

Washing table eggs: a review of the scientific and engineering issues

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Current European Union legislation prohibits the washing of Class A eggs. This is in stark contrast to countries such as the United States of America and, more recently Japan, which have embraced egg-washing technology. The emergence in the UK of egg associated *Salmonella enteritidis* as a significant cause of food poisoning has, combined with the increase in non-cage egg production systems, increased interest in technologies that might improve the microbial quality of the egg. This paper reviews the history of egg washing in the European Union and more specifically its restricted use in the UK and contrasts this with its uptake in the United States among other countries. Similarly the technological advances in egg washing are reviewed, in the context of the underpinning science.

Key words: egg washing; Salmonella; table eggs; contamination; sanitizers; bacteria

Introduction

The microbial quality of table eggs has had a higher profile in the mind of British consumers since egg-borne *Salmonella enteritidis* emerged as a major cause of food poisoning (Humphrey, 1994a). This can be put in the context of the trend for egg producers to move away from caged-layer egg production (NFU, 2001) to more extensive systems (*i.e.* systems which have a tendency to produce a smaller percentage of so-called nest-clean eggs) (Bruce and Drysdale, 1994). It can be appreciated therefore why the prospect of being able to wash eggs continues to attract interest although currently, in the UK, the washing of Class A eggs is not allowed (HMSO, 1995).

Contamination of egg contents may occur by vertical or horizontal routes. In the former, bacteria may colonise the ovaries and/or oviduct while in the latter contaminants

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originating in, for example, faecal material or dust, move through the shell before ultimately colonising the membranes and yolk (Bruce and Drysdale, 1994). As, under normal operating conditions, egg washing should not affect microbial development occurring as a result of vertical contamination this review will consider the impact of washing on horizontally-transmitted contaminants only.

The surface of the nest clean egg offers little protection to bacterial contaminants, resulting in organisms such as the Gram-positive Micrococci dominating the shell microflora (Board, 1966). However there are a number of factors that have been shown to either improve the survivability of bacteria in the inhospitable environment of the shell surface or reduce the eggs antimicrobial defence system in other ways. These include: the physical condition of the cuticle and underlying shell (Sparks and Board, 1984; Sparks, 1985); the presence of water on the shell (Board *et al.*, 1979); the concentration of iron in water that comes into contact with the egg (Board *et al.*, 1986); contamination of the shell with organic material such as faeces (see Bruce and Drysdale, 1994). While it is generally accepted that no one factor determines exclusively whether entry occurs, (Berrang *et al.*, 1999; Lucore *et al.*, 1997), it is important, in the context of egg washing, to understand why these factors can affect the efficacy of the eggs' antimicrobial defence system.

Factors that predispose an egg to contamination

PRESENCE OF WATER ON THE SHELL

Bacteria are less likely to move through the shell (*e.g.* through cracks) or along the pores, in the absence of water (Board *et al.*, 1979). The presence of water is a key factor therefore when considering the contamination of egg contents by faecal and other similar contaminants and is particularly important when considering egg washing.

The eggs first and main defence against water, and associated suspended contaminants, is the organic layer, or cuticle (Sparks, 1994) that covers the shell. The cuticle allows gaseous water to diffuse freely through the shell while inhibiting the movement of liquid water (Sparks and Board, 1984). However the mean thickness of the cuticle ranges from 0.5-12.8 µm (Simons, 1971) and it is not evenly distributed across the shell, the poles often being covered by a relatively thin layer (Sparks, 1994). The cuticle covers the some 10,000-17,000 pores that permeate the shell. At approximately 15-65 µm in diameter (Board *et al.*, 1977) the pores are significantly bigger than most micro-organisms (typically 1-5 µm).

The importance of water in allowing bacteria to penetrate the cuticle and underlying shell was confirmed by Padron (1990) who reported that water enhanced *S. typhimurium* penetration of the cuticle and shell but noted also that a moist shell surface was not essential for penetration to occur. The importance of water as an agent for facilitating bacterial contamination of eggs becomes particularly important when considering the egg immediately following oviposition. At this time the cuticle is moist and the egg's temperature is typically approximately 42°C and consequently is warmer than the environment. The resultant cooling of the egg causes the internal contents to contract, causing a negative pressure inside the egg. This pressure difference is equalised by pulling air (or water) from the external surface of the shell into the inside of the egg (Haines and Moran, 1940). The suction aids the passage of any bacteria on the surface of the egg through the fluid-filled pore lumen into the egg.

Apart from the deliberate introduction of water on to the shell through washing, condensation or so-called "sweating", can result in the surface of the egg becoming wet. This typically occurs when eggs are moved from a cold to a warmer environment (*e.g.* out of an egg store). If condensation forms on the shell, this liquid, and any associated

contaminants, can subsequently be drawn from the shell surface into the pore and shell membranes. The use of inefficient humidifiers in egg stores may have a similar outcome, since these can result in water droplets being sprayed on to the shell surface by the deficient equipment.

In this context it is also notable that the cuticle on white-shelled eggs has been reported to be less effective at preventing microbial contamination than that on brown-shelled eggs (Sparks, 1985). The relatively open structure of the cuticle on the white-shelled eggs (*cf* brown-shelled) examined reduced the ability of the cuticle to keep out water-borne bacteria.

ROLE OF IRON IN THE WASH WATER

The presence of iron in the wash water was identified by Garibaldi and Bayne (1962) as being associated with increased spoilage (both number and rate) of eggs washed on some farms in California. Subsequent studies (see Board *et al.*, 1986) have shown that injecting Fe³⁺ into the albumen or the addition of iron salts to the membrane with a bacterial inoculum would result in unhindered growth of bacteria due to the iron chelating properties of the ovotransferrin becoming saturated. Ovotransferrin is an important antimicrobial protein, accounting for some 12% of the albumen (Tranter and Board 1982). Each molecule of ovotransferrin is able to chelate two atoms of iron (Aasa *et al.*, 1963), lowering the free iron available to microbial contaminants in the albumen and hence exerting a bacteriostatic effect.

FAECAL CONTAMINATION ON THE SHELL

It is notable that Board (1977) reported a poor correlation between the levels of bacteria on the shell and the amount of soiling on the egg's surface. Similarly a number of studies (Mawer *et al.*, 1989; Humphrey *et al.*, 1991) have concluded that the presence of pathogens in faeces was not directly correlated to the number of pathogens in the egg contents. However when Henzler *et al.*, 1998 assessed the risk factors that influence contamination of eggs by *Salmonella enteritidis* the only variable found to be associated strongly with the production of *S. enteritidis*-contaminated eggs was a high level of contaminated manure (*i.e.* >50% manure samples testing positive for *S. enteritidis*). The study concluded that a flock with a high level of manure contamination was 11 times more likely to produce *S. enteritidis*-contaminated eggs than a flock with a low level (*i.e.* <50% manure samples testing positive) (Henzler *et al.*, 1998).

