RURAL INDUSTRIES RESEARCH
& DEVELOPMENT CORPORATION

Food Safety Risk Management

in Different Egg Production Systems

A report for the Rural Industries Research and Development Corporation

by R.C. Dawson, J.M. Cox, A. Almond, and A. Moses

October 2001

RIRDC Publication No 01/111
RIRDC Project No MS989-28

ISBN 0 642 58333 1
ISSN 1440-6845

Food Safety Risk Management in Different Egg Production Systems
Publication no. 01/111
Project no. MS989-28

For further information contact
Dr Irene Gorman
RIRDC – Egg Program Research Manager
PO Box 569
Hurstville NSW 1481
Phone**:** (02) 9570 9222
Fax: (02) 9570 9763
Email: ireneg@rirdc.gov.au

Contact details for the authors

The "whys" of food safety and typical process flow chart:
Mr Abe Moses
"Inspired Intentions" Pty Ltd
Ph: (02) 9602 0326
Fax: (02) 9602 6259
Mobile: 0418769372
Email: Abemoses@ozemail.com.au

Review of microbiological hazards and risk:
Dr Julian Cox
University of New South Wales
Department of Food Science and Technology
Ph: (02) 9385 5665
Fax: (02) 9385 5931
Email: julian.cox@unsw.edu.au

Review of chemical hazards and risk and food safety plans:
Mr Andrew Almond
Institute of Land and Food Resources
University of Melbourne
Ph: (03) 5362 2243
Fax: (03) 5362 2213
Email: a.almond@landfood.unimelb.edu.au

RIRDC Contact Details
Rural Industries Research and Development Corporation
Level 1, AMA House
42 Macquarie Street
BARTON ACT 2600
PO Box 4776
KINGSTON ACT 2604
Phone: (02) 6272 4539
Fax: (02) 6272 5877
Email: rirdc@rirdc.gov.au
Website: http://www.rirdc.gov.au

Published in October 2001
Printed on environmentally friendly paper by Canprint

Foreword

In March 1998 the RIRDC Egg Program conducted a workshop to discuss research needs in relation to layer hen welfare and production systems. One of the priority areas identified at this workshop was the issue of food safety risk management. As a consequence, RIRDC commissioned this review, with the aim to:

- Compile and summarise existing information on food safety risks and risk management and present this in a publishable, easy-to-read review that is suitable for use by the industry; and,
- Identify information gaps and make recommendations on areas for future research.

Four viewpoints were identified as being critical to a comprehensive investigation in this area:

- Technical
- Commercial
- Training
- Production

Therefore, this review was prepared by a panel selected for their contribution to the expertise required to cover these viewpoints.

This project was funded from industry revenue which is matched by funds provided by the Federal Government.

This report, a new addition to RIRDC's diverse range of over 700 research publications, forms part of our Egg R&D program, which aims to support improved efficiency, sustainability, product quality, education and technology transfer in the Australian Egg Industry.

Most of our publications are available for viewing, downloading or purchasing online through our website:

- downloads at www.rirdc.gov.au/reports/Index.htm
- purchase at www.rirdc.gov.au/eshop

Peter Core
Managing Director
Rural Industries Research and Development Corporation

Contents

Executive Summary

Consumer concern and awareness over food-related illness and deaths is increasing steadily, particularly in western countries.

A review was conducted to compile and summarise existing information on food safety risks and risk management in the shell egg industry. The relative merits of cage, floor and free-range production systems are discussed in terms of potential microbiological hazards to the eggs produced in these systems. The micro-biological organisms of highest concern for food safety in eggs are salmonellae and the discussion of microbiological hazards therefore concentrates on these organisms.

Most eggs contain no bacteria when they are laid. Contamination of the shell surface occurs principally after laying and originates from the environment. The relative risks from caged, floor and free-range systems are discussed in this context.

The advantages of cage systems for egg production with respect to food safety have been cited as including little or no bird contact with faecal material, resulting in reduced risk of enteropathogenic infestations, and the hygiene afforded to the birds and eggs by the nature of the cage structure. This has been seen to be at least partly due to the lack of dust and atmospheric contaminants resulting from this method of production. The only direct comparison of food safety hazard risk management in various production systems found in the literature (Quarles *et al.*, 1970) demonstrated that litter floor poultry houses averaged approximately nine times as many bacteria in the air as houses where the cage system was used.

Research from the University of Glasgow also found that eggs from the caged system had superior shell structural integrity with a resulting improvement in their resistance to penetration by *Salmonella* Enteritidis. However, the report on this study did not give any indications of other variables that may have had a bearing on the outcomes obtained.

Eggs from conventional litter floor environments are typically more contaminated than those from cage systems. One study found the total number of bacteria on eggs from deep litter production systems to be 15 times greater than that found on eggs from battery production systems. It was noted that bacteria from the litter were transferred to the nest linings on the feet and the feathers of laying birds and that the bulk of the bacteria on deep litter eggs consisted of types found in the litter itself. It was also concluded that cycling of salmonellae between litter and the intestinal tract of birds appeared to be significant in maintaining intestinal infection. Litter floor systems also have a risk of contamination of the litter by rodents. The point can be made that poultry and rodents cannot exist so closely in cage systems and therefore the potential for cross-infection with salmonellae may not be as great in cage systems as in floor or free-range systems.

In the Australian context free-range systems of egg production differ only from the floor systems mentioned above in that the birds have access to the external environment. Accordingly, all that applies in terms of the risk of salmonellosis in connection with floor systems also applies where free-range is concerned. In a free-range environment the additional hazards of wild birds and other animals, access to unchlorinated water and miscellaneous environmental sources pose further threats to the *Salmonella* status of poultry flocks.

Egg collection equipment can have an important bearing on the microbiological contamination of eggs. Automatic egg collection can increase the risk of contamination over hand collection due to the higher probability of cracked and obviously contaminated eggs being collected. However, this issue is not directly related to the production system.

Steps that are essential in attempting to prevent or minimise the infection of poultry include: obtaining *Salmonella*-free stock; using *Salmonella*-free feed; providing rodent and wild bird-free housing;

providing protective clothing for workers; disinfecting footwear; frequent cleaning of water supply systems, and water chlorination; removing sick or dead birds; removing droppings and litter; and cleaning, with subsequent decontamination of houses after removal of flocks (Simonsen *et al.*, 1987).

There is also a range of chemicals that may be used on or around poultry farms that have the potential to pose a risk to food safety of eggs. Possible sources of chemical contamination of eggs include:

- Free range birds on contaminated soils
- Insecticide sprays used while birds are present
- Water medication at incorrect rate
- Eggs washed in non-approved solutions
- Egg washing compound mixed at high concentrations
- Systemic pesticides used in grower shed
- Shed fumigation while birds present
- Chemical feed additives included at wrong rate
- Use of antibiotics

The application of HACCP (Hazard Analysis Critical Control Point) techniques provides the most effective use of control resources by emphasising monitoring of CCPs (Critical Control Points) rather than concentrating on analyses of end product.

It is recommended that the Australian egg industry develops specific codes of practice and generic HACCP-based food safety plans for the cage, litter and free-range systems. Training materials should be prepared to train poultry producers and farm staff about implementing food safety plans, using a range of training methods. Sample information on the development of a HACCP-based food safety plan is provided in this report. It is also recommended that a poultry specific chemical training course be developed to train all poultry people in the proper use and handling of farm chemicals.

1. The "Whys" Of Food Safety

Over the last two decades the number of cases of food-related illnesses and deaths in western countries has steadily increased. Public awareness of the fact that many mild cases of food poisoning go unreported has also increased. Illnesses such as 24-hour stomach viruses associated with vomiting and diarrhoea do little more than confine the host to a day of bed-rest and prevention from fulfilling normal daily duties. Consequently these incidents have often gone unreported in surveys of food borne illnesses. As awareness has increased, it has become more and more apparent that many more cases of food related illness actually happen than previously considered.

In the late 1950's NASA had a need to source and supply its astronauts with food and water that was completely safe for consumption, since providing medical assistance for astronauts whilst in space would be extremely difficult. The concept of HACCP was born at this point as the Pillsbury Food Company proceeded to meet the challenge. HACCP, which is an abbreviation for Hazard Analysis and Critical Control Point, has since evolved as an accepted method for providing a high level of assurance of food safety.

The evolution of HACCP as a method of assuring food safety has been timely in light of the noted increase in the incidence of food borne illnesses. At the same time there has been increasing pressure from various sources on food producers to demonstrate that they have an effective HACCP based food safety program in place. Poultry and eggs have traditionally been perceived as being a higher risk category of food.

There have been many direct and indirect sources of pressure on food producers to operate their businesses under a HACCP system. One important direct source of pressure has come from customers and consumers. The more serious cases of food borne illness have sometimes resulted in loss of human life and associated negative media publicity. Consumers perceived that food manufacturers were not maintaining sufficiently high standards and emphasis in either their HACCP or supporting good management practice (GMP) systems. The response was to ask suppliers to demonstrate that these systems are in place, and if not, to see commitment from them that adequate food safety /quality systems would be operating within an acceptable time span. Customers are now routinely a) asking this of their suppliers; b) conducting second party audits of their supplier's systems, and c) asking for third party audits to be conducted on their suppliers. In some cases the ability to demonstrate these systems is becoming a condition of doing business.

Other pressures on food producers have come from Federal and State governments. For example, the NSW Government introduced the Food Production (Safety) Act in December 1998, which established Safe Food Production NSW (Safe Food). The functions of Safe Food include:

- Review the construction, hygiene, operating procedures of premises, vehicles, vessels and appliances used to handle primary produce and seafood;
- Regulate the handling of primary produce and seafood in accordance with established food safety schemes.

The Australian New Zealand Food Authority (ANZFA) has been commissioned by the State and Territory Health departments to develop a new set of Food Safety Standards, which emphasise a preventative approach. Amongst other things, the new standards will require producers to comply with more stringent requirements for production practices, premises, equipment, training, and above all, HACCP.

In the past, when food producers have been implicated in cases of food illness or poisonings, legal proceedings have ensued with the producer being called upon to demonstrate "due diligence". This means that the courts require evidence to show that the producer has taken all reasonable steps and

care to ensure that the food produced is safe for human consumption. Inability to demonstrate this to the satisfaction of the courts often results in costly compensation and punitive damages to be paid out to the parties affected and may even result in criminal proceedings. In some cases this has meant such enormous losses, that the company has been forced to go out of business. ANZFA has declared that a comprehensive and auditable HACCP program may be used as support of a "due diligence" case. This situation provides further reason for implementing HACCP.

ANZFA, in it's publication titled "Food Safety Standards, Costs and Benefits", has monitored an increasing trend in the frequency of food borne illness. The US, UK and Australia are some of the countries where monitoring has been conducted. Globally, the egg industry has been a part of this increase in food borne illness. Incidences of *Salmonella* Enteritidis (SE) related food poisoning have occurred in Europe and the US during the last 10 years that have reportedly implicated eggs. Although SE has not been reported in poultry in Australia, it is widespread in the islands of Indonesia and South-East Asia. It therefore makes sound business sense that Australian egg producers and processors have fundamental food safety systems already in place and operating, thus enabling a rapid and effective response to any new hazard when or if it occurs.

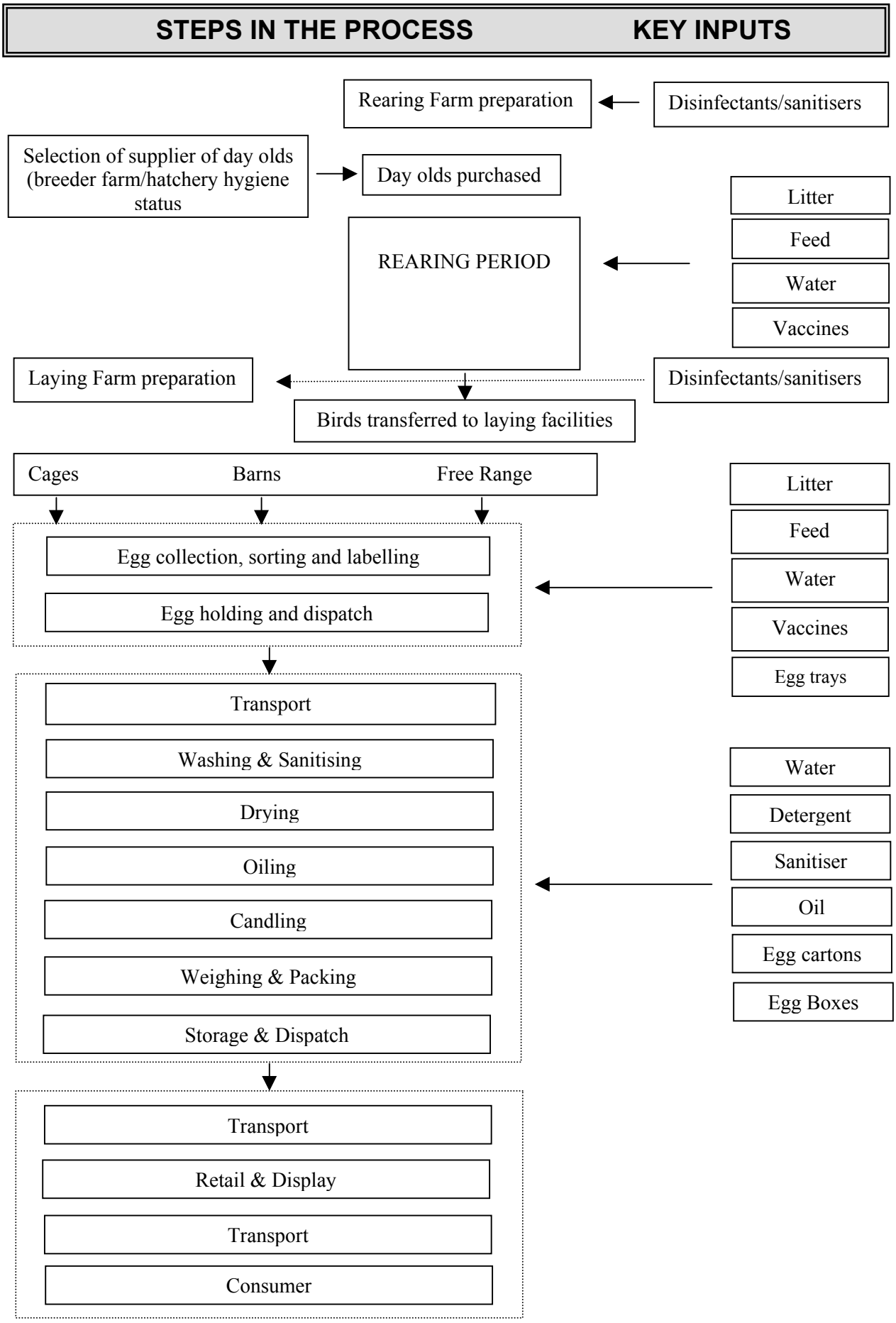
The challenge of implementing effective HACCP-based food safety plans in the egg industry has been increased by the changing trends in farming methods. The industry trend over the last 30 or 40 years has been in response to efficiencies of scale. Farms have become larger and moved away from traditional methods of farming – single deck cage plants – to multi-tiered cage units with highly automated mechanisms for feeding, watering, ventilation and egg collection.

