disproportionation, where gas diffusion from small bubbles to larger bubbles, due to a higher gas pressure in the large bubbles, results in shrinkage of small bubbles and growth of large bubbles in course of time. These mechanisms act by forces working both parallel and perpendicular to the surface (Hammershøj *et al.*, 1999).

The ability of protein to form and stabilize foams depends on the source of protein and degree of denaturation, other compositions (such as fat), the presence or absence of calcium ions, the size and flexibility of protein, pH, temperature, and whipping methods and time (Townsend & Nakai, 1983; Cheftel *et al.*, 1985; Ahmedna *et al.*, 1999). In addition, the presence of water, salt, sucrose and fat are also important (Phillips, 1981; Giese, 1994).

Sodium chloride (NaCl): At low concentration, it improves foaming capacity of protein solution (Akintayo *et al.*, 1999). It usually reduces surface viscosity and rigidity of protein films but increase spreading rate, thereby weakening interpeptide attractions and increasing foam volume for certain proteins. However, high levels of NaCl will depress foaming (Oshodi & Ojokan, 1997; Linden & Lorient, 1999). The NaCl reduces foam stability whereas the Ca^{2+} ions can improve stability by forming bridges between thecarboxylic groups of the protein. With whole eggs, adding NaCl before beating caused soft foams which were small in volume. Sponge cakes prepared with these foams were small and tough (Briant & Willman, 1956).

Temperature: Hagolle, Relkin, Popineau & Bertrand (2000) and Kato, Ibrahim, Watanabe, Honma & Kobayashi (1989) reported that thermal treatment of solutions drastically increased the foaming quality of lysozyme and improved that of ovalbumin, which both gave very stable foams after being heated to 90°C. Low temperature reduces surface tension. Thus, albumen foams more easily and attains greater volume at room temperature than at refrigerator temperature (St. John & Flor, 1931).

Carbohydrates: Carbohydrates (sucrose, lactose, dextrose, and maltose) depress the foaming capacity but improve foam stability. In this way, the foam-stabilizing role played by the glycoproteins of the egg white (ovomucoid, ovalbumin) is linked to their capacity to retain water in the lamellae (Linden & Lorient, 1999). Sucrose and other sugars often depress foam expansion but improve foam stability, because they increase the bulk viscosity (Cheftel *et al.*, 1985).

Fat: 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 (Cheftel *et al.*, 1985; Linden & Lorient, 1999). In addition, the small amounts of fat in flour are detrimental to the stability of egg-white foams (Forsythe, 1957). Commercially available egg substitutes, which contain albumen and added vegetable oils, are not optimal for sponge cakes, because the presence of even small quantities of oil decreases albumen's foaming ability (Kim & Setser, 1982).

Dilution: Henry and Barbour found that the volume of foams could be increased by adding small quantities of water to the albumen before beating. These foams were almost as stable as those made from whites to which no water was added (according to Yang & Baldwin, 1995).

pH: When the pH of egg white was adjusted to 8.75, it resulted in improved volume of cakes and whip-time (Seideman, Cotterill & Funk, 1963). However, Hammershøj *et al.* (1999) found pH 4.8 had the highest foaming overrun, and pH 7.0 had the most stable foam. They explained that at high pH values, the fast exchange of the thiol- and disulphide bonds can influence the surface properties of the protein film, as split-up of disulphide bonds increases the flexibility, opportunity of orientation, and unfolding of the molecule at the interface.

Others factors: Sagis, de Groot-Mostert, Prins & van der Linden (2001) found that the foams prepared with copper ions in eggs took more time to foam, but were also more stable.

2.4.2 Coagulation

Thermal coagulation is extremely important when using egg products with cereal foods. Because of this property, egg binds other food materials together and contributes to thickening. The structural integrity and crumb strength of sponge cake are attributable to coagulation properties of egg protein (Toney & Bergquist, 1983).

Coagulation is the term used to describe the change from the fluid (solution) to the solid or semisolid (gel) state (Linden & Lorient, 1999). Yang & Baldwin (1995) stated that the terms "coagulation" and "gelation" are used interchangeably as a "gel". It is a formation of a three-dimensional matrix through inter-protein bonding, and the concomitant immobilization of water within this gel structure, determines the textural and other properties of many food products (Gossett, Rizvi & Baker, 1983). A coagulum forms when the structure of egg-protein molecules is changed by heat, acids, alkalies, and other reagents such as urea. Gel viscosity increased with increasing temperature used for heating the protein solutions for all proteins investigated (Ahmedna *et al.*, 1999). The strengthening of the gel formed from egg protein is mainly attributed to hydrogen bonding and hydrophobic interactions and partially to the formation of intermolecular disulfide bonds (Kato, Ibrahim, Watanabe, Honma & Kobayashi, 1990). Thermal coagulation takes place from 62°C upward in egg white whereas the egg yolk coagulates at 65°C upward.