Bacteria commonly associated with eggs

The common external and internal contaminants of eggs have been comprehensively reviewed by Board (1966) and Mayes and Takeballi (1983). The dominant contaminants on the shell tend to be Gram-positive cocci and bacillus such as *Micrococcus* and *Arthrobacter* respectively. While the Gram-positive organisms dominate the contaminants on the shell of eggs the internal contaminants are primarily Gram-negative organisms such as *Alcaligenes*, *Achromobacter*, *Pseudomonas*, and *Escherichia*. However the seminal studies by Board (see Board, 1966 and Board *et al.*, 1994) did not identify *Salmonella* as one of the main contaminants of eggs. This was the situation even in the early to mid 1990's (Humphrey, 1994a,b) when there was a significant increase in the incidence of food poisoning caused by egg-borne *S. enteritidis*. The infection of, and growth within, eggs by *S. enteritidis* has been reviewed in detail by Humphrey (1994a). For the purposes of this Review it is important to note that while *S. enteritidis* may infect the oviduct and ovaries, allowing vertical transmission, faecal contamination is considered to be the most

likely source of other salmonellas that have been isolated from egg shells (Cantor and McFarlane, 1948). While *S. enteritidis* has also been isolated from shells the incidence is more variable (Humphrey *et al.*, 1989).

Egg washing - historical perspective

The washing of table eggs marketed as Class A is not permitted in the EU (HMSO, 1995; EU, 1991). The practice is permitted though at present for Class B eggs (which includes intact eggs with dirty shells) but this is seldom done except in Sweden and changes planned for 2004 to EU Egg Marketing legislation will mean that washed Class B eggs can only be used through approved processors or non-food industry. Sales through shell egg outlets will not be permitted. The situation in the EU is in contrast to that elsewhere in the world, with countries such as Japan, Australia and the USA allowing (and even encouraging) the washing of table eggs.

The reluctance within the EU to allow the washing of eggs may have its origin in the early part of the twentieth century when a series of tests confirmed that wetting or washing eggs before storage could have an adverse effect on the microbiological quality of the egg. Jenkins (1919) was one of the first to report that washing favoured the production of so-called "green whites" and "crusted yolks". Further attention was drawn to the deleterious effect that washing had on egg quality by the high incidence of rots in chilled washed shell eggs imported to the UK from Australia (Brooks, 1951). Brooks' (1951) review of earlier work confirmed that the effects of egg washing were unpredictable, and frequently deleterious to the eating quality. During this same period the washing of eggs was also under consideration in the USA. However the outcome from these appraisals led to the widespread adoption of egg washing by the end of the 1940s, in contrast to the negative approach taken in European countries.

The most common type of egg washer of the time consisted of a wire basket, which could contain 50-60 eggs (Nield, 1992). The basket was lowered manually into a rotating washing machine in which the eggs were submerged and agitated. The water used was typically heated to around 49°C. A household, dish, laundry or other detergent was added and the eggs were washed for three minutes before the operator lifted the basket from the water. In practice, eggs could be washed for different lengths of time and in water that could be dirty, at the wrong temperature and without sanitizer (Nield 1992). The result was a wide variation in egg quality because of uncontrolled egg washing (Nield 1992).

In the early 1960s, the British Egg Marketing Board (BEMB), recognising the problems associated with egg washing, imposed (i) a price penalty on dirty eggs; (ii) encouraged the use of dry-cleaning and (iii) prohibited packers from washing Class A table eggs (HMSO, 1968). In Northern Ireland, a "Clean Egg Scheme" was introduced in 1963 that allowed dry-cleaning but required producers to certify that eggs had not been subjected to any form of wet cleaning (HMSO, 1968). It was estimated that immediately prior to the introduction of the Scheme, 90-95% of all eggs produced in Northern Ireland were washed but this rapidly dropped to less than 0.5% (HMSO, 1968). In 1965, the BEMB proposed a similar scheme for Great Britain but it was strongly resisted by many sections of the industry and was never introduced (HMSO, 1968). A survey carried out by the BEMB in 1964 suggested that in the UK as a whole approximately 43% of all eggs tested had been washed.

At about this time (1966) the United States Department of Agriculture (USDA) published Market Research Report Number 757 (USDA, 1966) entitled "Improved Methods, Techniques and Equipment for Cleaning Eggs". The authors of report number 757 concluded that eggs with sound shells could be cleaned effectively with minimal

spoilage hazard and shell damage and without affecting internal quality.

Amongst the design features of the experimental machine featured in Report 757 were; egg wetting prior to washing, fogger-type nozzles, low water volume applied as high pressure cutting sprays, rotating impregnated brushes with bristles perpendicular to the direction of egg travel, an egg spinning device to increase contact between the egg and the brush and a separate conveyor in the drying unit. The report concluded with a list of recommendations for cleaning eggs which, it was felt, would considerably improve the washing of eggs. These were:

1. do not attempt to clean excessively dirty eggs
 2. avoid the use of wash water containing >2 ppm iron
 3. do not re-circulate the wash water
 4. use odourless cleaning materials
 5. wash eggs as soon as practical after they are laid
 6. maintain wash water at a temperature that is at least 20°F (equivalent to 11°C) higher than that of the eggs through all washing operations (wetting, cleaning and rinsing)
 7. moisten eggs with stained shells and adhering dirt before eggs are submitted to cutting-spray wash and brushes
 8. precede brushing with a water spray with sufficient force to cut away loose dirt
 9. augment abrasive power of ordinary brushes with abrasive material in brush bristles
 10. maintain an accurate control of the sanitizer-detergent level within the wash water
 11. use a final rinse for the washed eggs
 12. dry washed eggs completely before packing them
- (USDA, 1966)

The apparent success of egg washing in the USA led to renewed interest in egg washing in the UK. In the "Report of the Reorganisation Commission for Eggs" (HMSO, 1968), the possibility that wet cleaning methods could be used was raised. It was noted these might be easier and less time consuming than dry cleaning and that wet cleaning had already received official recognition in the USA. In view of the perceived success of egg washing in the USA, the Report concluded, in relation to the UK that:

"We see no reason why the development of wet-cleaning should be discouraged in this country. Clearly, however, the actual method of wet-cleaning employed is of vital importance to the subsequent quality of eggs and we therefore consider that it would be desirable for a code of practice to be drawn up by the central authority for the guidance of packing stations and others in this matter, and that all concerned should be encouraged to observe it so that best practices were followed."