Another trend in the egg industry has been towards Free Range and Barn egg production. Eggs produced by these alternative farming methods are growing in popularity, since consumers perceive them to be produced in a manner that is more humane and natural. One complicating factor is that these methods of farming may expose the birds and eggs they produce to higher food safety risks.

Research into evaluating these risks has not yet been thoroughly conducted. This paper reviews the information available on the potential food safety risks associated with the three major methods of commercial egg production and provides background information for the development of food safety plans for the commercial egg industry.

2. Typical Process Flow Chart

Egg Production



3. A Review of Food Safety Hazards and Risks in Cage, Barn and Free-Range Egg Production Systems

MICROBIOLOGICAL HAZARDS AND RISK

This review presents a summary of existing information relevant to food safety risk management where shell egg production is concerned. In the broadest view of the system, this includes the retail and consumer sections of the food chain. These have not been included for the purposes of this review. The relative merits of cage, floor and free-range production systems are discussed in terms of potential microbiological hazards to the eggs produced in these systems. It is recognised that in order to achieve microbiological integrity of shell eggs an integrated approach to production is required, this being one that ensures the highest standards practically achievable at all points of production, where the respective production systems are concerned. To this end suggestions are made in terms of critical control points (CCPs) for each system, but also where shell egg production is concerned generally. In addition, other issues that may have an impact in terms of improved food safety are identified and discussed, and recommendations for further research made.

INTRODUCTION

Egg production in Australia has changed dramatically during the last 50 years, having essentially turned full circle. Prior to World War II, the industry relied predominantly on backyard free-range operations, while post-War, it evolved into the ubiquitous cage-based system seen today. Circumstances, including animal welfare issues and market opportunities, have seen some return to alternative production systems, including both free-range and barn/floor operations. Although animal welfare has largely underpinned the trend toward alternative production, little consideration has been given outside of the industry to other issues, not the least of which is food safety. This review discusses food safety (and, to a lesser extent, quality) related to egg production, primarily in the context of *Salmonella*, the most significant pathogen of public health concern, and highlights variations in risk associated with different modes of production. It also considers the impact on food safety of other pathogens that may be associated with eggs, and the influence of production system on shelf-life/quality, due to microbial spoilage.

SALMONELLA

Salmonellae are acknowledged as being the most important human pathogens carried by eggs. The appearance and odour of eggs are not usually altered due to the presence of salmonellae (Vadehra and Baker, 1973); this means that an egg containing significant quantities of the bacterium could pass visual inspection and become a serious health hazard. For these reasons any review of the food safety of shell eggs will principally concern these organisms. The problems of microbial pathogens other than *Salmonella*, as well as the microbial causes of the spoilage of shell eggs will be addressed as separate issues, after an examination of the nature of the hazards posed by salmonellae.

Members of the genus *Salmonella* are maintained within a poultry population by means of asymptomatic infections in birds and the persistence of the organism in the other animals, the production environment, feed and water. These sources serve to keep birds re-infected in a cyclical manner and this can result in the subsequent infection of eggs collected from them. Infection of eggs may occur via the hen's oviduct or by faecal contamination; in the former case, oviduct infection may arise following systemic infection or ascending infection, via the cloaca. The importance of the two infection routes is strain-dependent, with *S.* Enteriditis (SE) Phage Type (PT) 4 , for example, being

more commonly infective of eggs via reproductive tissue (Humphrey, 1994), although other strains of salmonellae, including *S. Typhimurium* and *S. Heidelberg*, have also been isolated from the ovaries of naturally infected chickens (Barnhart *et al.,*1991). Schoeni *et al.* (1995) established that strains of the three serovars mentioned here, when present in faeces, can penetrate the shells of eggs and may grow within eggs during storage. If the shell is heavily contaminated, the microbial challenge is greater, and bacteria including salmonellae are likely to penetrate sooner and in greater numbers than for cleaner eggs (ICMSF, 1998a). How cage, barn and free-range egg production systems differentially affect infection rates, and the potential for re-infection with salmonellae, will be discussed. To begin with however, some general considerations relevant to the control of *Salmonella* should be noted and understood to apply irrespective of the type of production system used.

GENERAL CONSIDERATIONS IN THE CONTROL OF *SALMONELLA*

Feed

Salmonella infections are readily acquired by poultry through the consumption of contaminated feed. Multiplication in the intestinal tract is rapid, and as a result high populations of the organism may become established in birds, giving rise to the carrier state. Birds may remain carriers for a long time; this poses an important problem in egg production and has potential implications for human health. It has long been recognised that in any effort to eliminate salmonellosis from poultry it is essential to consider the potential for their continuous inoculation via infected foodstuffs. Extensive epidemiological investigation has established that contaminated feed has been the main source of infection of poultry with salmonellae (Bisgaard, 1992). As long as a poultry population receives contaminated feed, no basic or permanent improvement in flock infection status may be expected (Williams, 1981).

In an extensive review of the *Salmonella* status of poultry feeds, Williams (1981) quotes a number of studies that define a correlation between the serovars collected from feed samples at various farms and those isolated from the faeces and the meat of birds consuming the feeds; dissemination of feed-associated serovars may extend to egg contamination. Surveys of laying flocks performed in Queensland (Cox and others, unpublished), further support the link between contaminated feed and bird carriage of *Salmonella* serovars. Williams (1981) concluded that nearly every ingredient ever used in the manufacture of poultry feeds has been shown at some time to contain *Salmonella*, but that the organism occurs most frequently in sources of protein derived from animal products. Post-process recontamination of animal sources of protein has been considered to be the most important single factor responsible for the presence of salmonellae in these products (Wedman, 1961, cited in Williams, 1981). The inclusion of animal protein in poultry feeds, particularly as a raw material, is routine in Australia; given the high-risk status of animal proteins in feeds world-wide, as evident from the literature, the same risk logically applies in this country.

Grain constituents of poultry feeds have also been implicated in the transmission of salmonellae to poultry (Bains and MacKenzie, 1974). As well, other plant-derived components of feeds have been identified as harbouring the organism; *Salmonella* Tennessee, for example, has been isolated from soybean meal included in feed supplied to a layer flock. The organism was subsequently found in the viscera of birds from the flock at slaughter (Timoney *et al.,* 1970). Studies in Queensland (Cox and others, unpublished) have found a range of plant-derived feed components, including soybean, cottonseed and canola meals, to be contaminated with *Salmonella*.

Moisture levels of feeds influence the growth dynamics of salmonellae. Carlson and Snoeyenbos (1969) in a study using *Salmonella Typhimurium*, *S.* Tennessee, SE and *S. Heidelberg* found that for all four strains low moisture levels (eg 5%) allowed populations to remain stable for extended periods, irrespective of the type of feed tested. Feeds examined in the study were meat and bone meal, fish meal, feather meal, poultry by-product meal and a poultry mash. It was further found that as the moisture level increased the viable cell count decreased, until moisture levels reached water activity levels of about 0.96 or higher, corresponding to a moisture content of about 40%. From this point

significant increases in salmonellae populations were observed. Importantly, natural microflora present did not prevent the multiplication of salmonellae in the feeds used in this study.

The importance of keeping feed ingredients and finished feeds dry cannot be over-emphasised and has been identified as a practice contributing to the production of uncontaminated feeds, as has the practice of pelleting, where heat treatment is used. Zindel and Bennett (1968) found salmonellae in 13 (1.6%) of 808 samples of feed and feed ingredients but failed to isolate the organisms from any pelleted or extruded feeds. Morris *et al.* (1969), after extensive examination of different types of feeds, found that non-pelleted feed was contaminated more often than pelleted feeds. Vaughan *et al.* (1974) demonstrated that heat treatment applied to complete feed rations, as part of a feed pelleting process, was important in the reduction of infection with salmonellae in a broiler operation. In sampling poultry feed prior to and after pelleting, Stott *et al.* (1975) showed that the process reduced the numbers of Enterobacteriaceae (the taxonomic family to which *Salmonella* belongs) to as little as 1/1000 of the pre-pelleting value, depending on the type of process used. Further work carried out by Jones *et al.* (1991) resulted in isolation of salmonellae from mash feeds at a rate of 35% and from pelleted feeds at a rate of 6.3%, indicating that the pelleting process reduced the prevalence of the organism by 82%. The heat process must be of sufficient duration and magnitude in order that salmonellae do not survive however; Hacking *et al.* (1978) found salmonella in 4.3% of finished, pelleted feeds, where it appeared that pelleting failed to eliminate infection from a contaminated animal protein component of the feed.

The issue of post-production feed contamination from rodents and other animals, as well as other important control points for salmonellae in feeds, will be discussed more fully later in this review.

Drinking water

Contamination of drinking water with salmonellae may occur via faecal material, litter, feed and dust deposited in drinkers or by residual contamination of drinkers (Poppe *et al.*, 1985). Levels of 10^4 salmonellae per ml have been found in the drinking water of poults and chicks of less than one week of age. These birds may consume as many as 10^5 salmonellae per day and re-infect themselves continually (Sterski *et al.*, 1981). In consideration of this, Poppe *et al.* (1985) carried out a survey to investigate the relationship between chlorination and the bacterial contamination of drinking water in poultry houses. Chlorination was shown to lower the total plate count and the faecal coliform count in drinking water and, importantly, no salmonellae were found in water samples when the level of available chlorine was higher than 10 ppm. However, because the effectiveness of chlorination depends on pH, time of exposure, temperature and the amount of organic matter present in water (ICMSF, 1998_1) the method of delivery (eg trough drinkers, nipples) is likely to impact on the efficacy of any chlorination program. This was found to be the case in the study of Poppe *et al.* (1995). Nipple drinkers and other devices that prevent contact with the environment maintained available chlorine in the water at bactericidal levels, while trough-like devices, by comparison, did not. The implication here is that infection resulting from such devices is more likely than from nipple drinking systems. Also, relatively uncontrolled environments, such as free-range situations where untreated water may accumulate or be available and uncontrolled, pose a hazard in this regard. Interestingly, control measures mentioned in the literature (Bisgaard, 1992, Dawson, 1992, Edel, 1994, Mason, 1994, Wierup *et al.*, 1995), with respect to salmonellae in Denmark, Great Britain, the Netherlands, Sweden and the United States, neglect drinking water as a source of infection. The potential for *Salmonella* infection of poultry via drinking water exists, however (Jay *et al.*, 1997; ICMSF, 1998) and this must be considered in the formulation of any HACCP plan for safe shell egg production.

Rodents and other potential vectors of *Salmonella*

Effective rodent control is critical for the elimination and prevention of *Salmonella* in shell egg production environments (Henzler and Opitz, 1992, Mason 1994, ICMSF, 1998). In a microbiological survey for SE in ten mice-infested poultry farms, Henzler and Opitz (1992) found that on farms contaminated with SE the organism could be isolated from 24% of mice tested, but only 7.5% of environmental samples examined. The organism could not be isolated from mice from farms that were SE free. It was also found that SE persisted for at least ten months in an infected mouse

population. This may suggest a cycling of infection between mice and the environment. Henzler and Opitz suggested that a factor in the increase of SE food poisoning (and *Salmonella* food poisoning in general) may be the presence of *Salmonella*-infected rodents on poultry farms. While SE was the focus of the Henzler and Opitz study, it was apparent that their findings may be extrapolated, at least in part, to other *Salmonella* serotypes. Serovars isolated from the rodents in the study included *Heidelberg*, *Hadar*, *Typhimurium*, *Anatum*, *Mbandaka*, *Cerro* and *Schwarzengrund*. Interestingly, many of these serovars are found in poultry in Australia.

The fact that a significant difference was found in the percentages of isolations from mice as compared to environmental samples indicates both that mice are susceptible to the bacterium and that persistence within a population is, as already established, possible. It appears that rodents are able to bioconcentrate salmonellae. This has important implications for any program aimed at *Salmonella* control, in that premises may be thoroughly cleaned and disinfected to the point where salmonellae may not be detectable, but may be quickly reinfected if rodent control is inadequate. Rodent faecal pellets serve as a source of infection, as they may contaminate feed and water troughs. Henzler and Opitz found that one mouse could shed an average of 2.3×10^5 SE organisms per faecal pellet, a dose sufficient to easily infect adult hens. Other serovars were not enumerated in their study in this way, but their presence in faecal material was established, as previously indicated. Given that the average number of faecal pellets excreted by one mouse was found to be in the order of one hundred in 24 hours, the potential for widespread contamination in egg production facilities is considerable.

The fact that mice have been frequently observed to travel along egg belts may result in the contamination of not only the belts themselves, but also other egg handling equipment. This could occur by eggs becoming contaminated from belt surfaces and thereby spreading contamination to other equipment.

The different ecologies of rats and mice are relevant to the spread of salmonellae in and between poultry houses. Mice generally do not travel far if food, water and shelter are available, and this is the case in egg production situations. As a result, mice populations in poultry houses occur in clusters, and transmission between infected and uninfected clusters becomes more likely with increasing population density. In the Henzler and Opitz study of 1992 there appeared to be no evidence that mice from free-standing poultry houses had carried salmonellae to adjacent houses on the same farm. Surveys in Queensland (Cox and others, unpublished) have on several occasions found different patterns of serovar incidence between layer sheds on the same farm, supporting this contention. Rats, however are known to travel several kilometres in search of food and may easily transmit a pathogen over long distances (Henzler and Opitz, 1992).

Systematic appraisals of the roles of rodents in the epidemiology of salmonellae where poultry are concerned are not common in the scientific literature, and it was this that prompted Henzler and Opitz to initiate their survey. The results of this work led them to conclude that mice were the most important agents of bioconcentration of salmonellae on the egg-laying farms investigated. Guard-Petter *et al.* (1997) have also expressed concern that mice infected with *Salmonella* serve as a source of continual reinfection of poultry. In an Australian context, anecdotal evidence suggests the possibility that rats could be as important as mice in this regard. This will be further discussed in later sections on free-range and floor egg production systems.

The presence of rodents on egg-laying farms is clearly a problem, but they are also known to be responsible for the faecal contamination of feeds before these arrive at the farms. William's review (1981) cites many instances of this, including the assertion of Wedman (1961) that recontamination of finished feeds was considered the most important single factor responsible for the presence of salmonellae in animal-derived components of poultry feeds. Wedman further considered that rodents were very important in this recontamination.

Whilst rodents have long been recognised as vectors of salmonellae, the organisms are also found in the intestinal tract of a number of other vertebrates (Jay *et al.*, 1997). Animals other than rodents, that

may gain access to egg-laying farms, may also act as reservoirs of various *Salmonella* serotypes. Henzler and Opitz (1992) reported the isolation of salmonellae from cat faeces from the farms on which their study was based, suggesting that these animals could serve as vectors of the organism. During research for this review anecdotal accounts from farm workers indicated that cats, dogs and even foxes are not unusual visitors to egg-laying farms, and it may be that these also act as carriers of salmonellae. Wild birds that can gain access to feedstuffs, water or the environment in which egg-laying poultry are kept also represent a continual risk in terms of contamination with *Salmonella* spp., as well as other enteric pathogens such as *Campylobacter* spp. (Mossel *et al.*, 1995). Wild birds have been responsible for the transmission of *S. Pullorum* to poultry in a free-range situation in far north Queensland. In addition, arthropod pests are mentioned variously throughout the literature as being potential vectors of salmonellae and other enteric pathogens. Fly populations on farms visited in connection with this review were noted to increase significantly during the onset of warmer weather.