Parkinson (1966) stated that ovomucoid and ovomucin in egg white and livetins and phosvitin in egg yolk are noncoagulable by heat. The ovalbumin (Johnson & Zabik, 1981) and conalbumin (Cunningham & Lineweaver, 1965) in egg white are however, responsible for coagulation. The gelling properties of the yolk proteins are associated with the lipoproteins (Linden & Lorient, 1999). The denaturation temperature of conalbumin, globulins, ovalbumin and lysozyme are 57.3°C, 72.0°C, 71.5°C and 81.5°C, respectively (Woodward & Cotterill, 1983; Yang & Baldwin, 1995). The interaction between temperature, dilution, salts, sugar, acid and alkali or alone can influence the coagulation properties (Toney & Bergquist, 1983; Du Preez, 2000).

Dilution: Beveridge, Arntfield, Ko & Chung (1980) found that the firmness of the coagulum decreased with increasing dilution and Hsieh & Resenstein (1989) found that the egg white gel strength increased with the egg white concentration.

NaCl: The gelating ability decreased at higher concentrations of salt (Akintayo *et al.*, 1999). Catsimpoolas & Meyer (1971) stated that hydrogen and ionic bonds are responsible for the stabilization of the gel, and that addition of NaCl will decrease the viscosity of the gel.

Carbohydrates: The coagulation temperature increases with increasing sugar concentration. (Yang & Baldwin, 1995; Du Preez, 2000).

pH: The gel strength generally increased with increasing of pH (Handa, Takahashi, Kuroda & Froning, 1998). The pH alters the gelling ability such as gelling temperature and time and textural properties of protein gel (Chang & Chen, 2000).

Time and Temperature: According to Woodward & Cotterill (1987), there were significant differences in time and temperature interactions for hardness, cohesiveness, and springiness of bakery product. Lowe stated that "the average speed of coagulation of albumen is increased 191 times with a rise in temperature of 1 °C and approximately 635 times with a 10°C increase in temperature" (according to Yang & Baldwin, 1995).

2.4.3 Colour and flavour

The colour of the yolk determines the attraction and acceptability of the egg for the consumer (Linden & Lorient, 1999). The naturally occurring pigments in chicken egg yolk are mainly alcohol-soluble xanthophylls, lutein and zeaxanthin (Du Preez, 2000). These colour pigments are affected by the diet of the laying hens (Deethardt *et al.*, 1965b; Angalet *et al.*, 1976). Deethardt, Burrill & Carlson (1965a) stated that the egg yolk colour influenced the quality of sponge cakes.

Eggs have a very delicate flavour and significantly contribute to desirable sensory properties in finished foods due to its mild flavour and odour (Toney & Bergquist, 1983). However, flavour changes can occur during the storage and handling of eggs both before and after cooking and processing, such as pasteurisation and dehydration (Maillard reaction) (Hard, Spencer, Locke & Georage, 1963).

2.5 Functional property changes due to processing

Several processes can be used to extent the shelf-life of eggs. However, these processes could influence the functional properties of the egg products. Pasteurisation, freezing and dehydration may affect the foaming, coagulating, colour and flavour of egg product which may directly affect properties such as baking volume, texture, colour, flavour and shelf-life of sponge cakes.

2.5.1 Heat Treatment

Changes in egg products brought about by heat are of major concern to the processor and user alike. Damage to the whole egg is evaluated, using layer cakes or sponge cakes instead of angel cakes with egg white (albumen) and observing foaming and coagulating properties. In the temperature range of 56°C to 66°C, the denaturation of whole egg takes place and the viscosity of liquid whole egg is reduced. Above this range, fractional precipitation of proteins occurs, while coagulation takes place rapidly above 73°C (Cunningham, 1995).