The change in attitude in the UK was overtaken by legislation introduced when the UK joined the European Economic Council (EEC) in 1973 and became subject to European egg marketing regulations. These state that "Class 'a' eggs shall not be washed or cleaned by any other means before grading." (EU, 1991). These regulations have not changed since 1973, although various sections of the UK egg production industry have from time to time lobbied the Government and sought support from other European countries to persuade the Commission to re-appraise this policy.

While the UK turned its back on egg washing countries such as the USA embraced it and developed the technology over time. In contrast to both of these scenarios Japan adopted egg washing relatively recently. In so doing Japanese legislators and producers were able to take advantage of the experiences of countries such as the USA.

Egg washing became the norm in Japan in the late 1990's in response to the high number of the salmonella cases in Japan at that time (Tomosui, pers comm). This required the industry to implement a range of measures of which egg washing was just one. As in the

UK, there has been a large reduction in the incidence of salmonella achieved as a result of measures implemented at the farm level (*e.g.*, vaccination) with fewer than 1 in 1000 eggs now carrying the bacteria on the shell at the farm gate (and a lower incidence for the egg contents). The contribution of washing in further improving the reduction of the salmonella risk remains unclear and it is largely unproven by published data. However, the TVC (total viable count) on the shell has been reported (Tomosue, pers comm) as falling by three log units (typically from 10^5 to 10^2) as the result of egg washing. One might expect egg washing to be a more general insurance policy for a wide range of other pathogens; it is not clear whether there was a significant contribution from public pressure in Japan to bring about this change or whether there were more convincing scientific arguments. Nonetheless, the potential hazards of egg washing have not dissuaded the egg industry in Japan from adopting a technology that has brought its own additional cost. The need to monitor and maintain egg washing equipment in order to minimise the hazards is however paramount as was illustrated by the results of an egg survey in Hawaii (Chinglee *et al.*, 1991). Of 106 dozen (packs) eggs tested for salmonella, ten cartons were positive for salmonella – further investigations showing that 7 of the ten cartons could be traced to a processor with a faulty egg washing process (Chinglee *et al.*, 1991).

Egg washing procedures

EGG WASHING AS PART OF THE EGG PACKING OPERATION

Wang and Slavik (1998) reported a correlation between storage time and penetration of egg contents by *Salmonella* - the longer the storage time prior to washing, the higher the levels of penetration by the pathogen. However this is not inconsistent with current commercial practice that aims to minimise the time between laying, grading & packing and delivery to the point of sale and in countries where egg washing is permissible, companies aim to wash the majority of eggs within 24h of lay. The rapid throughput of eggs may however cause problems in itself. One particular concern is that the movement of eggs in and out of cold stores can cause condensation to form on the shell (so-called “sweating”) which in turn can move bacteria through the shell and beyond the reach of sanitizers.

THE EGG WASHING PROCESS

Current commercial egg washing practice itself forms part of the duties of the egg packing company. The general process can be divided into four stages: (i) wetting, (ii) washing, (iii) rinsing and (iv) drying (*Figure 1*). The normal grading and packing operations as carried out in installations not using washing would then follow.

Wetting process

The eggs are typically laid out in a regular pattern on a conveyor that carries them through the stages of the cleaning system. Prior to the main washing operation it is useful to provide some pre-washing to enable the softening of debris on the shell of the egg. In most cases, this is little more than a light spray of warm (~ 40°C) water sufficient to wet the shell surface and any debris entrained. A period of several minutes ideally follows (although in practice this may be only a few seconds) to enable the penetration of the water into the soil material; if this period is too brief, the benefit is reduced.

Washing process

The main washing process typically involves the gentle rubbing of the eggs with rotary or reciprocating brushes whilst being sprayed with warm (40 – 50°C) water (high pressure

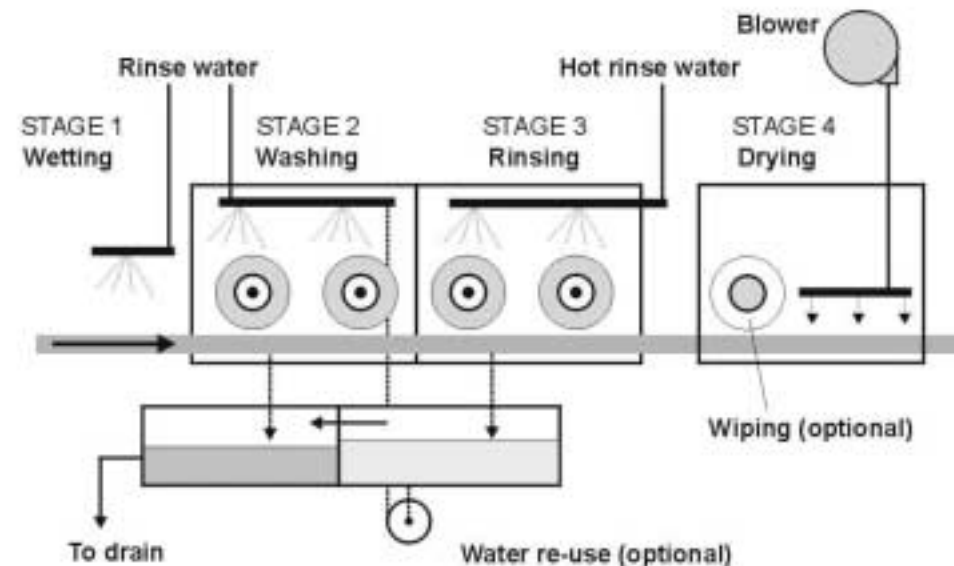


Figure 1 Diagram showing the key stages in commercial egg washing.

water jets alone have been used in some instances). The conveyor usually incorporates rollers that turn the eggs enabling all surfaces to be presented to the brushes or water jet as they move through the washer. Externally, a washer may appear to be a single operation but two or three distinct zones or stages of washing may exist within with increasing temperatures (*e.g.* 40-42°C) of water being applied. There may also be recycling zones with the drained water from the final stages being used for the pre-wash in the first stage (see later sections).

Rinsing process

The final stage of the wet part of the process is a rinsing with clean hot water to remove any loose debris picked up by the egg in the main washing process. This operation also serves to remove any residues left by chemicals or other dissolved matter in the wash water. It is at this stage in the process that the hottest (up to 60°C) water is applied to the egg, providing additional heat to aid the drying process that follows.