Airborne infection

Aside from the routes of feed, water, rodents and other pests, poultry can acquire salmonellae infections via small-particle aerosols and dust (Wathes *et al.*, 1988, Baskerville *et al.*, 1992).

Work carried out by Clemmens (1960, cited in Baskerville, *et al.*, 1992) and Timoney, *et al.* (1988) has established that chicks and other animals are susceptible to infection with aerosols of *S. Pullorum* and *S. Typhimurium*. Later work by Baskerville, *et al.* (1992) indicated that birds exposed to small particle aerosols containing various concentrations of SE may develop systemic infections. In some cases birds were still excreting the organism in faeces at the time of sacrifice, 28 days after infection. SE was present for a similar period in a wide range of alimentary tract tissues and, significantly, in terms of the risk of vertical transmission, in the ovary and oviduct. It was concluded that in a poultry house environment *Salmonella* infection may readily be spread by airborne droplets or dust particles and that as a result of a bird inhaling airborne infectious particles, whether experimentally or naturally in a contaminated environment, both a respiratory and oral infection is acquired. Systemic infection was presumed to occur rapidly because infection of the lungs resulted in rapid bacteraemia and a resultant dissemination of the bacteria to the liver, spleen, kidneys, ovary and oviduct, which supplements the colonisation and systemic spread from the gut. Even very low doses (2.9×10^2 bacteria) produced a generalised infection when administered by aerosols, with concomitant prolonged faecal excretion. Of 356 eggs laid by the infected birds, 0.6% were positive for SE on the shell, but none had *Salmonella*-positive contents. The real issue of this study however appears to be the low dose required to cause infection and the fact that an enteric pathogen can colonise poultry so easily via the respiratory tract. This clearly has implications for farm management in terms of *Salmonella* control.

One practice that could potentially increase the likelihood of the dissemination of salmonellae throughout a flock is the practice of fogging. In the poultry house where this was observed a purpose installed spray system dispensed a fine mist over the birds once the ambient temperature reached approximately 31ºC. The water used for this was not necessarily chlorinated. The potential for salmonellae infection via aerosols has been touched upon previously; it has been established that doses as low as several hundred bacteria are all that are required to cause generalised infection in birds (Baskerville *et al.*, 1992). Accordingly the ramifications of fogging, particularly in combination with any existing environmental contamination with salmonellae, need to be further investigated.

CAGE, BARN/FLOOR AND FREE-RANGE SYSTEMS OF EGG PRODUCTION: RELATIVE FOOD SAFETY RISKS

The first sections of this review aimed to provide a background understanding of how and why *Salmonella* infection may be introduced to poultry flocks and persist in them. Some discussion of the merits of cage, floor and free-range egg production systems regarding welfare and production efficiency exists in the literature. However, a comprehensive search of a wide variety of data bases has revealed little exhaustive research or direct comparison of the various production methods in terms of food safety hazard risk management with the exception of the work of Quarles *et al.* (1970). More

work needs to be carried out, given the changes that have inevitably occurred in the different production systems over the last 30 years.

Most eggs contain no bacteria when they are laid (Mayes and Takeballi, 1983). Contamination of the shell surface occurs principally after laying; in work carried out by Kerihara *et al.* (1996) no bacteria were detected on the shell surface of 55 (92%) of 60 eggs obtained aseptically from the oviducts of old hens. This was not the case for eggs collected after laying. This suggests that most bacterial contamination originates from the environment. In this context the relative risks associated with caged, floor and free-range systems for shell egg production will be discussed.

Cage systems

The advantages of cage systems for egg production with respect to food safety have been cited as including little or no bird contact with faecal material, resulting in reduced risk of enteropathogenic infestations, and the hygiene afforded to birds and eggs by the nature of the cage structure. This has been seen to be at least partly due to the lack of dust and atmospheric contaminants resulting from this method of production (Dunn, 1997). Quarles *et al.* (1970) had earlier demonstrated that litter floor poultry houses averaged approximately nine times as many bacteria in the air as houses where the cage system was used. In comparing the effects of housing systems for laying hens on eggshell quality, a research team at the University of Glasgow demonstrated that the mammillary layers of eggshells from battery, deep litter and free-range systems all showed a degree of variation from the norm, but that those from the battery system had superior structural integrity to the others (Anon., 1995). This was determined by the microscopic analysis of twelve structural variants in egg shells. Importantly, eggs with shells of superior structural integrity, that is those from the battery housing systems, showed very significant differences in their resistance to penetration by SE. This was found to be the case irrespective of whether sampling of eggs was from the beginning, middle or end phases of the laying cycle. On this basis alone, that is excluding the issue of the degree of environmental contamination, it would appear that battery or cage eggs may be intrinsically less hazardous in a microbial sense than those obtained from the alternative systems. Unfortunately, however, the report on this study did not give any indications of other variables that may have had a bearing on the outcomes obtained.

The Glasgow team's findings are nevertheless of interest, particularly in the light of the extent of environmental and equipment contamination that may occur in poultry houses. Kerihara *et al.* (1996) found that shortly after being laid in disinfected cages an average of 10^4 CFU bacteria per egg were detected. On the shell surface of eggs that were laid in commercial cages, and transported on egg conveyor belts, the populations per egg were in the order of 10^6 CFU. As a supplementary experiment in this study eggs carefully washed, disinfected and dried were transported on three conveyors and a lifter. Examination of the surface of these eggs revealed contamination in the order of 10^3 to 10^4 CFU per egg from each separate item of equipment. Bacteria isolated here were mainly of the genera *Micrococcus* and *Staphylococcus*. The levels of contamination from conveyor belts and egg lifting apparatus may result in less clean eggs than those collected by hand. Mayes and Takeballi (1983) cite early work of Rosser that indicated lower levels of contamination on eggs collected with gloved hands than those otherwise handled. In a cage-system poultry house visited during research for this review hand pick-up of eggs from roll-outs was observed. Given the findings of Kerihara *et al.*, and those of other studies (Harry, 1963, Jones *et al.*, 1995) it is likely that this practice may result in a microbially less hazardous product than eggs collected by belts and other apparatus. It has been observed in at least one poultry house that employs hand collection of eggs that a 5% greater recovery rate of product is achieved over that collected by belts and other equipment. This was apparently due to less cracked and obviously contaminated eggs being collected by the hand pick-up as opposed to the belt collection method (A. Moses, personal communication).

In a number of poultry houses visited in the course of gathering information for this review, wire roll outs and cage bottoms were dry-cleaned by brushing. A similar approach was adopted for egg collection belts and the lifting devices used to remove eggs from these collection belts, prior to grading, initial packing, washing and storage before distribution for sale. No suggestions are offered for alternative cleaning procedures of the bottom of wire cages; to clean these is clearly not an easy

matter, and any alternative method would have to be demonstrably superior to the one now used, and considered in terms of cost-benefit. The differences in bacterial populations on the surface of eggs from disinfected cages and those from commercial cages (see above) found in the study of Kerihara *et al.* (1996) may not be significant in the context of an integrated control program for *Salmonella.*

The positioning of the cage roll-outs (the sloping floor of the cage that transports the eggs to collection belts or to a point for manual pick-up) relative to the feed source is important in terms of the potential for the faecal contamination of eggs (A. Moses, personal communication), and therefore the risk of contamination with salmonellae. If feed is dispensed from the centre of a double row of cages (i.e. from a trough) the result will be increased faecal contamination of eggs and the cage roll-out area, that part of the cage that will have most contact with the eggs. This is because the birds' anus will be oriented towards the roll out area due to a preoccupation with the feed source at the centre of the cage rows. Conversely, if feed troughs are above the roll-out, at the outer edge of the cage row, the anus of a feeding bird will be oriented away from the area of the cage where the egg has most contact. This results in a decreased risk of protracted contact with any faeces that may adhere to the cage floor wires. In this regard the slope of the cage floor is also crucial; optimal slope will facilitate rapid transfer of eggs thereby reducing the chance of faecal soiling (Bruce and Drysdale, 1994).

The Code of Practice for Shell Egg Production, Grading, Packing and Distribution (Australian Egg Industry Association, 1999) recognises that hygiene control may "be more difficult in non-cage egg production systems". This is vindicated by the findings of Quarles *et al.* (1970) that eggs from flocks on wire routinely had less gross bacterial contamination than eggs from conventional litter floor houses. Reasons for this, in addition to those already presented, will become apparent in the ensuing sections on floor and free-range systems.

Floor systems

Floor systems of egg production are intensive production situations where birds are housed in large barns and are free to move about on what is initially a layer of fresh straw or similar material. This becomes a deep layer of composted material consisting of broken down straw, faecal material and feathers, ultimately to a depth of 100 to 120 mm. A number of older studies have examined the relationship between egg spoilage, the environment when laid, the microbiology of poultry litter and, specifically, the survival of salmonellae in built-up litter (Harry, 1963; Schefferle, 1965; Tucker, 1967; Quarles *et al.*, 1970).

Eggs immediately after laying are moist, and this contributes to their soiling, this being proportionate to the presence of contaminating material in the surrounding environment (Mayes and Takeballi, 1983). Studies such as that of Kerihara *et al.* (1996), Smeltzer *et al.* (1979) and much earlier work by Harry (1963) have established that the degree of egg contamination appears to be a function of the cleanliness of the surface onto which they are laid, and the manner in which the eggs are handled after laying. That eggs from conventional litter floor environments are typically more contaminated than those from cage systems has been established (Quarles *et al.*, 1970); Harry (1963) found the total number of bacteria on eggs from deep litter production systems to be 15 times greater than found on eggs from battery production systems. He also noted that the bacteria of the litter are transferred to the nest linings on the feet and feathers of laying birds and that the bulk of the bacteria on deep litter eggs consisted of types found in the deep litter itself. It follows that if salmonellae are present in the litter they may be present in nest linings and therefore the potential exists for their transfer to the surface of eggs laid on these linings.

After using *S. Infantis* and *S. Typhimurium* in preliminary studies on the persistence of salmonellae in poultry litter, Fanelli *et al.* (1969) concluded that cycling of salmonellae between litter and the intestinal tract of birds appeared to be significant in maintaining intestinal infection. This cycling was more evident in unchanged new litter than in built-up litter. Tucker (1967) had earlier determined that *S. Pullorum* and *S. Gallinarum* persisted longer in fresh litter than in built-up litter while Schefferle (1965) had found that the alkaline conditions of older litter lowered the numbers of Gram-negative bacteria and fungi. Fanelli *et al.* (1969) suggested that the contrast in shedding rates of birds on fresh

litter relative to those on old litter indicated the presence of inhibitory substances or flora in the old litter. It was thought that these substances could act to reduce the numbers of salmonellae in the litter itself or could influence the persistence of salmonellae in the intestinal tract of the bird. Irrespective of these differences in old and new litter, it has been demonstrated that salmonellae can persist for sufficient periods of time in the latter for infection cycling to become established between litter and birds. This obviously has negative implications for the contamination of egg surfaces. When new litter was infected with *S. Thompson* survival varied between eight and 20 weeks, the longer survival time being associated with lower moisture levels. In old litter *S. Thompson* survived for a maximum of five weeks, and this resulted in nest boxes being frequently positive for the organism (Tucker, 1967). *Salmonella*-infected eggs were recovered from these nest boxes, although the frequency of this was not mentioned in Tucker's work. *S. Thompson* was observed to have much longer survival times in litter, old or new, than *S. Gallinarum* or *S. Pullorum*.

Any of the studies thus far referred to take into account the cycling of salmonellae between poultry and litter irrespective of its age. That old litter may be less of a problem in this regard is no cause for complacency. Additionally, in real-world commercial situations, other factors may contribute to the cycling and persistence of salmonellae in litter. Notable among these factors are rodents. Anecdotal accounts of farm workers spoken to during information gathering for this review revealed that rats have been observed to move freely among poultry in floor egg production systems, particularly at night. These accounts appeared credible and it was thought that significant numbers of rats could be involved. The point can be made that poultry and rodents cannot exist so closely in cage systems of production, and therefore the potential for cross-infection with salmonellae may not be as great as in floor or free-range systems.

The nature of the material used to line nest boxes in floor production situations may have some influence on the potential for contamination of eggshell surfaces with salmonellae. There appears to be little mention of this in the literature, but at one farm visited during the course of this work "Astroturf" was used in the bottom of nest boxes. This material is a rubber-like synthetic matting, with projections of approximately 8 to 10 mm over its surface. This material has an obviously larger surface area compared to that of a wire cage floor, and the potential for the accumulation of faecal material would appear to be greater. The implications of this for contamination of eggs with salmonellae should be investigated; studies in the literature concerning nesting materials only appear to compare materials such as wood shavings and calcined clay, with discussion of disinfection methods for these (Bruce and Drysdale, 1994).

Eggs are also collected directly from the litter in floor systems and these may be expected to carry higher loads of bacteria than those from nesting boxes. Smeltzer *et al.* (1979), in comparing the incidence of bacterial penetration between floor and nest eggs, found that penetration was detectable in 10.5% of nest eggs but 15.3% of floor eggs. No specific mention of salmonellae was made in this study but the findings here suggest that penetration rates can be correlated with contamination levels. That is, where the bacterial challenge is large, as is likely with eggs laid in faecally contaminated floor litter, increased bacterial penetration can be expected (Sparks and Board, 1985, $ICMSF_1$, 1998).

Free range systems

In the Australian context free range systems of egg production differ only from the floor systems mentioned above in that the birds have access to the external environment; they are not constrained within a poultry house during the day. Accordingly, all that applies in terms of the risk of salmonellosis in connection with floor systems also applies where free-range is concerned. Rodents, arthropod pests, water and feed have been previously mentioned as potential agents of *Salmonella* infection. The potential for cycling of infection between litter and birds has also been noted. In a free-range environment the additional hazards of wild birds, access to unchlorinated water and miscellaneous environmental sources pose further threats to the *Salmonella* status of poultry flocks.

Contaminated drinking water is an effective means of *Salmonella* transmission to poultry (Mayes and Takeballi, 1983). In a free-range production system visited during preliminary work for this review

roofs of poultry houses were being cooled with untreated river water. As a consequence water was pooling around the buildings and birds were observed drinking from these pools. This may not be a common practice throughout the industry, but is mentioned here as a matter of interest in terms of possibly unforeseen routes of infection. Wild birds were also observed to be in the same enclosure as foraging free-range poultry, raising the possibility of cross infection should the former be carriers of salmonellae. In effect free-range production situations represent a partly uncontrolled environment. The occasional presence of animals other than wild birds cannot be discounted and these may also represent a potential hazard where the spread of salmonellae is concerned.