Certain added substances help to stabilize liquid egg against heat denaturation. Carbohydrates such as sucrose, glucose, fructose, arabinose, mannitol, and xylose have been found to inhibit heat denaturation, as evidenced by preventing the formation of sulfhydryl groups (Woodward & Cotterill, 1983). Carbohydrates also protect whole eggs from coagulation by heat and increase the coagulating temperature of egg products (Cunningham, 1995). In addition, salt also protects against heat denaturation (Woodward & Cotterill, 1983).

Pasteurised frozen whole egg has a different appearance when thawed compared to unpasteurised frozen whole egg. When a temperature of 61°C with a holding time of 3 min was used, the viscosity of the product is reduced. In addition, pasteurisation and freezing increased the beating time required for the preparation of a sponge cake, but improved the foam stability as measured by drainage (Cunningham, 1995).

2.5.2 Freezing

Freezing provide a long shelf-life, but undesirable changes occur in whole egg due to freezing and thawing. Parkinson (1977) reported denaturation of egg during freezing. The slower the freezing rates, the more the denaturation of egg protein. However, Cotterill (1995) reported that the functional properties of whole egg are not drastically affected by freezing.

A lot of workers reported that uniform appearance (such as colour distribution), gelation, thickening and lumpiness were found in frozen whole egg after thawing (Ijichi *et al.*, 1970; Palmer, Ijichi & Roff, 1970; McCready & Cotterill, 1972). In addition, Ijichi *et al.* (1970) found that the thawed whole eggs showed separation and dark colour liquid.

Liquid whole egg undergoes gelation upon freezing and thawing. However, it is less drastic than in yolk alone (Cotterill, 1995). Freezing of liquid whole egg was found to decrease foaming and whipping properties in several studies (Pearce & Lavers and Mori according to Heralda & Smith, 1989). Furthermore, these workers observed that freezing of egg reduced the baking quality of whole egg, but it improved after frozen storage for three months and then decreased again thereafter. In addition, fast thawing may reduce the gelation if a high temperature is used for thawing which "melted" the gel or lumps (Palmer *et al.*, 1970). The freezing rate is very important as it influences viscosity. Fast freezing at –29°C limited viscosity increase to about ¾ of the viscosity of whole eggs frozen in a slow airflow, but was not effective in preventing appearance defects (Ijichi *et al.*, 1970; Linden & Lorient, 1999) and functional performance (Palmer *et al.*, 1970).

Besides high temperature, McCready & Cotterill (1972) found that centrifugation of liquid whole egg can also be used to avoid viscosity changes caused by freezing. In addition, homogenisation, colloid milling or stirring with a mixer before freezing limited viscosity changes in liquid whole eggs during frozen storage, but none of these mechanical treatments were effective in preventing liquid separation and caused a curdled appearance in those eggs thawed after storage at –18 to –29°C (Ijichi *et al.*, 1970).

Addition of NaCl, sugar and skimmed milk prior to freezing protected against the gelation of frozen egg products (Ijichi *et al.*, 1970; Dill, Brough, Alford, Gardner, Edwards, Richter & Diehl, 1991). In addition, syrups, glycerin, gum, phosphates, and other sugars can also be used. However, these ingredients may be restricted to specific food products (Cotterill, 1995).

2.5.3 Dehydration

Dehydrated whole eggs have historically been a poorly accepted product (Bergquist, 1995). Egg proteins denature over a wide range of temperature. In addition, the amount of heat that is absorbed by the dried egg product, the method of drying, the dryer design and conditions of its operation, and how rapidly the product is cooled after drying are major factors that affect the functional properties of dried egg products.

Spray-drying is frequently used to obtain powdered eggs (Guardiola *et al.*, 1995a). However, the presence of oxysterols in powdered eggs during drying have been confirmed, and their formation depends on two main factors: (1) the direct or indirect air heating system (Missler, Wasilchuk & Merritt, 1985), and (2) the inlet and outlet temperature (Tsai & Hudson, 1985). When the air is heated indirectly, the formation of oxysterols in the dried egg is lower than when direct heating is applied. According to some authors, this is due to the formation of nitrogen oxides (NO and NO_2) in the air directly heated by passage through a natural gas flame, and these compounds have an oxidative effect on the product (Guardiola *et al.*, 1995b). In addition, Lai, Gray, Buckeley & Kelly (1995) observed that oxysterol formation during the storage of egg powder was greater in samples dried by direct heating than in samples dried by indirect heating (Guardiola, Codony, Rafecas, Grau, Jordán & Boatella, 1997). In addition, Guardiola *et al.* (1997) found that the spray-drying temperature and its interaction with storage time influenced the water activity and moisture of dried egg product. Samples obtained at high spray-drying temperature initially showed lower moisture and water activity. During storage, the low temperature and consequently water activity of dried egg increased more, since it is easier to absorb water. Lipid oxidation lead to a decrease in the nutritive value of egg powder. Addition of antioxidant during preparation and storage (Huber, Pike & Huber, 1995) or packing of the product in nitrogen and carbon dioxide, or a mixture of the two (Bergquist, 1995) might reduce the lipid oxidation during storage.