Drying process

The drying process is carried out in two or more stages. It involves two distinct physical processes - (i) the mechanical removal of 70-80% of the surface water carried by the egg and (ii) the removal of most of the remainder by evaporative mechanisms. The first stage involves an element of drainage usually assisted by the use of air jets - for this reason, in some designs, the rotation of eggs is temporarily stopped in this part of the process. Evaporation itself is enhanced by the same air jets; the process can be aided by de-humidification or pre-warming of the air used. An alternative mechanism that also achieves both types of drying is the use of very soft brushes to “wipe” the eggs dry. In this case a general movement of air through the cabinet is required to maintain the brushes as dry as possible.

Microbiological considerations of the egg washing process

Given that water can facilitate the movement of bacteria through the shell in to the egg contents the way in which the water is applied (*e.g.* temperature, duration, use of brushes/jets) and the quality of that water is critical to the success of the egg washing process. The major parameters which influence egg washing are: water temperature, wash water quality and mineral content, wash chemicals, pH of wash water and the use of brushes and jets.

WATER TEMPERATURE

Water temperature is important. Haines and Moran (1940) observed that when eggs are placed in a cooler bacterial suspension, a pressure gradient is set up which draws bacteria through the shell into the interior. When the culture temperature was of a higher temperature, a negative hydrostatic pressure was created which minimises the movement of solvent into the egg. This finding is fundamental to understanding how to wash eggs in such a way that the risk of bacteria moving through the shell is minimised. Brant and Starr (1962) concluded that the temperature of the wash water should be >11°C higher than the egg temperature.

Leclair *et al.* (1994) studied the effects of wash water temperature in the range 38°C to 46°C on the inactivation of *S. typhimurium* and *Listeria monocytogenes*. Both pathogens were significantly affected (>4-log reduction) by increasing wash water temperature (Leclair *et al.*, 1994). Similarly, Bartlett *et al.*, (1993) reported that in the presence of wash chemicals there was an inverse correlation ($r^2 > 0.65$) between the temperature of egg wash water and the total aerobic counts that the water contained. More recently, Lucore *et al.* (1997) used a spray wash system to compare the effects of three wash water temperatures (15.5°C, 32.2°C and 48.9°C) upon internal and external shell surface bacterial counts. The treatments used were shorter in duration than would normally be applied in commercial practice, namely ten seconds for washing and three seconds for rinsing. Under these conditions, Lucore *et al.* concluded that spray washing of eggs at the lowest temperature did not increase internal shell bacterial counts and recommended a re-examination of cold water washing procedures.

An important consideration with respect to temperature is that as wash water temperature rises, there is an increased risk of cuticle damage and thermal cracking (Wesley and Beane 1967). For this reason Wesley and Beane recommended that wash water temperatures greater than 45°C should be avoided. The USDA (2001) recommended a wash water temperature in excess of 32°C with a minimum differential of 12°C. For the machines reviewed previously by ADAS (Gittins 1996), the water temperatures were maintained within a range of 40 – 45°C. Brant and Starr (1962) reported that provided the temperature of the wash water was at least 11°C higher than the egg temperature, treatment time was relatively unimportant in terms of bacterial uptake into the egg. They concluded that the treatment time should be determined by considerations of shell cleanliness rather than by the danger of spoilage.

In the UK the temperature of a table egg immediately prior to entering the washing machine may range from *cf* 41°C (body temperature of the hen) to 12°C (temperature that eggs may be stored at). It is important therefore that the temperature of the eggs is considered when setting up the egg washing machine if thermal cracking or negative pressure differentials are to be avoided.

The temperature of the final rinse water should also always be slightly higher than the temperature of the wash water in order to prevent the temperature differential causing a negative pressure in the egg which in turn would draw wash water into the egg. In the past, some manufacturers (*e.g.* Diamond Systems) have recommended a temperature as high as 58 – 59°C for this final stage, in order to aid the subsequent drying of the shell.

WASH WATER QUALITY

To ensure that washing does not result in contamination of the egg with organic or inorganic residues, potable water should be used at all stages of egg washing. Soft water with low calcium content is ideal for egg washing because it will reduce the rate of calcification on components within the washing machine due to calcium release from shell fragments. For reasons referred to above (see “Role of Iron in the wash water”), water used to wash eggs should have an iron level of <2 ppm (Garibaldi and Bayne 1960, 1962).

THE EFFECT OF WASH WATER CHEMICALS AND PH ON EGG QUALITY

Chemicals used when washing eggs should be food safe and compatible with the machine, the eggs and other chemicals used in the washing process. Moats (1978) concluded that eggs washed with a sanitising chemical in the wash water invariably spoiled less than eggs washed in water alone. However, bacteria that had penetrated into the pores of the shells were protected from the antimicrobial action of the sanitising chemicals. Moats further concluded that reports on the effectiveness of various sanitizers were conflicting. This is consistent with the views of Nield (1992) who contended that the success of a particular chemical was dependent on the quality of the water being used.

Favier *et al.* (2000a), compared how the survival of *Yersinia enterocolitica* and total aerobic counts was influenced by washing using hypochlorite, lactic or acetic acid. Although chlorine, at concentrations of 200 ppm, was far more effective at reducing aerobic counts on the shell surface, *Yersinia* was equally sensitive to chlorine and organic acid (Favier *et al.*, 2000a). So called super-chlorination of water is however not an option under current legislation in many countries.

While chlorine and quaternary ammonium compounds are commonly used for sanitising eggs other compounds such as peracetic acid have also been used in commercial egg washing machines. However chemicals which may be effective in reducing the bacterial load may also damage the egg's cuticle or shell (Wang and Slavik 1998; Favier *et al.*, 2000b; Sauter *et al.*, 1978).

Favier *et al.* (2000b) used both scanning electron microscopy and a blue lake dye tracer to study shell fragments of eggs that had been washed by hand in water containing: (i) Extran, (ii) Tergitol (type 08), (iii) sodium hypochlorite (100ppm) and (iv) combination of Tergitol and sodium hypochlorite. The blue lake dye was used to mimic the process of bacterial entry through egg shells because the dye particles are similar in size to Salmonella (Kim and Slavik, 1996). However, each chemical treatment was performed at different temperatures, making direct comparisons difficult and a control (consisting of water without additives) was also omitted although the study did compare unwashed eggs with those washed in the presence of the above additives. The authors concluded that the severity of the structural alteration was dependant on the chemical(s) which were added to the wash water. Thus the cuticle on eggs treated with Extran was eroded and etched. Extran also appeared to etch the internal surface of the shell. Furthermore, the treatment showed a significant ($P < 0.05$) increase in the penetration of blue lake dye through the shell (Favier *et al.*, 2000b). Tergitol treatment caused a pronounced granulation of the external surface of the egg. Viewing the cuticle in cross section showed that it was badly eroded. The inside of the shell was also badly etched by treatment with Tergitol with numerous large ($\sim 5 \times 10^{-5}$ m in length) fissures and pores observed. As with Extran, the Tergitol treatment showed a significant increase in the penetration of dye through the shell. Favier *et al.* (2000b) did not perform electron microscopy on shell fragments for the chlorine and chlorine/Tergitol treatments although the dye assay revealed that the chlorine/Tergitol combination caused the greatest increase to the shell permeability of all the treatments. This contrasted with washing where only 100 ppm chlorine caused the least change.