Upon comparing cage, floor and free-range egg production systems it is apparent from the literature (Harry, 1963; Quarles *et al.,* 1970; Carter *et al.,* 1973; $ICMSF_1$, 1998) that eggs from cage systems have lower contamination rates than eggs laid into nests in either floor or free-range systems. This is principally because greater environmental control is possible in cage production systems. The potential for bird-litter cycling of pathogens is reduced considerably, as is the potential for the close association with rodents that may occur in the other systems. The likelihood of airborne contamination is also considerably less in cage production systems compared to the others. The nature of the material onto which eggs are laid is also of relevance. The surface area of wire cage floors relative to the nesting environments of the other systems is of itself a determinant of the lower level of contamination of cage system eggs. Despite this salmonellae may still be a potential problem in cage production situations. With this in mind the following section discusses measures for the control of salmonellae in cage systems, and egg production generally.

CONTROL

The Code of Practice published by the Australian Egg Industry Association for shell egg production recognises that a hygiene chain should be maintained from feed to breeding flocks /hatcheries through to the final consumer. To this end the control of some *Salmonella* species in food production systems, such as those concerned with shell eggs, involves the selection of uncontaminated feeds, the prevention of contamination of the production environment and/or the prevention of the multiplication of the organism. The application of HACCP (Hazard Analysis Critical Control Point) techniques provides the most effective use of control resources by emphasising monitoring of CCPs (Critical Control Points) rather than concentrating on analyses of end product (Simonsen *et al.,* 1987).

Steps that are essential in attempting to prevent or minimise the infection of poultry include: obtaining *Salmonella*-free stock; using *Salmonella*-free feed; providing rodent and wild bird-free housing; providing protective clothing for workers; disinfecting footwear; frequent cleaning of water supply systems, and water chlorination; removing sick or dead birds; removing droppings and litter; and cleaning, with subsequent decontamination of houses after removal of flocks (Simonsen *et al.,* 1987).

The importance of obtaining *Salmonella*-free stock cannot be over-emphasised. It is to be expected that chicks obtained for use in layer production will be specified *Salmonella*-free by the supplier. On arrival at egg farms however, a major risk of potential contamination with *Salmonella* occurs during the growing-out phase of chicks. Currently the most effective approach to prevent the colonisation of live poultry by salmonellae is competitive exclusion (CE; Bailey *et al.*, 1995). Application of the competitive exclusion concept (also known as the Nurmi concept) was first reported by Nurmi and Rantala (1973). The principle involved is the oral introduction of intestinal microflora from salmonellae-free adult birds into newly hatched chicks. The CE concept can be summarised as follows: (1) newly hatched chicks may be infected by a single cell of *Salmonella* (2) resistance to salmonellae infection in older birds exists because of the presence of a characteristic intestinal microflora of the gut (3) the oral inoculation of flora from an adult bird to a day-old chick accelerates the maturation process of the bird's gut microflora, thereby increasing the resistance of most chicks to salmonellae colonisation.

As recently as 1992 the undefined status of the then currently available CE preparations was seen as a major problem (Nurmi *et al.,* 1992). Undefined in this sense refers to mixed bacterial cultures derived

from the entire caecal contents of an adult bird. The more recently developed CE products have undergone a selection process that excludes avian and human pathogens. These products have a specifically defined bacterial composition, and this has facilitated their approval by the USFDA as an anti-*Salmonella* spray for chicks (Glaser, 1998; Schneitz, 1998; Stephenson, 1998). The commercial versions of these CE products are water-based and are sprayed as a mist over newly hatched chicks. The product is then ingested, incidental to the birds preening themselves. A related issue here is the administration of antibiotics to young birds. The susceptibility of chicks to salmonellae colonisation is greatest during the first days of life, due to the immature state of the intestinal microflora; a developing intestinal microflora can be destroyed either partly or completely by using antibiotics at therapeutic levels or even as growth promoters.

The efficacy of CE has been established in a number of studies. In a large scale commercial field trial Blankenship *et al.* (1993) found 41% of untreated broilers to be *Salmonella*-positive after processing, while only 10% of those that were CE treated gave positive results. Bailey *et al.* (1994) in another trial found 11% of untreated processed chickens to be *Salmonella* positive, compared to 5% of CE treated birds. It should be emphasised, however, that while the development of CE products such as those mentioned here represent a valuable tool in *Salmonella* control, they are no panacea or replacement for unsatisfactory production hygiene. The exposure of young birds to high levels of salmonellae, early in grow-out, by ingesting water and feed contaminated by droppings from an infected flockmate, can override the beneficial effect of a treatment such as CE, or negate intervention efforts aimed at environmental sources of salmonellae (Cox *et al.,* 1990). Competitive exclusion, therefore, should be seen as only one part of an integrated pathogen management program.

The importance of *Salmonella*-free feeds has already been discussed. Feed production, *per se*, may not be the immediate concern of egg producers, but an awareness of the control measures necessary to minimise the risk of salmonellae contamination in feeds is advantageous in terms of any pathogen management program. The $ICMSF_2$ (1998) has identified the following points as necessary in the control of salmonellae in feeds:

- avoiding the use of *Salmonella* contaminated ingredients. Testing for the presence of salmonellae in ingredients on receipt at the feed mill may identify sources of contaminated ingredients.

- appropriate plant lay-out to avoid cross-contamination between raw materials and finished feedstuffs.

- correct use of bactericidal treatments such as conditioning and pelleting, or alternative preservation techniques such as chemical disinfection (e.g. using short-chain fatty acids).

- correct operation of equipment and good hygienic housekeeping. Control of condensation to prevent moistening of feeds in coolers, especially at the top of cooling towers. Care must be taken to prevent wet surfaces and wet feed deposits in storage facilities, mixers and transport systems. Air used to cool pelleted products should be filtered; insects, rodents, and other vermin should be eliminated.

- environmental and line sampling to identify sources of contamination has proven to be more effective for salmonellae control than end-product testing.

The addition of weak organic acids (e.g. lactic, formic or propionic acids) to feeds has been shown to reduce the incidence of salmonellae infection in chicks (Hinton and Linton, 1988). Commercial products including propionic acid, its salts or a mixture of these in liquid or solid form are available, but their antimicrobial activity is reduced if poultry are exposed to other sources of infection, or if the feed contains large numbers of microorganisms ($ICMSF_2$, 1998).

That the chlorination of drinking water is an important control point in terms of *Salmonella* control is obvious from previous discussion concerning the issue. The relative efficacy of water delivery devices where bactericidal levels of chlorine are concerned were also discussed, but these systems are also important in their potential for leakage and the consequent wetting of litter. The resultant elevated moisture levels may give rise to significant population increases of salmonellae where these are present.

The importance of rodent control where egg production is concerned is self-evident; rodent control programs are critical for the elimination and/or prevention of a *Salmonella* problem (Henzler and Opitz, 1992). Equally important may be the use of mice for monitoring the presence of invasive as well as other strains of salmonellae on farms. It has been recommended that thirty mice per month per farm be sampled and examined for salmonellae (Guard-Petter *et al.,* 1997). Determination of the presence of salmonellae in mice and rats has been achieved by culture of liver, spleen and lymphoid tissue, as well as intestinal contents and faecal pellets (Henzler and Opitz, 1992; Guard-Petter *et al.,* 1997). Such sampling may act as a verification procedure in any control program for salmonellae, and also for monitoring the efficacy of any vaccination protocol that may be in place, that is the incidence of a particular serotype in rodent organs may indicate waning immunity. Mice are particularly valuable for monitoring the presence of SE and *S. Typhimurium* on poultry farms, because of the susceptibility of these animals to these serotypes.

PREVALENCE OF *SALMONELLA* IN EGGS

Reports of the incidence of salmonellae in eggs throughout the literature indicate that no meaningful conclusions may yet be drawn in terms of the quantification of risk. Humphrey and co-workers (1991) in a study on the numbers of SE in the contents of naturally contaminated eggs found 0.6% of eggs to be positive. In excess of 5700 eggs were examined and these were sourced from 15 different flocks. In most cases the levels of contamination were low, but three eggs were found to contain many thousands of cells. Humphrey *et al.* (1991) also cite an earlier study conducted by the Public Health Laboratory Service (London) wherein 0.1% of egg contents were found to be positive for salmonellae. However, Batchelor (1988), in investigating egg contamination rates in infected flocks, demonstrated that SE PT4 could be isolated from the contents of up to 50% of the eggs examined. Timoney *et al.* (1989) in a study carried out to determine rates of egg transmission of SE in artificially inoculated hens found that 10% of eggs tested were positive for the organism in the two weeks following inoculation. Humphrey and co-workers (1991) concluded that such disparate results may be due to clustering of *Salmonella*-positive eggs and that the chances of detecting contamination is influenced by both the timing of sampling and the techniques used. This was further elaborated upon in a review by Humphrey (1994). Here he conceded that the variability in the prevalence of eggs with contents positive for *Salmonella* may be due to different patterns of contamination, but also stressed that it was important to take into account the impact of different laboratory techniques.

For example, it has been noted that when eggs are pooled for the culture of salmonellae the isolation rate can be significantly increased when the culture time is extended from 24 to 48 hours (Gast and Beard, 1992; Humphrey and Whitehead, 1992). Studies of the prevalence of salmonellae in eggs may therefore have underestimated the extent of infection in a given sample, if culture time was not taken into account. Another factor that may lead to an under-estimation of infection rates is the examination of yolks only for salmonellae. This has apparently been the practice in some studies (Humphrey, 1994) and would result in either the failure of detection of *Salmonella*-positive eggs or misleadingly low indications of infection rates. This is because the principal internal site of egg contamination would appear to be either the albumen or the exterior of the vitelline membrane (Humphrey *et al.,* 1991).

The point to be made here is that little comfort is to be gained from estimates of egg infection rates of one in ten thousand, for example. While SE infects eggs primarily via infected reproductive tissue (Humphrey, 1994) Schoeni and co-workers (1995) have established that this organism as well as *S. Typhimurium* and *S. Heidelberg*, when present in faeces, can penetrate to the interior of eggs and

grow during storage. Even considering the possible infrequency of such events, the importance of eggs as a human food and the large number consumed each day can mean that even a low incidence of *Salmonella* contamination may be significant (Board, 1994).

PATHOGENS OTHER THAN *SALMONELLA*

CAMPYLOBACTER JEJUNI

Because poultry flocks are often infected with *Campylobacter jejuni* it may be expected that this pathogen would be frequently found on egg surfaces. This has proven not to be the case. Doyle (1984), in testing the eggs from 226 hens excreting *C. jejuni* in faeces, isolated the organism from only two shell surfaces, but no egg contents. He further found that while the organism was able to be isolated occasionally from the inner shell and membranes of refrigerated eggs, when the shells had been artificially inoculated, none were able to penetrate into the egg contents. Doyle concluded that *C. jejuni* is not likely to contaminate the contents of sound (uncracked) eggs. Doyle's work agreed with the observations of Acuff et al. (1982), who were unable to isolate *C. jejuni* from 20 fertile turkey eggs or 20 newly hatched turkey poults. Shanker et al., (1982) were unable to isolate the organism from the broilers of eight flocks that were stocked with birds hatched from the eggs of a *C. jejuni* contaminated breeder flock, suggesting that vertical transmission of the pathogen is unlikely. Further work carried out by Shanker et al., (1986), involving experimental egg-penetration studies, led them to conclude that *C. jejuni* transmission via eggs is not easily achieved. However, recent evidence supports vertical transmission (Cox, personal communication).

C. jejuni dies off rapidly due to the humidity and temperature conditions that occur on the egg surface during storage; it is particularly sensitive to drying and atmospheric oxygen (Neill et al., 1985). Because of this, plus the apparent infrequency of its isolation from eggs generally (ICMSF, 1998), it is usually considered that transmission of *C. jejuni* via eggs is highly improbable (Bruce and Drysdale, 1994). Up to 1998 the literature reports only one outbreak of campylobacteriosis that could be linked to the consumption of (undercooked) eggs. However, despite the low risk status of *C. jejuni* as an egg-borne pathogen, Doyle (1984) observed that there may be potential for contamination of liquid egg from infected shell membrane during the breaking procedure.

Of relevance to this review is that Acuff et al., (1982) noted that faecally contaminated litter and communal drinking water were likely to be sources of *C. jejuni*. The work of Doyle (1984) showed that when birds that had previously excreted the organism were individually caged and provided with *C. jejuni*-free water and feed their excretion rates were substantially reduced.

ESCHERICHIA COLI

Foodborne illness involving various pathotypes of *Escherichia coli*, in particular enterohaemorrhagic strains (EHEC), raised concerns as to the potential of carriage by poultry. Schoeni and Doyle (1994) found that hens challenged with low populations of *E. coli* O157:H7 became caecally colonised for up to 3 months. Additionally, the bacterium was isolated from the shells of 14% of eggs produced by hens shedding the organism faecally, but there was no evidence of contamination of egg contents. It is possible then that poultry and eggs may serve as a vehicle of transmission of pathogenic strains of *E. coli*.

LISTERIA MONOCYTOGENES

Whilst *Listeria monocytogenes* has been recovered from commercially broken liquid whole egg with high frequency, the source is suspected to be contamination from the shell and the egg processing environment (Bartlett, 1993). The organism has also been isolated from chickens but not as yet, from a survey of the current literature, from the contents of intact shell eggs. Bartlett (1993) studied the survival of a mixture of five strains of *L. monocytogenes* inoculated onto the surface of eggs that were stored at 10ºC for up to 14 days. No *Listeria* was found after 11 days and furthermore none was recovered from the contents of any of the inoculated eggs. There is concern that *L. monocytogenes* may pose a potential hazard in egg products (Leclair *et al.,* 1994) but there is as yet no evidence that

shell eggs constitute a similar threat. This is, of course, no cause for complacency; any food poisoning incident connected with eggs or egg products of any type cannot be of benefit to the industry as a whole.

In terms of the relative risk of shell egg contamination from the cage, barn and free-range systems of egg production it is of interest to note that the main reservoirs of infection in egg production facilities have been identified as feed, water, faeces and litter (Anon., 1996). Additionally there is evidence that *Listeria* has a close saprophytic relationship with the soil (Sutherland and Porritt, 1997). Welshimer (1960) showed that *L. monocytogenes* could persist in soil for up to 295 days. Welshimer and Donker-Voet (1971), in later work concluded that *Listeria* not only existed saprophytically in soil, but also on plant matter and vegetation. It is therefore reasonable to expect a reduced risk of listerial infection of shell eggs in cage systems; here the birds have reduced contact with faeces, relative to either barn or free-range systems, and no contact with litter or soil.

YERSINIA ENTEROCOLITICA

Yersinia enterocolitica has been reported to survive and grow in egg washwater (Southam *et al.,* 1987), and Amin and Draughon (1990) have demonstrated that this microorganism is able to contaminate eggs in a manner analogous to common egg spoilage organisms and *Salmonella* spp. In this study eggs were immersed in various suspensions (derived from centrifugation and resuspension in sterile distilled water) containing *Y. enterocolitica* at population densities of 10^6/mL, stored at 10ºC and the egg contents subsequently examined. The organism could not be recovered until seven days after inoculation, at which time it was detectable in 14% of the eggs, the lag period is likely a reflection of the antimicrobial properties of albumen (Bruce and Drysdale, 1994) rather than any intrinsic lack of adaptive ability of the bacterium. Supplementation with iron substantially increased both the rate and extent of infection. After 14 days all of the eggs inoculated tested positive.