Maillard reactions take place during the storage of dried egg products. It causes the colour to darken and flavour to change in dried egg products. However, this can be prevented by removing the sugar prior to dehydration. Off-flavours are also produced in dehydrated products during storage (Guardiola *et al.*, 1995b; Yang & Baldwin, 1995). The flavour stability of whole-egg powder can be improved by acidifying the liquid to pH 5.5 before drying (Lieu, Froning & Dam, 1978; Mine, 1997). This inhibits the browning reaction involving the glucose and protein, but does not completely prevent it (Bergquist, 1995).

If stored under proper drying and storage conditions, dried egg products retain their heat-coagulating properties quite well. However, if drying conditions are too severe or if storage conditions are adverse, whole egg and yolk products can lose their heat-coagulation properties as well as their solubility. The conditions under which the dried product is stored will also affect its whipping performance (Bergquist, 1995). Lewis, Marcelli & Watts (1953) found that hexametaphosphate and tripolyphosphate effected the greatest improvement in whipping ability of dried whole eggs. The foaming ability of dehydrated whole egg can also be improved by increasing the temperature at which the reconstituted material is whipped (Bergquist, 1995). Furthermore, Kim & Setser (1982) found that addition of sodium lauryl sulfate and gum stabilizers can improve the foaming ability and stability.

An increase in viscosity in dehydrated whole egg and yolk products can also be observed during storage. Viscosity in the reconstituted product increases quite rapidly at temperatures above 38°C (Bergquist, 1995).

Kato *et al.* (1989) found a significant improvement of functional properties such as the foaming, emulsifying and gelling properties of dried egg white by heating the product in dry state at 80°C for several days. The important structural factors for foaming properties are protein flexibility (Kato *et al.*, 1986), protein-protein interaction and surface hydrophobicity. Since these structures change with heating in the dry state, the foaming properties may be improved.

2.6 Sponge cake

Sponge cakes are low in fat and the moisture can be lost very rapidly when exposed to the atmosphere. Thus, a good moisture vapour barrier packaging is required. High quality cakes should have various attributes including high volume and tenderness, that result from optimized formulas (Géllinas, Roy & Gulliet, 1999). A shelf-life of three weeks can be obtained by optimizing the formulation and choosing the correct wrapping material (Jones, 1994). The main ingredients in sponge goods are egg, sugar and flour with air, which are introduced during the mixing process (Bennion & Bamford, 1997). Emulsifier is important for sponge cake baking when egg powder is used in the formula.

Soft wheat flours are normally used for cake baking. In some cases, baking industries require their own specific milling for their product. The cake flours which are treated with chlorine can improve cake grain texture, volume and it can reduce microorganisms in flour (Posner & Hibbs, 1997). This is because chlorination accelerates the thickening of viscosity of the batter, which allows improved setting of the batter at final stage of baking (Gaines & Donelson, 1982a).

Sugar plays an important role in bakery products. It contributes not only to sweetness, colour and flavour (Maillard reaction) but also serves as tenderizing agent by retarding gluten development during mixing (Bosman, Vorster, Setser & Steyn, 2000). In addition, sugar delay starch gelatinization and raise the coagulation temperature of protein, so that the air cell of batter can be expanded by carbon dioxide and water vapour (Yamazaki & Kissell, 1978). These reactions can maximize the volume of cakes (Bosman *et al.*, 2000).

The function of emulsifier in cakes are to: (1) increase cake volume; (2) provide uniform texture, better crumb structure; (3) softness and tenderness; (4) reduce egg/ shortening; (5) increase shelf-life and retard staling; (6) flavour dispersion and release; (7) reduce mixing time; (8) improve performance of dried egg in cake mixes; (9)

stabilize foam and (10) emulsification (Kamel & Ponte Jr, 1993). Glycerol monostearate (GMS) has been used for many years as an improver in bread, rolls and enriched morning goods. It has powerful emulsifying properties and has the ability to complex with starch, slowing down the rate of product staling (crumb firming). GMS can be added as a crumb softener, reducing the fat required for that purpose (Brown, 1993).