Wang and Slavik (1998) also used scanning electron microscopy to observe changes to

the physical structure of egg shells caused by commercial washing chemicals. The three chemicals used in the study were a quaternary ammonium compound (pH 7.5), sodium carbonate (pH 12) and 100 ppm sodium hypochlorite (pH 7.5). This study allowed better comparisons between each of these wash additives than those from the Favier *et al.* (2000b) study because all of the treatment washes were replicated, performed at the same temperature (43.3°C) and the experiment also included the inclusion of a tap-water wash control.

Wang and Slavik's study reported that the cuticle for eggs washed with only water was of normal thickness (20-30 µm) and appeared unaffected by the treatment. The cuticle on eggs washed with 100 ppm sodium hypochlorite was not altered significantly. Although washing with quaternary ammonium similarly appeared to preserve the cuticle, residues of the wash compound were left on the shell after washing and drying. Conversely, washing with sodium carbonate caused severe damage to the cuticle, presumably as a direct result of the high pH, and removed it almost entirely. Other chemicals that have been shown to have a deleterious effect on cuticle quality include cetylpyridinium chloride (used at 10, 50 and 100ppm) and trisodium phosphate (used at 0.5, 1.0 and 5.0%) (Kim and Slavik, 1996). Studies undertaken by the authors (spray washing using sodium hypochlorite) have similarly demonstrated the degradation of the cuticle that can occur when shells are subjected to sanitizer (Chlorwash 3g/l) sprayed under relatively high pressure onto the shell (Figure 2).

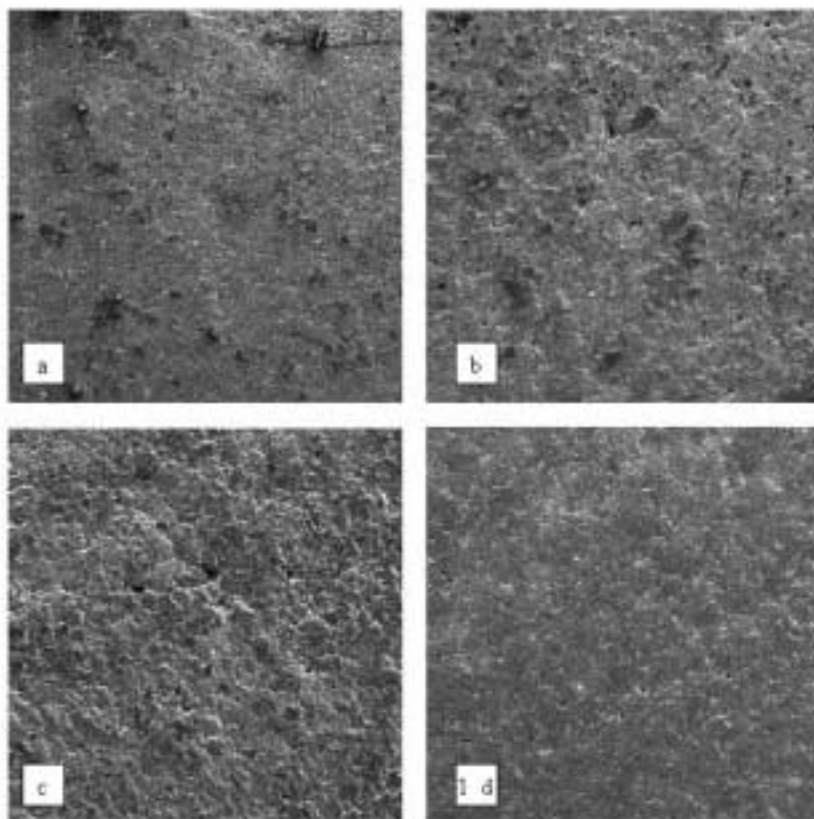


Figure 2 Scanning electron micrographs showing (a) the typical shell surface of an unwashed egg and (b - d) eggs that have been spray washed (with sodium hypochlorite). Bar marker 100 µm.

Jones *et al.* (1995) have isolated *Salmonella heidelberg* from the shell of eggs washed under commercial conditions when the pH of the wash water was allowed to fall below pH 10.2. Furthermore, pH-dependent reductions to the levels of *S. typhimurium* and *L. monocytogenes* have also been reported by Leclair *et al.* (1994). More generally, Bartlett *et al.* (1993) report that there is a strong relationship between high pH (≥ 10.5) and low counts of total aerobic bacteria in wash water sampled from commercial facilities.

Pearson *et al.* (1987) reported that egg wash water of high pH was bactericidal to *E. coli* and *Salmonella* and contended that HACCP programmes should involve regular sampling and analyses.

THE EFFECT OF WATER MANAGEMENT PRACTICES

Whilst various guidelines advise that a minimal quantity of wash water is used, (J. Gittins, pers comm) the consumption of large amounts leads both to high supply costs and effluent disposal problems. To achieve better use of limited amounts of water, some degree of recycling is therefore used in some egg washer designs in deference to the recommendations to use only fresh potable water throughout (USDA, 1966). Typically, such recycling would involve the use of drainage water from the final rinse stages to provide the initial wetting and cleaning in the first stages. The potential hazards of this approach lie principally with the inevitable higher concentration of organic debris in the wash water and the increased risks of cross contamination especially in the light of the occasional damaged egg. The latter is a more general problem with egg washing as the liberal use of water will provide some degree of transfer between one egg and its close neighbours. The main problem with the re-use of spent wash water is the associated build up of bacterial numbers in warm water carrying an organic load. The use of permitted sanitizers can negate this effect to some extent but there is no guarantee that such reagents will not be neutralised unless very large amounts are used. A key design factor is the residence time of the recycled wash water (total volume of wash water held up in the washer system divided by the volume feed-rate of fresh water) which gives an indication of the opportunity for microbe build up. This does not need to be more than 30 minutes or so but it should be noted that "dead zones" may exist within the washer where the effective residence time of the retained water may be much longer.