Obviously care must be exercised in washing, storage and handling of eggs to prevent contamination with *Y. enterocolitica,* given its alkalotolerance, its ability to grow at refrigeration temperatures and the capacity to survive at the relatively low pH of 4.6. It should be emphasised however, that despite these properties and the fact that the organism is wide-spread in the environment, an extensive search of the literature failed to uncover any reports of food poisoning incidents involving eggs, where *Y. enterocolitica* was able to be identified as the causal agent. It is thus yet to be shown that eggs are an important vehicle for infection with *Y. enterocolitica* (Board, 1994).

SPOILAGE

Much of the extant literature dealing with microbial spoilage of shell eggs is relatively old. Why this is the case is not clear, but it may be that there is a perception that there is little left to contribute concerning this literature, or that present day egg production protocols mean that spoilage is not currently as economically a significant problem as it once was.

Microorganisms most often present on the surface of eggs are not necessarily those most frequently associated with spoilage (Mayes and Takeballi, 1983). Egg shell microflora varies both quantitatively and qualitatively, depending on the geographic region and bird type. Despite this the microorganisms responsible for spoilage tend to be the same and this suggests that it is the intrinsic defence mechanisms of the egg that select for organisms capable of growth in that environment (Bruce and Drysdale, 1994).

Fluorescent pseudomonads, ubiquitous in soil and water, are a major cause of spoilage ("rots") during the storage of eggs (Lorenz and Starr, 1952; Ayres, 1960). Reasons cited include the ability to penetrate and grow before other bacteria, due to their motility, their production of a fluorescent pigment that competes for metal ions with the conalbumin of the white and their resistance to other protective mechanisms of the white. *Pseudomonas* spp. may colonise the external side of the inner membrane with the result that fluorescent pigment may diffuse into the egg white prior to the penetration of any bacterial cells. Pyoverdine-producing pseudomonads characteristically penetrate

and grow in shell eggs more rapidly than any other group of bacteria, and are often the only microorganisms present in stored eggs (Lorenz *et al.,*1952).

Bacteria other than pseudomonads are also capable of primary invasion of shell eggs, however, and these include members of the genera *Alcaligenes, Proteus, Flavobacterium* and *Citrobacter.* Genera that are able to grow in eggs (as distinct from those capable of shell penetration only) include *Acinetobacter, Moraxella, Alcaligenes, Proteus, Escherichia, Flavobacterium* and *Enterobacter.* This growth is dependent on the egg defences having first been challenged by another bacterium, that is one acting as a primary invader (Florian and Trussel, 1957; Elliott, 1958; Ayres, 1960). The secondary invaders, such as those mentioned above, are then able to use the metal ions sequestered by the siderophores produced by the primary invaders. Board (1964) has presented evidence that a lack of available iron in the albumen is a deterrent to bacterial growth.

The nature of the rots associated with spoiled eggs depends on the species or strains of the bacteria present. Some rots may not be macroscopically detectable. *Acaligines faecalis,* some strains of *Pseudomonas fluorescens* and some *Enterobacter* spp. may form large populations that are not apparent from any discolouration, and such defects therefore may not be detected via candling (Johns and Berard, 1946). Strongly proteolytic microorganisms digest the albumen with a resultant blackening of the yolk. Such black rots are most commonly associated with *Alcaligenes, Escherichia, Aeromonas* and *Proteus* (Stadelman, 1994), although some genera of *Pseudomonas* may also cause yolk blackening. Spoilage due to the presence of non-proteolytic pseudomonads is manifested in other ways. *Pseudomonas putida* produces fluorescence in the white, whereas *Ps. maltophilia* causes a slight crusting of the yolk, with streaks of ferric sulphide apparent on its surface; eggs so affected have been said to have a "nutty" flavour. The presence of *Ps. fluorescens* is indicated by pink colouration of the egg white and this is thought to be due to Fe^{3+} ovotransferrin chromogen (ICMSF, 1998). Spoilage by pseudomonads is favoured in eggs stored under cold conditions (Lorenz and Starr, 1952; Ayres and Taylor, 1956).

Whilst most of the literature concerning egg spoilage discusses bacteria, moulds may be a problem under certain circumstances. Mould growth has been observed on eggs from free range flocks when egg collection is delayed (ICMSF, 1998). Moulds are also capable of causing spoilage during refrigerated storage when the humidity is maintained at high levels. *Cladosporium herbarum* is the species most often associated with mould spoilage of eggs; it's hyphae are able to penetrate the shell's pores and membrane and spread throughout the albumen and yolk. Spoilage of this type may be apparent from 'whiskers' of mould on the outer shell (Board *et al.,* 1994).

Common spoilage microorganisms, unlike salmonellae, do not gain access to eggs via transovarian transmission (Philbrook *et al.,* 1960; Board *et al.,* 1964). Amongst other factors (eg negative pressure formed within eggs upon cooling, wet shell surface, egg age) the incidence of bacterial penetration of egg shells increases proportionately with the numbers of bacteria on the shell (Brooks, 1960; Sparks and Board, 1984; Stadelman, 1994). Winter (1942, cited in Stadelman, 1994) reported that the source of infections of most black rot eggs was dirt on the shell. Trussel (1955) cited heavy visible soiling of eggs and nesting materials as important in the contamination of eggs with spoilage organisms. It is logical to infer that because eggs from the cage system of production can be shown to have lower contamination rates, relative to those obtained via barn or free range systems, (Harry, 1963; Quarles *et al.,* 1970; Carter *et al.,*1973; $ICMSF_1$, 1998) that this would translate to lower spoilage rates. The reasons for these lower contamination rates have been previously mentioned and include the reduced potential for bird-litter cycling of the relevant microorganisms; the absence of nesting materials in cage systems; reduced potential for close association with rodents and other vectors of spoilage microorganisms; and reduced likelihood of the airborne contamination of eggs. In short, the good manufacturing practices that can be adopted to reduce the incidence of pathogens in eggs are equally applicable in reducing the incidence of spoilage organisms.

CONCLUSIONS AND RECOMMENDATIONS

It is clear from the literature that *Salmonella* is the major public health concern with respect to eggs as a vehicle of transmission, and that the means by which *Salmonella* (and perhaps other pathogens) persists in the production environment are reasonably well understood. However, there is little detailed information in the scientific literature as to the impact of production system on the dissemination and persistence of salmonellae in the production environment; what information is available is by and large anecdotal. Of the published information available, aspects of various studies preclude extrapolation to the Australian industry. Differences in climate, feedstuffs, and even serovar prevalence are likely to exert significant effects upon differences in the food safety risks posed by different production systems. Thus, there is clearly a need to undertake research under carefully controlled conditions, excluding other variables, to determine the impact of production system on the safety and quality of eggs.

CHEMICAL HAZARDS AND RISKS

There is a range of chemicals that are registered for use on commercial and backyard egg farms.

Many of the chemicals used by egg producers contain anticholinesterase compounds. This group of chemicals is effective in controlling insects. The common names of some of these chemicals are bug master, malathion, 'beetle spray' fenitrothion, alfacron and a range of other brand names. The concern raised during this investigation is that knowledge of the **mode of action** of this group of chemicals is limiting among egg producers.

Chemicals used to sanitise equipment, eggs and facilities are produced from a wide range of chemical categories with different modes of action. Most chemical compounds used are within the Schedule 5 and 6 group and require specific handling and application procedures to be followed. The risk of incorrect use of sanitisers could be personal injury or egg contamination.

The chemicals used on farms generally fall into one of the following categories:

- Quaternary Ammonium Compounds
- Hypochlorites
- Iodophores
- Cresols
- Phenol compounds
- Phosphoric Acids
- and a range of other organic acids and alkali compounds.

Information on chemical handling procedures, mode of action and active ingredients are readily available from chemical companies and the Australian Veterinary Chemical Association (AVCA).

POSSIBLE SOURCES OF CONTAMINATION OF EGGS

- Free range birds on contaminated soils
- Insecticide sprays used while birds are present
- Water medication at incorrect rate
- Eggs washed in non-approved solutions
- Egg washing compound mixed at high concentrations
- Systemic pesticides used in grower shed
- Shed fumigation while birds present
- Chemical feed additives included at wrong rate
- Use of antibiotics

CHEMICAL HANDLING CONTAMINATION

- Selecting an unsuitable chemical
- Incorrectly reading the label
- Incorrect safety clothing used
- Mixing the chemical at the wrong rate
- Application equipment wrongly calibrated
- Incorrect storage of the chemical

CHEMICALS OF CONCERN

- antibiotics
- insecticides Schedule 5 and 6
- anticholinesterase compounds
- Chlorine
- Dieldrin and other heavy metal compounds found as spray residue in the soil (free range and backyard farms).

4. Food Safety Plans for the Commercial Egg Industry

WHAT'S NEEDED?

Three major components are identified as being critical in assisting the Australian egg industry in ensuring high standards of safety in its products: a Code of Practice, a generic Food Safety Plan and an industry-specific chemical handling training course.

A 'CODE OF PRACTICE'

A 'Code of Practice' is a document that states the minimum standards of hygiene, grades, facilities and egg handling procedures required for a commercial egg farm. At this stage a generic code of practice has been adopted by AEIA, but this document falls short when used as an audit document. A strict code needs to be developed that gives black and white guidelines of the standards expected with regards to food safety issues.

Recommendation: That specific codes of practice be developed for the three farming systems; cage, barn lay and free range.

A GENERIC 'FOOD SAFETY PLAN'

A generic Food Safety Plan that meets the requirements of ANZFA and major customers, needs to be developed that can be adapted by egg producers for their farms.

Recommendation: That specific FSP outlines be developed for the three farming systems; cage, barn lay and free range.

Recommendation: That training material be prepared to train poultry producers and farm staff about implementing food safety plans, using a range of training methods including, video, CD Rom, pictures and written material, backed up by up front tuition.

A POULTRY SPECIFIC CHEMICAL HANDLING TRAINING COURSE

Recommendation: That a poultry specific chemical handling training course be developed to train all poultry people in the proper use and handling of farm chemicals to minimise the dangers that use of these chemical pose to themselves, the birds, the environment and the potential for chemically contaminating eggs.

FOOD SAFETY IN THE EGG INDUSTRY

A generic code for shell egg production can been adopted by AEIA. The code provides a basis for a Hazard Analysis Critical Control Point (HACCP) based quality assurance system for shell eggs and egg products, aiming at protecting the consumer from potential health problems associated with substandard shell eggs and egg products.

The code emphasises food safety from the production site to the plate, with the key areas of risk in the egg industry being:

1) Biological hazards - the principal concern is *Salmonella* whose primary source is the intestinal tracts of birds. Hens may become infected from the consumption of contaminated feed or from contact with infected animals. Eggs can become infected by movement of bacteria through the

shell, thus stressing the importance of removing cracked or dirty eggs. Eggs can also become infected during egg development within the hen.
2) Physical hazards - the main concerns are blood spots, metal fragments, rodent droppings and insects.
3) Chemical contamination. eg. cleaning and pest control chemicals

The codes are voluntary guidelines for quality assurance and form the framework for a HACCP approach undertaken at farm and processing plant level. The majority of the larger, more sophisticated egg operations are capable of introducing these systems and so using the generic code of practice as a guide can produce a Code of Practice that meets the specific requirements of their operation.

HACCP (Hazard Analysis Critical Control Points)

A quality monitoring tool does exist that is used mainly in large operations in the food industry. This system, called HACCP, can be adapted to help identify hazards to food safety associated with various stages in egg production and storage, therefore virtually eliminating the need for final product testing.

The HACCP system can ensure egg safety, improve egg quality and help productivity without the need for the over use of inspectors or finished product sampling. Hazard Analysis can provide the customer with an assurance of food safety and quality by identifying the food safety risks that can arise in each of the egg production steps.

Many poultry farms in Australia are implementing the HACCP process, as it is the cheapest and best available method of ensuring that the eggs remain safe. HACCP builds preventative measures into the egg production process to help reduce and control food safety and spoilage hazards.

Hazards or contamination issues.

Physical	unhygienic areas glass, metal, dust, moisture extraneous matter
Biological	Bacterial pathogens Spoilage bacteria Toxin producing moulds Birds, insects, rodents - parts - waste Human contact
Chemical	Natural Heavy Metals Pesticides Environmental contaminants Strong chemicals Veterinary products

The egg producer using a HACCP program can devise measures to prevent eggs from becoming contaminated by checking the critical steps in production. These checks make sure that all staff are following the steps that have been laid out.
The farm manager may use information, such as continuous monitoring (eg. having cool room temperature on display) or devising checking measures (eg. changing egg wash water every 1000 eggs). Hazard Analysis can eliminate biological, chemical and physical hazards by anticipating and preventing egg safety problems rather than inspection.

HACCP PRINCIPLES

There are seven principles that the HACCP program follows and these are consistent with the Codex Alimentarius Commission:

Hazard Analysis Principle One
Identify and list the food safety hazards that can occur at each step in the production process. The Hazards are Biological, Chemical or Physical that can result in unsafe food.

Hazard Analysis Principle Two
Identify the Critical Control Points (CCP) where food safety hazards are prevented, eliminated or reduced to an acceptable level.

Hazard Analysis Principle Three
Establish critical limits for preventive measures at each CCP. A critical limit is the absolute value of that control point that must be controlled to prevent, eliminate or reduce the food safety hazard.

Hazard Analysis Principle Four
Establish monitoring procedures for each CCP, including allocating responsibility to properly trained personnel.

- Ask What, When, Where and How is monitoring occurring, and who is doing it.

Hazard Analysis Principle Five
Define the corrective action to be taken when monitoring indicates that a CCP has been exceeded. These steps stop contaminated eggs being sold to customers and prevent contamination occurring again.

Hazard Analysis Principle Six
Develop and maintain effective record keeping procedures.

Hazard Analysis Principle Seven
Develop a verification program that confirms the adequacy of CCPs and critical limits; ensures proper operation of the HACCP plan and reassesses the plan. Documentation is required that verifies CCPs are being controlled.

To verify that the HACCP process is working, occasional checks of the farms' HACCP manual and food safety standards are necessary to ensure that the standards are being maintained and what you say is happening on your farm is actually occurring.

RECORDING SYSTEMS

Documentation is a critical part of any quality assurance program as it supplies the proof that eggs and egg products being produced are of the quality expected by customers and, more importantly, the quality is consistently being maintained.

These farm records must be maintained on a regular basis and stored for future reference.

The records are also used by a third party quality auditor to check that the appropriate quality systems in place on the farm are being maintained.

CURRENT SITUATION AND COMMON BELIEFS

- Little productivity record keeping is carried out by the majority of producers and so it should be assumed that asking these producers to keep records associated with QA or egg safety verification is a big ask.
- A common comment from producers is "we have been producing eggs this way for the last X years and have never killed anyone!"
- Comment: "Extra time and maybe more labour is required to set up a proper quality assurance system on farm and so the producer would *request* extra payment for QA certified eggs"
- A common belief is that the same bugs are on today's farm as were present a generation ago, and those bugs were not present on or in eggs.
- Cracked eggs are a saleable product and there are customers that request them.

FARMING SYSTEMS

CAGE AND BARN LAY FARMS

Generally these farms are part of a marketing organisation that has imposed grades and standards, and so adoption of a Code of Practice and Food Safety Plans for each of these farms is achievable. Where cage and barn egg producers sell through a marketing organisation there may be opportunities for synergies in training and adoption activities with the cage sector.