2.7 Microbiology

2.7.1 *Fresh eggs*

Salmonella is the primary concern for eggs and egg products (Cunningham, 1995). *Salmonella* is effectively destroyed by conventional egg pasteurisation, in which the content of broken eggs are heated to 56.6°C for no less than 3.5 min. However, this process results in decreases in the coagulation and foaming properties of albumen (Hank, Kunkel, Dawson, Acton & Wardlaw, 2001).

Fresh egg has three structures, each of which is effective to some degree in retarding the entry of microorganisms: the outer, waxy shell membrane; the shell; and the inner shell membrane. Internally, lysozyme in egg white which is an enzyme has been shown to be quite effective against gram-positive bacteria. Egg white also contains avidin, which forms a complex with biotin, thereby making this vitamin unavailable to microorganisms. In addition, egg white has a high pH (about 9.3) and contains conalbumin, which forms a complex with iron, thus rendering it unavailable to microorganisms. Generally speaking, more microorganisms are found in egg yolk than in egg white, due to the lack of anti-microbial substances in egg yolk. Furthermore, the pH of the yolk is around pH 6.8, making it an excellent environment for most microorganisms (Jay, 1986; Board & Tranter, 1995).

The entry of microorganisms into shell egg is favoured by high humidity. In this case, growth of the microorganisms on the surface of eggs is favoured, followed by penetration through the shell and inner membrane. Moulds generally multiply first in the region of the air sac, where oxygen favours the growth of these forms. Under high humidity conditions, moulds may be seen growing over the outer surface of eggs. In contrast, in low humidity and low temperature environment, surface growth is not favoured, but eggs lose water at a faster rate and thereby become undesirable as products of commerce (Jay, 1986).

Rotten eggs normally contain a mixed infection of gram-negative bacteria and, on occasion, a few gram-positive organisms are present also. The most common contaminants are from the genera *Alcaligenes, Acinetobacter, Pseudomonas, Serratia, Cloaca, Hafnia, Citrobacter, Proteus,* and *Aeromonas* (Board & Tranter, 1995). Generally, less than 1% of the bacteria of raw egg products survive pasteurisation. However, *Alcaligenes, Flavobacterium, Bacillus, Proteus, Pseudomonas, Escherichia, Staphylococcus,* coryneform bacteria, and faecal streptococci are found in pasteurised egg and egg products. Furthermore, *Salmonella* has also been reported to survive in unpasteurised spray-dried whole eggs (Moore *et al.*, 1988).

2.7.2 Sponge Cake

Sponge cakes belong to the category of intermediate moisture food products due to their high concentrations of sugars, which restrict the availability of water. It has about 20% moisture, and water activities (a_w) within the range 0.65-0.85. With these water activities, sponge cakes can be spoiled by yeast and moulds especially xerophilic organisms. However, bacterial spoilage is rare in this range of water activity (Jay, 1986; Jones, 1994). The sources of spoilage are many such as the cake ingredients, especially sugar, nuts and spices. Fortunately, baking temperatures are sufficient to destroy these organisms. Moulds may enter baked cakes from handling, and air and post-processing contaminations are unavoidable. Usually, bakery products are packaged in plastic films after baking and cooling, and they are consumed within

1 or 2 months. But, a wide range of moulds, such as *Penicillium*, *Aspergillus*, *Cladosporium* and *Eurotium* species gain access to the product surface prior to packaging (Abellana, Magri, Sanchis & Ramos, 1999).

2.8 Sensory evaluation

Descriptive sensory analysis techniques identify, describe and quantify sensory qualities of a given product (Gillette, 1984). They are the most sophisticated tools in the arsenal of the sensory scientist. These techniques help identify underlying ingredient and process variables and/or determine which sensory attributes are important to acceptance (Lawless & Heymann, 1998). These techniques are ideal for shelf-life testing, especially if the judges were well trained and are consistent over time. This technique requires a panel of 5 to 10 trained persons who are thoroughly familiar with the product's sensory characteristics and who can accurately and precisely communicate their perceptions (Gillette, 1984). The descriptive panel provides the food technologist with detailed descriptions on how the colour, aroma, flavour, and/ or texture of the product change over time. While chemical tests are often used, a sensory panel can detect critical changes that the chemical test might miss.