Effectiveness and problems of the egg washing process

THE DEVELOPMENT OF EGG CLEANING SYSTEMS

The first mechanical continuous egg washing systems were developed in the 1950's. The eggs sat on plastic trays and high-pressure nozzle type washers were used to spray detergent and water onto the eggshells in order to clean them. At this stage, brushing systems were impractical because the eggs were static within the cells of the tray and the brushes could not access the entire surface. These high-pressure jet systems were considered to cause an unacceptable number of the more vulnerable eggs (*e.g.* from older flocks) to break (Nield, 1992). In addition, very small particles of shell could plug individual nozzles causing the pressure through the remaining nozzles to increase and hence causing further breakage.

As the table egg industry grew, mass candling systems were introduced as part of the quality control procedures. This requirement created the need to unload eggs from trays onto a roller or spool conveyor so that the whole of the egg could be observed. The same technology was applied to egg washing machines, thus the egg was rolling as it passed through the washer and this improved the cleaning process.

MECHANICAL CLEANING WITH BRUSHES

The first brushes to be used in egg washers moved across the egg in an up-and-down motion. However it was found that the “up” motion did little or no cleaning and the “down” motion could damage the eggs. Brushes were then placed on cylinders and given a side-to-side motion. This action was gentler on the egg, since the side of the bristle was in contact with the egg rather than the end of the bristle.

While the side-to-side motion has been retained in many egg washing systems, flat brushes, mounted at an angle to the egg, are also commonly used. The brushes are arranged on frames such that alternating brushes travel in opposite directions. These opposing forces should reduce the risk of the egg being displaced from the tray. In some cases, the brushes are scalloped to fit the contour of the egg but all brushes have a potential to damage eggs. The cleaning action itself can result in the egg rocking in the conveyor causing a collision with the conveyor structure or with another egg. An added complication is the adjustment of the brushes to meet the requirements of the different sizes of eggs within a single batch. This can result in large eggs being damaged by excessive abrasion and small eggs being inadequately washed (personal observation). For these reasons, some commercial scale egg washing machines rely on jets of water only, with no brushes.

Where brushes are used, the bristles are normally made of nylon but some have reinforced tips to the brush fibres, comprising fine-grained sand or epoxy adhesives in an attempt to improve the washing process (Kuhl, pers comm). The brushes themselves may also harbour egg material and faecal matter and therefore the brush action has to be combined with a high volume of water which continually cleans the brushes during the washing process (Nielsen 1992). Furthermore, to ensure efficient cleaning of the egg washer it is important that the rows of brushes can be removed easily from the machine and cleaned separately at regular intervals.

Apart from damage caused to eggs by chemicals there is also the possibility that the cuticle and shell may be eroded or damaged in some other way by the action of either the brushes or high-pressure spray jets used in the washing machine. While some authors (Kuhl, 1987; Overfield, 1989) have reported that, under normal operating conditions, spray jets do not damage the cuticle, there are reports of the cuticle being significantly eroded by spray jets used under standard operating conditions (Sparks and Burgess, 1993).

SPRAY CLEANING

High pressure jets of water and sanitizer remove the risk of cross contamination that is associated with brushes and have been found to clean eggs effectively (ADAS, 1994). However, as noted in the report, further work is required to confirm that at the higher pressures there is no risk of shell damage or wash water being forced through the pores in the shell potentially causing contamination of the egg contents.

Post washing treatments

EGG DRYING PROCESSES

Eggs should be dry before being packed as wet eggs will accelerate the growth of fungi, particularly when the eggs are packed in sealed units. Failure to adequately dry eggs following washing can also lead to the conveyor becoming wet, washed eggs becoming contaminated on the surface and, if the egg cools, there is a risk that moisture and bacteria will be drawn through the shell.

Early studies by ADAS (Gittins, 1996) as well as an assessment of commercial egg washing in Sweden in the mid 1970s (ADAS, 1974) reported that machines frequently

failed to adequately dry eggs. Drying was also a problem in the commercial machines tested by ADAS in field trials in 1988 and 1989 (Overfield, 1989). Although in a subsequent study by ADAS (1994) eggs were dried successfully.

The provision of mechanical drying such as can be supplied as fine pressure air jets “cutting” the free water from the shell, is achieved relatively easily. The main problem with drying comes from the final stages of the operation that rely primarily on evaporation as the principal mechanism. High-speed air should be further supplemented with a hot-air dryer or de-humidified air. This is especially so in regions with high humidity or in packing stations with a low ambient temperature. The temperature of the outer egg shell is also an important factor in determining the rate at which eggs can be dried (Nielsen, 1992), suggesting that a very hot final rinse after washing could be beneficial. However, there is a large difference between quantities of heat to warm, and those needed to evaporate; *e.g.*, it takes 42 kJ to warm one kilogram of water by 10°C but to evaporate this amount, ten times as much heat (4,400 kJ) is needed!

The volumes of air required are also much higher than one might expect, one cubic metre of air at 30°C holding just 30g of water at saturation. On the basis that ambient air enters the dryer at 20°C and 30% RH (*i.e.*, after de-humidification) and that exhaust air leaves the dryer at 80% RH it can be expected to pick up a maximum of just *nine grams* of water per metre cubed (Mayhew and Rogers, 1976). Furthermore, even the provision of enough thermal energy and enough capacity to remove the residual water does not guarantee a complete process as a minimal period of time is also necessary. The kinetics of drying are governed by the resistance of a thin film of air that surrounds the egg:

$$N \text{ (kg water removed/sec.egg)} = k(C^* - C)$$

where C is the prevailing moisture concentration in the air and C* the saturation value at the operational temperature. The constant, k, depends on transport properties such as air velocity (as is the case for the related heat transfer coefficient); it will fall though as drying progresses and (i) dry spots appear on the egg and (ii) free moisture is removed leaving bound moisture as set out by standard texts on drying (*e.g.*, Treybal, 1968). The combined effect of the preceding drying constraints is the likelihood of many systems not providing enough time for the complete evaporation process. The relatively short dwell time of 10-20 seconds in many modern systems suggests that drying by mechanical water removal (rather than evaporation) will be the dominant process within the dryer. Thus inadequate drying may well be a problem but verification and control is difficult (beyond establishing that the egg is not visibly wet) owing to the difficulty in determining what constitutes an adequately dried egg.