FREE RANGE FARMS

Potentially the greatest problem of training and adoption exists in this area. Generally free range egg producers have an ambition to sell eggs to retail outlets at a premium price to cage eggs. At present there are no regulations precluding people with sufficient land from producing and selling eggs and so many farms are being established by people with little or no experience in understanding the relevant food safety issues, let alone how a HACCP system works.

The pleasing trend in this area of production is that larger farms are usually aligned to an association of producers, an egg company or a marketing authority. These bodies generally have grades and standards in place for production, grading and marketing of eggs. What is not known is the actual standards in place and the extent that areas of HACCP and food safety plans have been introduced onto the farms.

Relatively few producers of over 300 birds operate outside of industry organisations - but they exist. The problem with the latter farms is how can they be reached, and encouraged to adopt accepted industry practices.

BACKYARD OPERATIONS

The industry has to ensure that all eggs sold are safe to eat. The scenario here is that most backyard farms use second hand packaging material - usually branded with a reputable label. The package looks acceptable at point of sale, but may contain eggs that are contaminated biologically, chemically, or even physically.

These farms need to also be drawn into any food safety education program that is implemented for the industry.

HOW TO CHANGE PERCEPTIONS

For a producer to implement a program there must be a reward available, following are some suggestions:

- Staff training with Certification for successful completion of training
- Training to demonstrate the food safety hazards of producing and selling eggs
- Increased efficiency on farm
- Financial support for training

WHY WILL EGG PRODUCERS CHANGE THEIR ATTITUDE?

- Customers are now telling producers to have a system in place or they can't supply
- Producers will be alerted to the number of food safety issues that have eggs as a prime contributor
- The effect of a major food safety scare that has eggs as the major cause
- Possibility of shell eggs being imported into Australia
- Demonstrate that the precursors to a disease outbreak exist on commercial egg farms
- Preferred supplier status may be offered to the farm

WHAT INFORMATION NEEDS TO BE PREPARED?

- Reference material is gathered
- Scientific verification of facts is established
- Produce written material
- Produce audio visual material to complement written material
- Alert the producers to the need for a program

TRAINING COURSES CURRENTLY AVAILABLE

Farm chemical users course

Industry organised Farm Chemical Users Course for all producers where the safe handling and use of farm chemicals are discussed. These courses can be tailored to meet egg producers requirements. The course is TAFE accredited in each State of Australia so a Certificate is available.

Elements of the Course:

- Pests and diseases of poultry
- Understanding farm chemicals

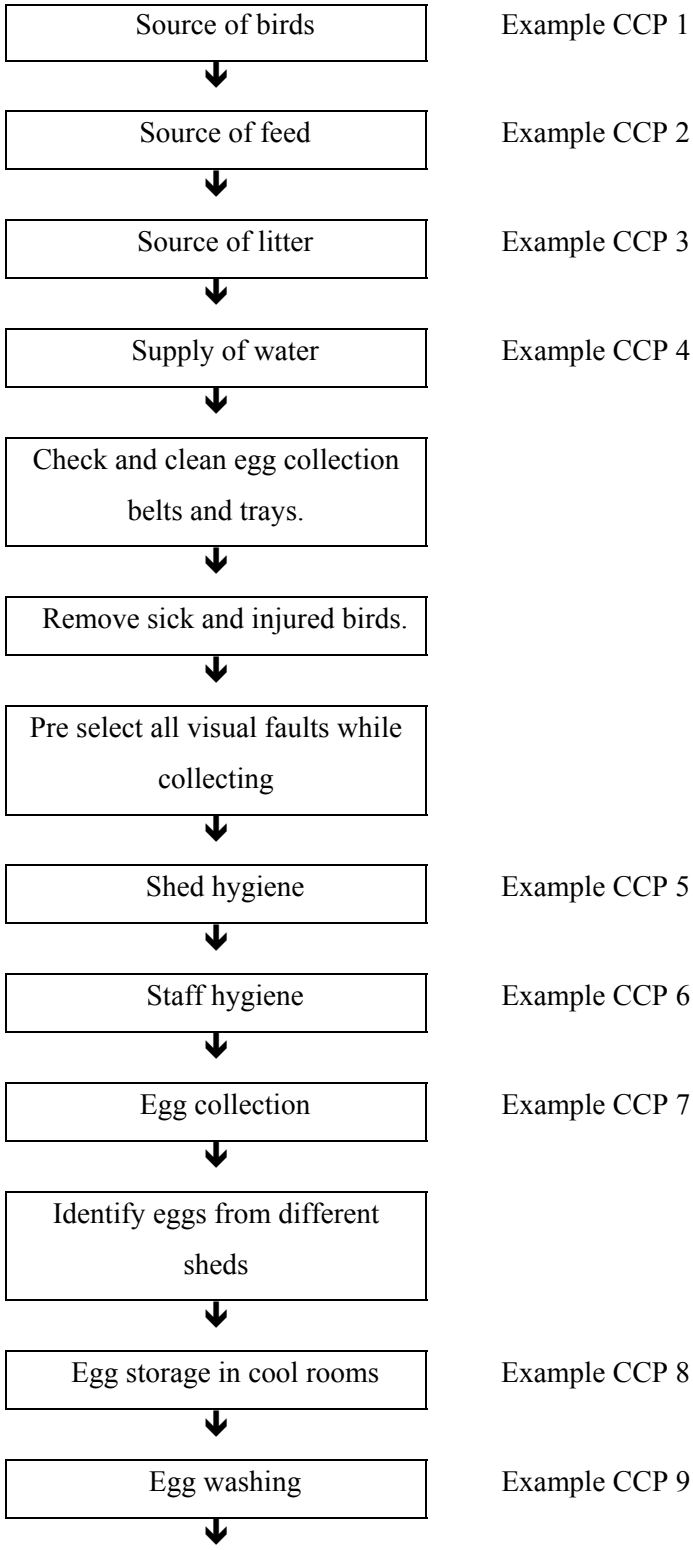
- Selecting the chemical
- Transport and storage
- Decanting, mixing, vaccination preparation
- Application of chemicals
- Emergency first aid
- Planning chemical use
- Integrated pest management

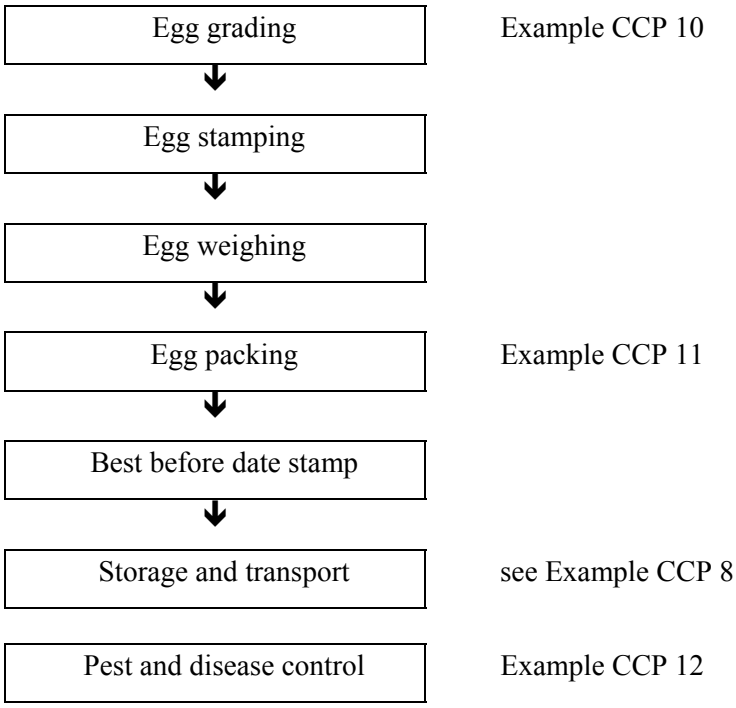
Other courses

- California Quality Assurance Program - Ralph Ernst - Dept Avian Sciences, University of California
- SQF 2000 - developed by WA Ag Dept
- ISO 9002
- Company or farm specific training
- Certificate IV in Agriculture -AG4525DY
- Certificate IV in food processing - General Foods Stream

Appendix 1: Example of a Flow Chart for Egg Production Processes

Examples of possible Critical Control Points are numbered. Critical Control Points can vary from farm to farm.




Egg grading
Example CCP 10
Egg stamping
Egg weighing
Egg packing
Example CCP 11
Best before date stamp
Storage and transport
see Example CCP 8
Pest and disease control
Example CCP 12

EXAMPLE CCP 1. SOURCE OF BIRDS

BACKGROUND

To ensure eggs are safe to eat, hens laying eggs should be, to the best of the supplier's knowledge, healthy and free of disease. Producers should ensure that hens are purchased from facilities that engage in hygienic practices. All hatcheries and breeder farms must keep birds in accordance with the Model Code of Practice for the Welfare of Animals.

HAZARDS

Biological

Salmonella and *E. Coli* bacteria have certain species that can cause food spoilage and illness to consumers. These bacteria species can enter eggs through faeces of infected birds. It is important that new birds purchased for egg production are free of pathogenic bacteria.

Chemical

Minimal risk.

Physical

Minimal risk.

PRODUCTION SYSTEMS

Overview of common hazards

Purchase of birds is independent of each of these systems, but management of birds once on the farm can lead to infection of pathogenic bacteria.

Risk awareness

Cage:
Risk of infection from birds reared in cages is low as contact with potentially hazardous bacteria is reduced as faeces have minimal contact with birds.

Barn Lay:
Risk of transferring diseases between birds is greatly increased because of direct contact between birds and contact with faeces in the litter.

Free Range:
Risk of transferring diseases between birds is greatly increased because of direct contact between birds and contact with faeces in the litter. Risk is greatest when the birds are housed at night.

Control measures

A written assurance is to be sought from breeders or hatcheries in relation to the relevant pathogen status of their stock.

Monitoring effective control

Written assurance must be obtained and filed for verification.

Corrective action steps

Do not purchase birds from a supplier who cannot verify specified salmonella and other pathogenic bacteria status.

EXAMPLE CCP 2. SUPPLY OF FEED

BACKGROUND

To ensure hens stay healthy and free of disease it is important that feeds are not contaminated with pathogenic bacteria. The steaming process used to make pellets eliminates this risk, but using ingredients that have not been heated to over $70^{O}C$ can carry pathogenic bacteria.

HAZARDS

Biological

Pathogenic bacteria can be added to the feed from infected ingredients, such as grains, meat meals and legumes. The risk is reduced if these ingredients are purchased from a supplier who can verify the bacterial status.

Chemical

Ingredients can become contaminated with chemical residue by incorrect application of chemicals.

Physical

Minimal risk of contamination that can cause a food safety risk.

PRODUCTION SYSTEMS

Overview of common hazards

Feeds purchased from feed mills that follow Good Manufacturing Practices (GMP's) present little risk of contamination. Farms that prepare their own feed must be aware of the increased risks of introducing pathogenic bacteria to the hens.

Risk awareness

Risk is the same for Cage, Barn Lay and Free Range systems.

Control measures

Request written assurance of the pathogen status from the feed or ingredient supplier.
Vehicles used for carrying raw ingredients should not be used for transporting prepared feeds until they have been effectively cleaned and sanitised.

Appropriate measures must be taken to prevent recontamination of feed during storage and distribution on the farm. Attention should be paid to silos, feed augers, and feeders and ensure the exclusion of vermin from feed.

Monitoring effective control

Obtain certification of bacterial status of the feed ingredients. If status is not known, then do not purchase.

Corrective action steps

Feed ingredients that are, or have been, contaminated must not be used to feed birds. The birds must be tested for salmonella species if contaminated feed is fed. Follow recommended procedures to eradicate the disease – eggs should only be sold for pasteurisation during the eradication process.

EXAMPLE CCP 3. SUPPLY OF LITTER

BACKGROUND

Litter and nesting material can be a source of pathogenic bacteria. The risk of contamination can be minimised by purchasing litter from a reliable source that can certify the litter is free of pathogenic bacteria.

HAZARDS

Biological

Bacteria, insects and fungal contaminants can be in the litter at the time of purchase and so increasing the risk of passing on these diseases to the birds.

Chemical

Insecticide sprays or chemical preservatives can contaminate some litters. Obtain assurance from the supplier of the chemicals that can be in the litter.

Physical

Presence of glass, metals of other objects in the litter can present a welfare hazard, but nor a risk to food safety.

PRODUCTION SYSTEMS

Risk awareness

Cage:
Minimal risk.

Barn Lay:
Nesting material must be replaced frequently with non contaminated litter. Floor little must be kept friable and replaced if it becomes wet.

Free Range:
Nesting material must be replaced frequently with non contaminated litter. Floor little must be kept friable and replaced if it becomes wet.

Control measures

Do not use litter from a non-assured source and do not reuse litter unless sanitised eg composting.

Monitoring effective control

Purchase litter only from manufactures that follow GMP's and can certify the biological status of the litter.

Corrective action steps

Do not purchase or accept litter if signs of contamination are present or the certification is not available.

EXAMPLE CCP 4. WATER SUPPLY

BACKGROUND

Water can be a source of pathogenic bacteria. The risk of contamination can be minimised by taking water from a reliable source. The risk of bore or town water being contaminated is low, but the risk is greatly increased if water is taken from rivers or dams.

HAZARDS

Water that is taken from a source that can be contaminated must be treated before use.

Biological

The greatest risk comes from bacteria and viruses that can be transferred to the birds in their drinking or fogging water.

Chemical

Chemicals such as salt or chlorine can cause a welfare concern or affect production levels or product quality, but risk to food safety is low.

Physical

Minimal risk.

PRODUCTION SYSTEMS

Overview of common hazards

Source of water is an important issue in all production systems. Measures must be implemented that will ensure that birds are not given access to contaminated water.

Control measures

Water that contains pathogens must be treated by a method that minimises the risks such as chlorination or ultra violet irradiation. Water from rivers or dams cannot be risk free and so must be chlorinated at all times.

Monitoring effective control

Town and bore water must be checked for microbial and chemical contamination. Water storage areas must also be tested and routinely treated.

Corrective action steps

Water that tests outside of potable standards must be treated using methods recommended by local councils.

EXAMPLE CCP 5. SHED HYGIENE

BACKGROUND

Cleaning removes organic matter that can harbour microbes and also removes materials that could be a food source. Sanitising is the process of destroying pathogenic microbes. Effective cleaning and sanitising will minimise the risk of eggs becoming contaminated and hens becoming infected with pathogenic microbes.

HAZARDS

Biological

Risk of carry over bacteria, viruses and fungal diseases that can infect the new birds can occur if the sanitation process is inadequate.

Chemical

Eggs can be contaminated if chemicals are used when the birds, eggs or packaging are present during spraying. The risks are increased if the correct dose rates are exceeded.

Physical

No risk of contamination.

PRODUCTION SYSTEMS

Overview of common hazards

Cleaning and sanitation should be carried out between flocks for single age sheds or at replacement for multi age sheds. Use of chlorine, steam, or other approved sanitisers is recommended.

Cage:
Relatively easy to sanitise, low risk to egg safety.

Barn Lay:
The need for removal of litter is a necessary part of thorough shed sanitation and so makes this system more difficult to maintain low microbial levels.

Free Range:
Fixed sheds present the same sanitation problems as barn lay. Many free range farms use mobile houses and strict paddock rotation to minimise the risk. If no strict sanitation and rotation program is in place, the risk to egg safety is high.

Control measures

A cleaning schedule must be drawn up for all poultry houses, packing and storage areas. Cleaning tasks, frequency of cleaning and sanitisers to be used should be noted and given to each staff member.

An effective, frequent and well-maintained system of manure removal will reduce the risk of faecal contamination of eggs, collection systems and feed troughs.

Monitoring effective control

A recording system for the required sanitation processes must be available and the dates of sanitation recorded. A record of the type and rates of chemical used is necessary to verify that the correct procedure was followed.

Corrective action steps

If eggs or birds become contaminated during, or because of, the sanitation process, or testing shows contamination then these eggs are to be destroyed. No eggs are to be sold for retail or for manufacture.

EXAMPLE CCP 6. STAFF HYGIENE

BACKGROUND

Disease causing microbes can spread from staff by poor hygiene practices. All staff must carry out proper personal hygiene practices to prevent spread of disease. Facilities and instructions must be available to all staff handling eggs and birds.

HAZARDS

Biological

The risk of the spread of *E. Coli* and *Salmonella* Spp. between staff, eggs and birds is high if hygiene and sanitation procedures are not followed.

Chemical

Minimal risk of spread.

Physical

Minimal risk of spread.

PRODUCTION SYSTEMS

Overview of common hazards

Microbes are commonly found on the skin, and nose of healthy people. Hands can transfer pathogenic bacteria to birds and eggs so every person working with eggs must maintain high personal hygiene standards.

The risk of contaminating eggs increases with the frequency of handling eggs - even if hygiene practices are adequate.

Hands that have been in contact with birds must not handle eggs.

Risk Awareness

Cage:
Risk during hand collection is related to the hygiene standards maintained by the staff collecting the eggs and the cleanliness of the roll-out trays. Risk during machine collection is related to the cleaning and maintenance of egg belts.

Barn Lay:
The risk of contamination is increased as eggs are in contact with the birds; therefore staff may have to handle birds during collection.

Strict hygiene practices for staff must be maintained.

Systems must be in place to ensure that eggs are not handled after birds or contaminated surfaces have been handled.

Free Range:
This system presents the highest risk as birds can become contaminated from sources outside of the shed. Most collection is by hand and so handling of birds is necessary.
Strict hygiene practices for staff must be maintained.

Systems must be in place to ensure that all staff minimise the risk of transferring pathogenic bacteria to eggs.

Control measures

Hands must be sanitised after handling birds. The risk of egg contamination is greatest when eggs are handle soon after dead birds are handled. Ensure all staff are aware of the industry code of practice regarding personal hygiene.

Monitoring effective control

Daily checking of egg handling procedure for all staff is necessary.

Corrective action steps

Isolate eggs that have become contaminated through poor handling techniques and send to processing. No contaminated eggs are to be sold on the shell egg market.

EXAMPLE CCP 7. EGG COLLECTION

BACKGROUND

Eggs when first laid are relatively free of harmful microbes; it is the conditions where the eggs are laid, and how they are handled, that can lead to pathogen and chemical contamination.

HAZARDS

All eggs must be sorted during collection into first quality eggs, suitable for retail sale, and second quality eggs. Removing second quality eggs from retail sale reduces the risk of contaminated eggs entering the market.

Biological

Eggs have a high risk of contamination from E. Coli and pathogenic salmonella bacteria. Eggs in contact with faeces or contaminated surfaces can be a cause of a food safety problem.

Chemical

Minimal risk of spread.

Physical

Minimal risk of spread.

PRODUCTION SYSTEMS

Overview of common hazards

The egg laying area should be kept clean, sanitised and free of broken eggs. All egg collecting equipment and trays must be cleaned or replaced regularly. Blood eggs and eggs with heavy faecal stain must be disposed of during collection and must not be sold.

Systems must be in place to stop the handling dead or diseased birds during collection.

Risk awareness

Cage:
Low risk if collection is automatic, but risk increases if eggs are hand collected. Separating egg handling from dead bird handling is relatively easy if farms have instructed staff on the correct procedure.

Barn Lay:
Low risk if collection is automatic, but risk increases if eggs are hand collected. Separating egg handling from dead bird handling is relatively easy if farms have instructed staff on the correct procedure.
It is important to instruct staff that risk of egg contamination is higher as eggs can come into direct contact with potentially contaminated birds.

The type of nest lining and maintenance is important. Different lining materials may be more conducive to soiling and microbial proliferation.

Free Range:
The risk of contamination is high in this system, but will be minimised with frequent egg collection, fresh nesting litter and a thorough culling program.

Control measures
Eggs to be packed in clean egg trays. If the trays become damp, dirty or contain liquid egg and cannot be adequately cleaned they must be discarded.

Eggs must be collected at least once per day for cage and automatic barn lay systems and at least twice per day for manual barn lay and free range systems.

Egg handling is to be kept to a minimum.

Monitoring effective control
All staff involved in egg collection must be aware of the Code of Practice for shell egg production procedures. Egg collection is to be monitored daily for compliance.

Corrective action steps
All contaminated eggs must be down graded to second (product) quality and are suitable only for processing. Low risk if collection is automatic, but risk increases if collection is by hand. Separating egg handling from dead bird handling is relatively easy if farms have instructed staff on the correct procedure.

EXAMPLE CCP 8. EGG STORAGE AND TRANSPORT

BACKGROUND

Eggs must be stored and transported from the farm in a way that prevents contamination by and growth of any surviving pathogens.

HAZARDS

Biological

Egg storage and transport temperature must be less than $17^{O}C$ to slow the development of pathogenic bacteria that can be on the surface of the egg.

Chemical

Minimal risk if chemicals are not stored with eggs, or application rates of sanitation chemicals are not exceeded.

Physical

Dust and dirt in the cool room and transport vehicle can be a risk to egg safety.

PRODUCTION SYSTEMS

Overview of common hazards

Each production system must have a cool room capable of maintaining a temperature range of 12 - $17^{O}C$ and transport eggs to markets at less than $17^{O}C$. The condition in the storage areas must avoid surface contamination or condensation.

Eggs must be delivered to the grading floor within 96 hours of lay and be in the market place within 7 days of lay.

Risk awareness

Criteria for minimising risks is the same for cage, barn lay and free range systems.

Control measures

Ensure transport vehicles and farm cool rooms are capable of operating between $12^{O}C$ and $17^{O}C$ and are free of dirt and other contaminants and are vermin proof. These storage areas must be sanitised at least monthly.

Monitoring effective control

Measure and record maximum temperature of the cool room daily and the transport vehicle when in use.

Corrective action steps

If temperatures are outside of critical limits readjust equipment or service it. If problem persists then eggs cannot be sold on the retail market and must be processed.
Maintain a regular baiting program for vermin.

EXAMPLE CCP 9. EGG WASHING

BACKGROUND

Only eggs that are dirty need to be washed. If only slight soiling of the shell surface is evident, then sand papering or scraping is recommended.

Washing eggs removes the natural cuticle from the shell, thus increasing the risk of food spoilage microbes entering the egg. Egg washing must only use a purpose built machine that has separate wash and rinse compartments.

No damp cloth cleaning is permitted under any circumstances.

Dry cleaning of eggs using sandpaper or scraping is permitted.

HAZARDS

Biological

High risk of contamination of harmful bacteria to large numbers of eggs during washing if the sanitisers fail to kill the bacteria.

Chemical

Low risk of alkali or chlorine contamination on egg surface.

Physical

Minimal risk

PRODUCTION SYSTEMS

Overview of common hazards

Criteria for minimising risks is the same for cage, barn lay and free range systems.

Control measures

Water in washing section of machine must contain a minimum of pH 11 alkali salts and or a minimum of 50 ppm chlorine.

Rinse water must contain a minimum of 50 ppm chlorine.
Eggs must be dry before packing.
Wet eggs must not come in contact with unsanitised surfaces.

Monitoring effective control

pH levels must be tested every hour that the machine is operating by using pH test strips.
Chlorine levels are tested hourly by using chlorine test strips.
Chemical levels tested on the hour are recorded on a log sheet.
A member of staff must be responsible for washing machine operation.

Corrective action steps

When pH levels less than 11 in wash water are identified and chlorine levels less than 50 ppm in rinse water, the washing process is stopped, and the required chemical added.

Eggs that have been washed in less than pH 11 solution or less than 50 ppm. chlorine cannot be sold as shell eggs, they are manufacturing quality only.

EXAMPLE CCP 10. EGG GRADING

BACKGROUND

Each egg must be visually checked for internal and external faults and downgraded if faults are detected.

HAZARDS

Eggs that are cracked, thin shelled or have heavy contamination may allow pathogenic bacteria into the shell.

Eggs rejected during the grading process must be placed in separate containers used solely for these eggs and so labelled. The grading machine must be sanitised after use.

Biological

A clean dry egg has a low risk of becoming contaminated during the grading process, but the risk to egg safety increases if dirty or cracked eggs are not removed during grading.

The surfaces of grading equipment can become contaminated with bacteria and fungi and thrive on egg contents.

Chemical

Minimal risk of chemical contamination if chemicals used to sanitise the equipment are applied at the correct rate.

Physical

Low risk of contaminants being packed into cartons. Risk increased if second hand cartons are used.

PRODUCTION SYSTEMS

Overview of common hazards

Contamination of eggs occurs during or prior to egg grading. The risk of contamination during grading is related to the level of contamination on the eggs coming into the grading floor and their shell quality. If a production system tends to produce eggs that are inferior in these respects the risk of contamination during grading will be increased.

Control measures

Eggs should be free from dirt, stains, blood spots and meat spots and must not be cracked, thin shelled, rough or misshapen.

Use of an identification stamp on the egg is recommended to ensure that each individual egg can be identified as to the grading floor and date packed. Egg substitution cannot occur with egg stamping. Blood stained and heavy faecal stained eggs must be destroyed.

Monitoring effective control

Egg collection staff are to be trained in candling and packaging procedures. Grading records are to be completed at the end of each grading session to allow for trace back if a food safety problem occurs.

Corrective action steps

All contaminated eggs must be sold for product manufacture. Cracked eggs cannot be sold for human consumption.

Retrain staff if monitoring identifies contaminated eggs being packed for retail sale.

EXAMPLE CCP 11. EGG PACKING

BACKGROUND

After grading and candling egg are to be packed into new clean cartons. Second hand cartons cannot be used as packaging for retail scale. A 'best by date' of 28 days after grading must be placed in a prominent place on the carton and other outer packaging.

HAZARDS

Biological

The risk of contamination can be low if the eggs are clean and dry before packaging. The risk increases if broken or dirty eggs are allowed to contaminate the grading machine or egg collecting equipment or packaging. Rodent damage to packaging material also increases the food safety risk. Ensure all staff follow good hygiene practices.

Chemical

Minimal risk.

Physical

Low risk if packaging material is new and has no contamination.

PRODUCTION SYSTEMS

Overview of common hazards

Contamination of eggs occurs during or prior to egg packaging. Packing is independent of the type of housing system.

Control measures

All eggs to be packed into clean single use trays or cartons.
A legible best before date must be placed on the carton and outer packing material.
The carton must identify the grading floor where the eggs were packed.

Monitoring effective control

Observe staff actions; ensure proper staff training and check grading log sheets have been completed after each day of grading.

Corrective action steps

Eggs that are in cartons that are over the best before date must be down graded to manufacturing quality and not re-graded for retail sale.

Contaminated packing material must be destroyed.

EXAMPLE CCP 12. PEST AND DISEASE CONTROL

BACKGROUND
Pests can be a source of disease and cause significant damage to sheds and property and can contaminate birds, feed, water, eggs, equipment and packaging.

HAZARDS

Biological
Pests of concern are rodents, insects, wild birds and feral animals. Major areas of risk are egg packaging and egg handling equipment.

Chemical
Minimal risk of spread.

Physical
Minimal risk of spread.

PRODUCTION SYSTEMS

Overview of common hazards
Packaging areas should be pest proof.
Poultry houses and ancillary buildings should be wild bird and rodent proof where possible. Measures should be taken to control insects and vermin and their breeding areas.
Areas around sheds and buildings must be kept clean and vegetation kept under control.

Risk Awareness

Cage:
Sheds are to be kept vermin and pest proof if possible to reduce the risk of egg contamination.

Barn Lay:
Same risk as above.

Free Range:
These areas present a high risk as unwanted pests cannot be as easily controlled as in the other systems. Ensure an effective baiting system is in operation that the birds cannot gain access to. The risk of eggs becoming contaminated is also higher than both cage and barn lay as nest boxes are open during the day and not protected from pests.

Control measures
Routine sanitation of all egg handling equipment will reduce the risk of eggs becoming contaminated.
Have an effective baiting and spray program in place.

Monitoring effective control
A pest control program should be put in place so all staff are aware of what is expected. A log book of inspections and treatments must be kept to monitor pest control.
Equipment and egg handling surfaces must be cleaned prior to egg handling.

Corrective action steps
Contaminated packaging material must be destroyed. Contaminated eggs are to be used for product only.

Appendix 2: Example of a HACCP Worksheet

CCP Step _____

Background
(A description of the process and why this step is a Critical Control Point).

Hazards
(Identify the types of hazards to look for).

A. Biological

B. Chemical

C. Physical

Production Systems

Overview of common hazards
(Identify the hazards that are common to each system).

Risk Awareness
(Identify level of risk that the hazard presents in each of these housing systems).

Cage

Barn Lay

Free Range

Control Measures
(Outline the control measures taken to ensure that contaminated eggs do not leave the farm).

Monitoring effective control
(Describe how the control measures are being monitored).

Corrective Action Steps
(If the control measures fail, what action is required to ensure that contaminated eggs are withdrawn from the market place).

Appendix 3: Hazard Work Sheet Layout for a full HACCP Layout

Production System _____

Critical Control Point Number _____

Flow Chart Step _____

Critical Control Point	Hazards Identified (B, C, P)	Critical Limits	Monitoring process	Recording systems	Corrective action steps

Appendix 4: Hazard Work Sheet

This page of a food safety plan is an example of how a critical control point can be broken down into HACCP procedures. In this example, temperature of wash water was not included in the plan and only the chemical procedures were developed.