EGG OILING

It has been reported (Ball *et al.*, 1976) that the shells of eggs oiled after washing are physically stronger than those of un-oiled eggs. However the main benefit is a reduction in the rate of decline of internal egg quality by reducing the rate of water and carbon dioxide loss from the egg and possibly also inhibiting entry of micro-organisms.

Tests carried out by the New Zealand Poultry Board in the early 1980's assessed the effects of washing and oiling on albumen quality (Haugh Units) after 28 days of storage (Anon, undated). Using commercial egg washing and oiling machinery, they compared eggs which had been washed and oiled with those which had been washed only. A control group of unwashed eggs was also tested. At the end of the storage period, they found that quality was highest in the eggs which had been both washed and oiled. Unwashed eggs were superior to those that had been washed but not oiled.

In spite of the experimentally proven benefits, oiling is by no means universally

practised on commercial sites where egg washing is undertaken. In the USA, it has been estimated that 50% of eggs are oiled after washing (Nield, 1992). The practice is adopted mainly in warmer regions of the country where there is a risk of inadequate refrigeration or if the eggs are destined for export. It is not considered necessary when eggs were distributed using refrigeration conditions (<12°C) and likely to be consumed quickly.

Conclusions

It has been demonstrated that egg washing can reduce the number of micro-organisms on the shell of the egg however it can, under certain circumstances, cause food poisoning and spoilage organisms to be moved from the surface of the shell into the contents of the egg. Given the number of countries that allow or demand table-egg washing it is notable there are relatively few contemporary papers in the scientific literature that provide microbiological data for eggs that have been washed using commercial conditions. Similarly there is a paucity of information on the impact on the microbiological flora of relatively small changes in the egg washing machine's operating parameters (e.g. temperature of the water used, concentration of active sanitizer, changes in eggshell due to effect of flock age etc). Proponents of egg washing will undoubtedly point to the low incidence of food poisoning linked to washed eggs however the associated use of a cool chain or oiling with washed eggs makes it difficult to assess the efficacy of washing *per se*. This is compounded by a recent survey (J. Gittins, pers comm.) that showed that in countries where egg washing is commonplace many companies do not routinely monitor the microbial status of the washed egg.

Given the advances in the technology associated with egg washing machines and that many of the current recommendations are based on data generated using machines that predate the current technology by several generations it is arguably appropriate to re-evaluate the current criteria for egg washing machines. This should allow current technology to be fully exploited so as to maximise the benefits of egg washing.

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References

- Aasa, R., MALSTROM, B.G., SALTMAN, P. and VANNGARD, T. (1963) The specific binding of iron (III) and copper (ii) to transferrin and conalbumin. *Biochim biophys Acta* **75**: 203-222.
- ADAS (1974) Commercial Egg Washing – report of a study tour undertaken in Sweden.
- ADAS (1994) Egg washing trials ADAS Gleadthorpe Research Centre, ADAS workshop notes.
- ANON (undated) Reports on egg washing. Published by the New Zealand Poultry Board circa 1980.
- BALL, R.F., HILL, J.F., LOGAN, V. and LYMAN, J. (1976) The effect of washing, oiling, holding and temperature of eggs on shell strength. *Poultry Science* **55**: 335-340.
- BARTLETT, F.M., LAIRD, J.M., ADDISON, C.L. and MCKELLAR, R.C. (1993) The analysis of egg wash water for the rapid assessment of microbiological quality. *Poultry Science* **72**: 1584-1591.
- BERRANG, M.E., COX, N.A., FRANK, J.F. and BUHR, R.J. (1999) Bacterial penetration of the eggshell and shell membranes of the chicken hatching egg: A review. *Journal of Applied Poultry Science* **8**: 499-504.
- BOARD, R.G. (1966) The course of microbial infection of the hen's egg. *Journal of Applied Bacteriology* **29**: 319-341.
- BOARD, R.G. (1977) The Microbiology of eggs. *Egg Science and Technology* (Stadelman, W.J. and Cotterill, O.J., Eds.) AVI Publishing Company Inc Westport Connecticut pp. 49-64.