Production System____Laying cage / Barn Lay/ Free Range_____.
Critical Control Point Number_____*6?*_____
Flow Chart Step__*Egg Washing*_____

Critical Control Point	Hazards Identified (B, C, P)	Critical Limits	Monitoring process	Recording systems	Corrective action steps
Washing eggs removes the natural cuticle from the shell, so increasing the risk of food spoilage microbes entering the egg. Egg washing can only be undertaken using purpose built machines that have separate wash and rinse compartments. No damp cloth cleaning is permitted under any circumstances. Dry cleaning of eggs using sandpaper or scraping is permitted.	Biological - potentially harmful bacterial can contaminate large numbers of eggs during washing. Chemical - low risk of alkali or chlorine contamination on egg surface.	Water in washing section of machine contain minimum of pH 11 alkali salts and or minimum of 50ppm chlorine. Rinse water must contain minimum of 50ppm chlorine. Eggs must be dry before packing. Wet eggs must not come in contact with unsanitised surface.	pH levels must be tested every hour that the machine is operating by using pH test strips. Chlorine levels are tested hourly by using chlorine test strips.	Chemical levels tested on the hour are recorded on a log sheet. A member of staff must be responsible for washing machine operation.	When pH levels less than 11 in wash water are identified and chlorine levels less than 50ppm in rinse water, the washing process is stopped, and the required chemical added. **Eggs that have been washed in less than pH 11 solution or less than 50ppm. chlorine cannot be sold as shell eggs. They are manufacturing quality only.**

References

Acuff, G.R.C., Vanderzant, C., Gardner, F.A. and Golan F.A. (1982). Examination of turkey eggs, poults and brooder house facilities for *Campylobacter jejuni.* J. of Food Prot., 45: 1279-81.

Almond, A. Personal communication. Affiliation: Longeronong College, University of Melbourne, Institute of Land and Food Resources, Horsham, Vic., Australia.

Amin, M.K. and Draughton, F.A. (1990). Infection of shell eggs with *Yersinia enterocolitica.* J. of Food Protection. 53: 826-30.

Ayers, J.C. (1960). The relationship of organisms of the genus *Pseudomonas* to the spoilage of meat, poultry, and eggs. J. Appl. Bacteriol. 23: 471-86.

Ayers, J.C. and Taylor, B. (1956). Effect of temperature on microbial proliferation in shell eggs. Appl. Microbiol. 4: 355-9.

Anon.(1995). Eggshell quality influenced by alternative housing systems. World Poultry-Misset. 11(11): 19-20.

Bailey, S., Cox, N. and Stern, N. (1995). Risk Management Factors Associated with Implementation of HACCP in the Poultry Industry. From an address to the Hazard Analysis and Critical Control Point (HACCP) Symposium in association with the 75th Annual Meeting of the Conference of Research Workers in Animal Diseases, Chicago.

Bains, B.S. and MacKenzie, M.A. (1974). Transmission of *Salmonella* through an integrated poultry organization. Poultry Sci. 53: 1114.

Barnhart, H.M., Dreesen, D.W., Bastien, R. and Pancorbo, O.C. (1991). Prevalence of *Salmonella enteriditis* and other serovars in ovaries of layer hens at time of slaughter. J. Food Prot. 54: 488-491.

Baskerville, A., Humphrey, T.J., Fitzgeorge, R.B., Cook, R.W., Chart, H., Rowe, B. and Whitehead, A. (1992). Airborne infection of laying hens with *Salmonella enteriditis* phage type 4. Vet. Rec. 130: 395-398.

Batchelor, P.J. (1988). *Salmonella enteriditis,* phage type 4 and hen's eggs. Lancet, 1988: ii: 1421.

Bisgaard, M. (1992). A voluntary *Salmonella* control programme for the broiler industry, implemented by the Danish Poultry Council. Int. J. of Food Microb. 15: 219-224.

Board, R.G. (1964). The growth of Gram-negative bacteria in the hen's egg. J. Appl. Bacteriol. 27: 350-64

Board, R.G., Ayers, J.C., Kraft, A.A. and Forsythe, R.H. (1964). The microbiological contamination of egg shells and egg packing materials. Poultry Sci. 43: 584-95.

Board, R.G., Clay C., Lock J. and Dolman, J. (1994). In, Board, R.G. and Fuller, R. (eds.), The egg: a compartmentalised aseptically packaged food, in Microbiology of the Avian Egg. Chapman and Hall, London.

Bruce J. and Drysdale, E.M. (1994), Trans-shell transmission. In, Board, R.G. and Fuller, R.(eds.). Microbiology of the Avian Egg. Chapman and Hall, London.

Carlson, V.L. and Snoeyenbos, G.H. (1970). Effects of moisture on salmonellae populations in animal feeds. Poultry Sci. 49: 717-25.

Carter, T.A., Gentry, R.F. and Bressler, G.O. (1973). Bacterial contamination of hatching eggs and chicks produced by broiler systems. Poultry Sci., 52: 2226-36.

Cox, N.A., Bailey, J.S., Mauldin, J.M. and Blankenship, L.C. (1990). Research Note: Presence and Impact of *Salmonella* Contamination in Commercial Broiler Hatcheries. Poultry Sci. 69: 1606-1609.

Dawson, P.S. (1992). Control of Salmonella in poultry in Great Britain. Int. J. of Food Microb. 15: 215-217.

Doyle, M.P.(1984). Association of *Campylobacter jejuni* with laying hens and eggs. Appl. Environ. Microbiol. 47: 533-6.

Dunn, N. (1997) European cage critics find no better system. World Poultry-Misset. 13(9) :32-39.

Edel, W. (1994). *Salmonella enteriditis* eradication programme in poultry breeder flocks in The Netherlands. Int. J. of Food Microb. 21: 171-178.

Elliott, R.P. (1954) Spoilage of shell eggs by pseudomonads. Appl. Microbiol. 2: 158-64.

Gast, R.K. and Beard, C.W. (1992). Detection and enumeration of *Salmonella enteriditis* fresh and stored eggs laid by experimentally infected hens. J. Food Protect. 55: 152-156.

Glaser, V. (1998). *Salmonella* and rivals PREEMTed from chickens. Nature Biotech. 16:413.

Guard-Petter, J., Henzler, D.J., Mahbubur Rahman, M. and Carlson, R.W. (1997). On-Farm Monitoring of Mouse-Invasive *Salmonella enterica* Serovar Enteriditis and a Model for its Association with the Production of Contaminated Eggs. Appl. and Environ. Microb. 72: 1588-1593.

Harry, E.G. (1963). The relationship between egg spoilage and the environment of the egg when laid. Br. Poultry Sci. 4: 91-100.

Henzler, D.J. and Opitz, H.M. (1992). The Role of Mice in the Epizootiology of Salmonella enteriditis Infection on Chicken Layer Farms. Avian Diseases, 36: 625-631.

Hinton, M. and Linton, A.H. (1988). Control of *Salmonella* infections in broiler chickens by the acid treatment of their feed. Vet. Rec. 123: 416-421.

Humphrey, T.J. (1994). Contamination of egg shell and contents with *Salmonella enteriditis*: a review. Int. J. of Food Microbiol. 21: 31-40.

Humphrey, T.J. and Whitehead, A. (1992). Techniques for the isolation of salmonellas from eggs. Br. Poult. Sci. 33: 761-768.

Humphrey, T.J., Whitehead, A., Gawler, A.H.L., Henley, A. and Rowe, B. (1991). Numbers of *Salmonella enteriditis* in the contents of naturally contaminated hens' eggs. Epidemiol. Infect. 106: 489-496.

International Commission on Microbiological Specifications for Foods (ICMSF) (1998a) Eggs and egg products. In *Microbial Ecology of Food Commodities. Vol. 6: Microorganisms in Foods*, p. 225. Blackie, London.

International Commission on Microbiological Specifications for Foods (ICMSF) (1998b) Feeds and Pet Foods. In *Microbial Ecology of Food Commodities Vol. 6: Microorganisms in Foods*, pp. 208-209. Blackie, London.

Jay, S., Grau, F.H., Smith K., Lightfoot, D., Murray, C. and Davey, G.R. (1997). In Hocking, A.D., G. Arnold, I. Jensen, K. Newton and P. Sutherland (eds.). Foodborne Microorganisms of Public Health Significance, 5th edn., AIFST (NSW Branch) Food Microbiology Group.

Johns, C.K. and Berard, H.L. (1946). Effect of certain methods of handling upon the bacterial content of dirty eggs. Sci. Agric. 26:11-15.

Jones, F.T., Axtell, R.C., Rives, D.V., Scheideler, S.E., Tarver, F.R., Walker, R.L. and Wineland, M.J. (1991). A survey of *Salmonella* contamination in modern broiler production. J. Food Prot. 54: 502-507.

Jones, F.T., Rives, D.V. and Carey, J.B. (1995). *Salmonella* Contamination in Commercial Eggs and an Egg Production Facility; Research Notes. Poultry Sci., 74: 753-757.

Kerihara, K., Chuhei, I., Koukichi, G., Konuma, H. and Shinagawa, K. (1996). Bacterial Contamination on the Shell Surface of Hen Eggs and the Source of Contamination. Jpn. J. Food Microbiol. 13(3): 111-116.

Lorenz, F.W. and Starr, P.B. (1952). Spoilage of washed eggs I. Effect of sprayed versus static water under different washing temperatures. Poultry. Sci., 31: 204-14.

Lorenz, F.W., Starr, P.B., Starr M.P. and Ogasawara, F.X. (1952). The development of *Pseudomonas* spoilage in eggs I: Penetration through the shell. Food Res. 17:351-60.

Mason, J. (1994). *Salmonella enteriditis* Control Programs in the United States. Int. J. of Food Microb. 21:155-169.

Mayes, F.J. and Takeballi, M.A. (1983). Microbial Contamination of the Hen's Egg: A Review. J. of Food Protection. 46(12): 1092-1098.

Moses, A. (1998). Inspired Intentions; Creative Solutions for Personal and Organisational Transformations, Sydney.

Mossel, D.A.A., Corry, J.E.L., Struijk, C.B. and Baird, R.M. (1995). Essentials of the Microbiology of Foods; A Textbook for Advanced Studies. John Wiley and Sons, Chichester.

Neill, S.D., Campbell, J.N. and O'Brien, J.J. (1985). Egg penetration by *Salmonella enteriditis.* Avian Pathol. 14; 313-20

Nurmi, E., Nuotio, L. and Schneitz, C. (1992). The competitive exclusion concept: development and future. Int. J. of Food Microbiol. 15: 237-240.

Nurmi, E. and Rantala, M. (1973). New aspects of *Salmonella* infection in broiler production. Nature: 210-211.

Philbrook, F.R., MacCready, R., van Rockel, H., Anderson, E.S., Smyser, C.F., Sanen, F.J. and Groton, W.M. (1960). Salmonellosis spread by a dietary supplement of avian source. N. Engl. J. Med. 263: 713-18.

Poppe, C. Barnum, D.A. and Mitchell, W.R. (1985). Effect of Chlorination of Drinking Water on Experimental Salmonella Infection in Poultry. Avian Diseases, 30: 362-369.

Quarles, C.L., Gentry, R.F. and Bressler, G.O. (1970). Bacterial contamination in poultry houses and its relationship to egg hatchability. Poultry Sci., 49: 60-66.

Schefferle, H.E. (1965). The Microbiology of Built Up Poultry Litter. J. Appl. Bacteriol. 28(3): 403-411.

Schneitz, C. (1998). Competitive Exclusion of Salmonella: Defined or Undefined Products. Poultry Internat. August, 1998, p. 18.

Schoeni, J.L. and Doyle, M.P. (1994) Variable colonization of chickens perorally inoculated with *Escherichia coli* O157:H7 and subsequent contamination of eggs. Appl. Environ. Microbiol. 60: 2958-2962.

Schoeni, J.L., Glass, K.A., McDermott, J.L, and Wong, A.C.L. (1995). Growth and penetration of *Salmonella enteriditis, Salmonella heidelberg* and *Salmonella typhimurium* in eggs. Int. J. of Food Microb. 24: 385-396.

Shanker, S., Lee, A. and Sorrell, T.C. (1986). *Campylobacter jejuni* in broilers: the role of vertical transmission. J. Hyg. Camb. 96: 153-159.

Simonsen, B., Bryan, F.L., Christian, J.H.B., Roberts, T.A., Tompkin, R.B. and Silliker, J.H. (1987). Prevention and control of food-borne salmonellosis through application of Hazard Analysis Critical Control Point (HACCP). Internat. J. of Food Microb. 4: 227-247.

Smeltzer, T.I., Orange, K., Peel, B. and Runge, G. (1979). Bacterial penetration in floor and nest box eggs from meat and layer birds. Aust. Vet. J. 55: 592-593.

Sparks, N.H.C. and Board, R.G. (1985). Bacterial penetration of the recently oviposited shell of hen's eggs. Aust. Vet. J. 62(5): 169-170.

Sparks, N.H.C. and Board, R.G. (1984). Cuticle, shell porosity, and water uptake through hens' eggshells. Br. Poultry Sci.: 297-76.

Stadelman, W.J. (1994). Contaminants of liquid egg products. In, Board, R.G. and Fuller, R. Microbiology of the Avian Egg. Chapman and Hall, London.

Stephenson, J. (1998). Fighting Flora with Flora: FDA Approves an Anti-*Salmonella* Spray for Chickens. JAMA, 279(15): 1152.

Sterski, A., Blanchfield, B., Thacker, C. and Pivnick, H. (1981). Reduction of *Salmonella* excretion into drinking water following treatment of chicks with Nurmi culture. J. Food Prot. 44: 917-920.

Stott, J.A. Hodgson, J.E. and Chaney, J.C. (1975). Incidence of salmonellae in animal feed and the effect of pelleting on the content of enterobacteriaceae. J. Appl. Bacteriol. 39: 41

Sutherland, P.S. and Porritt, R.J. (1997). In, Hocking, A.D., Arnold, G., Jenson, I., Newton, K. and Sutherland, P.S., Foodborne Microorganisms of Public Health Significance (5th edn.). AIFST (NSW Branch) Food Microbiology Group.

Timoney, J., Kelly, W.R., Hannan, J. and Reeves, D. (1970). A study of *Salmonella* contamination in some Dublin poultry processing plants. Vet. Rec. 87: 158.

Timoney, J.F., Shivaprasad, H.L., Baker, R.C. and Rowe, B. (1989). Egg transmission after infection of hens with Salmonella enteriditis phage type 4. Vet. Rec. 125: 600-601.

Trussel, P.C. (1955). Bacterial spoilage of shell eggs; Bacteriology. Food Technol. 9: 126-9

Tucker, J.F. (1967). Survival of salmonellae in built-up litter for housing of rearing and laying fowls. Brit. Vet. J. 123: 92-103.

Vadehra, D.V. and Baker, R.C. (1973). Effect of egg shell sweating on microbial spoilage of chicken eggs. J. Milk Food Technol., 36: 321-2.

Vaughn, J.B., Williams, J.R. LeBlanc, D.R. , Helsdon H.L. and Taylor C. (1974). Salmonella in a modern broiler operation: A longitudinal study. Am. J. Vet. Res. 35: 737.

Welshimer, H.J. (1960). Survival of *Listeria monocytogenes* in soil. J. Bacteriol. 80:316-320.

Welshimer, H.J. and Donker-Voet, J. (1971). *Listeria monocytogenes* in nature. Appl. Microbiol. 21: 516-519.

Wierup, M., Engstrom, B., Engvall, A. and Wahlstrom, H. (1995). A Review Paper; Control of *Salmonella enteriditis* in Sweden.

Williams, J.E. (1981). Salmonellas in Poultry Feeds – A Worldwide Review. World's Poultry Sci. J. 37: 6-19. Int. J. of Food Microbiol. 25: 219-26.

Zindel, H.C. and Bennett, M.V. (1968). *Salmonella* in poultry feeds. Poultry Sci. 47: 1925.