- BOARD, R.G., TULLETT, S.G. and PERROTT, H.R. (1977) An arbitrary classification of the pore system in avian eggshells. *Journal of Zoology (London)* **182**: 251-65.
- BOARD, R.G., LOSEBY, S. and MILES, V.R. (1979) A note on microbial growth on hen eggshells. *British Poultry Science* **20**: 413-420.
- BOARD, R.G., SPARKS, N.H.C. and TRANTER, H.S. (1986) Antimicrobial defence of avian eggs. In: *Natural antimicrobial systems*. (Gould, G.W., Rhodes Roberts, M.E. and Charnley, A K, Eds.) Bath University Press, Bath, UK pp. 82-96.
- BOARD, R.G., CLAY, C.E., LOCK, J. and DOLMAN, J. (1994) The egg: a compartmentalized, aseptically packaged food. (Board R.G, Fuller R. Eds). *Microbiology of the Avian Egg*. London, Chapman and Hall, pp. 43-61.
- BRANT, A.W. and STARR, P.B. (1962) Some physical factors related to egg spoilage. *Poultry Science* **41**: 1468-1473.
- BROOKS, J. (1951) The washing of eggs. *Food Science Abstract* **23**: 545-54.
- BRUCE, J. and DRYSDALE, L. (1994) Trans-shell transmission. In: *Microbiology of the Avian Egg*. (Board, R.G. and Fuller, R. Eds.). London, Chapman and Hall, pp. 63-91.
- Cantor, a. and McFarlane, v.h. (1948) Salmonella organisms on anin chicken eggs. *Poultry Science* **27**: 350-355.
- CHINGLEE, M.R., KATZ, A.R., SASAKI, D.M. and MIETTE, H.P. (1991) Salmonella egg survey in Hawaii – evidence for routine bacterial surveillance. *American Journal of Public Health* **81(6)**: 764-766.
- EUROPEAN UNION (1991) Commission regulation (EEC) No 1274/91 "Introducing detailed rules for implementing Regulation (EEC) No 1907/90 on certain marketing standards for eggs".
- FAVIER, G.I., ESCUDERO, M.E., MATTAR, M.A. and GUZMAN, A.M.S. (2000a) Survival of *Yersinia enterocolitica* and mesophilic aerobic bacteria on eggshell after washing and hypochlorite and organic acid solutions. *Journal of Food Protection* **63**: 1053-1057.
- FAVIER, G.I., ESCUDERO, M.E., VELAQUEZ, L. and DE GUZMAN, A.M. (2000b) Reduction of *Yersinia enterocolitica* and mesophilic aerobic bacteria in egg-shell by washing with surfactants and their effect on the shell microstructure. *Food Microbiology* **17**:73-81 .
- GARIBALDI, J.A. and BAYNE, H.G. (1960) The effect of iron on Pseudomonas spoilage of experimentally infected eggs. *Poultry Science* **39**: 517-1520.
- GARIBALDI, J.A. and BAYNE, H.G. (1962) The effect of iron on the Pseudomonas spoilage of farm-washed eggs. *Poultry Science* **41**: 850-853.
- GITTINS, J. (1996) UK Egg washing update: An ADAS perspective. PE5313, 1-20, London, MAFF.
- HAINES, R.B. and MORAN, T. (1940) Porosity of, and bacterial invasion through, the shell of the hen's egg. *Journal of Hygiene, Cambridge* **40**: 453-461.
- HENZLER, D.J., KRADEL, D.C. and SISCHO, W.M. (1998) Management and environmental risk factors for *Salmonella enteritidis* contamination of eggs. *American Journal of Veterinary Research* **59**: 824-829.
- HMSO (1968) Report of the Reorganisation Commission for Eggs.
- HMSO (1995) Egg (Marketing Standards) Regulations 1995 (Statutory Instrument 1995 No. 1544).
- HUMPHREY, T. (1994a) Contamination of egg shell and contents with *Salmonella enteritidis*: a review. *International Journal of Food Microbiology* **21**:31-40.
- HUMPHREY, T. (1994b) Contamination of eggs with potential human pathogens. In: *Microbiology of the Avian Egg*. (Board, R.G. and Fuller, R. Eds.). London, Chapman and Hall, pp. 93-116.
- HUMPHREY, T., BASKERVILLE, A., MAWER, S.L., ROWE, B. and HOPPER, S. (1989) Salmonella enteritidis PT4 from the contents of intact eggs: a study involving naturally infected hens. *Epidemiology and Infection* **103**: 415-423.
- HUMPHREY, T., CHART, H., BASKERVILLE, A. and ROWE, B. (1991) The influence of age on the response of SPF hens to infection with *Salmonella enteritidis* PT4. *Epidemiology and Infection* **106**: 33-43.
- JENKINS, M.K. (1919) USDA Bulletin No 775.
- JONES, F.T., RIVES, D.V. and CAREY, J.B. (1995) Salmonella contamination in commercial eggs and an egg production facility. *Poultry Science* **74(4)**: 753-757.
- KIM, J.W. and SLAVIK, M.F. (1996) Changes in eggshell surface microstructure after washing with cetylpyridinium chloride or trisodium phosphate. *Journal of Food Protection* **59**: 859-863.
- KUHL, H. (1987) Washing and sanitising hatching eggs. *International Hatchery Practice* **2(3)**: 20-1.
- LECLAIR, K., HEGGART, H., OGGEL, M., et al. (1994) Modelling the inactivation of *Listeria monocytogenes* and *Salmonella typhimurium* in simulated egg wash water. *Food Microbiology* **11**: 345-353.
- LUCORE, L., JONES, F.T., ANDERSON, K.E. and CURTIS, P.A. (1997) Internal and external bacterial counts from shells of eggs washed in a commercial-type processor at various wash-water temperatures. *Journal of Food Protection* **60**:1324-1328.
- MAWER, S.L., SPAIN, G.E. and ROWE, B. (1989) *Salmonella enteritidis* PT4 and hen's eggs. *Lancet* **i**: 280-281.
- MAYES and TAKEBALLI (1983) Microbial contamination of the hen's egg: A review. *Journal of Food Protection* **46**: 1092-1098.

- MAYHEW, Y.R. and ROGERS, G.F.C.** (1976) *Thermodynamic and Transport Properties of Fluids*. Second edition. Oxford, Basil Blackwell.
- MOATS, W.A.** (1978) Egg washing - a review. *Journal of Food Protection* **41(11)**: 919-925.
- NIELD, J.M.** (1992) American approach to egg washing. *Conference Proceeding*.
- OVERFIELD, N.** (1989) Egg washing – time for re-assessment. *ADAS Report*.
- PADRON, M.** (1990) *Salmonella typhimurium* penetration through the eggshell of hatching eggs. *Avian Diseases* **34(2)**: 463-465.
- PEARSON, J., SOUTHAM, G.G. and HOLLEY, R.A.** (1987) Survival and transport of bacteria in egg washwater. *Applied Environmental Microbiology* **53**: 2060-2065.
- SAUTER, E.A., PETERSON, C.R., PARKINSON, J.F. and STEELE, E.F.** (1978) Effect of pH on eggshell penetration by Salmonellae. *Poultry Science* **58**: 135-138.
- SIMONS, P.C.M.** (1971) Ultrastructure of the hen eggshell and its physiological interpretation. *Communication No. 175*. Central Institute Poultry Research, Beekbergen, The Netherlands
- SPARKS, N.H.C.** (1985) The hen's eggshell: a resistance network. *PhD Thesis*, University of Bath.
- SPARKS, N.H.C.** (1994) Shell accessory materials: structure and function. In: *Microbiology of the Avian Egg*. (Board, R.G. and Fuller, R. Eds.). London, Chapman and Hall, pp. 25-42.
- SPARKS, N.H.C. and BOARD, R.G.** (1984) Cuticle, shell porosity and water uptake through hens' eggshells. *British Poultry Science* **25**:267-276.
- SPARKS, N.H.C. and BURGESS, D.** (1993) Effect of spray sanitising on hatching egg cuticle efficacy and hatchability. *British Poultry Science* **34**: 655-662.
- TRANter, H.S and BOARD, R.G.** (1982) The antimicrobial defence of avian eggs; Biological perspective and chemical basis. *Journal of Applied Biochemistry* **4**:295-338.
- TREYBAL, R.E.** (1968) *Mass Transfer Operations*. Second edition. McGraw-Hill, Kogakusha.
- USDA** (1966) Improved Methods, Techniques and Equipment for Cleaning Eggs. Marketing Research Report No. 757 (in co-operation with the University of California) .
- USDA** (2001) Agricultural Marketing Service (Standards, Inspections, Marketing Practices) Part 56 - Voluntary Grading of Shell Eggs, Code of Federal Regulations Title 7, Volume 3, U.S. Government Printing Office, pp. 48-68.
- WANG, H. and SLAVIK, M.F.** (1998) Bacterial penetration into eggs washed with various chemicals and stored at different temperatures and times. *Journal of Food Protection* **61**: 276-279.
- WESLEY, R.L. and BEANE, W.L.** (1967) The effect of various wash water and internal egg temperatures on the number of thermal checks of oiled and un-oiled eggs. *Poultry Science* **46**: 1336-1338.