Salmonella risk profile of UK-produced hen shell eggs: Exposure assessment

3.1 The egg supply chain - summary

The steps in the egg supply chain are outlined below in Table 2 and consider the key risks of each stage of the supply chain from farm to consumer. Eggs can become contaminated with *Salmonella* at various stages of the egg supply chain. They can be contaminated via direct contamination, where the egg is infected during the formation, or indirectly after the egg has been laid. The indirect contamination can occur during the egg production process, storage, handling or food preparation, making the source difficult to identify and manage (Whiley and Ross, 2015).

Once an egg becomes contaminated, there are several points in the egg supply chain (Table 2) at which cross contamination can occur, increasing the volume of contaminated eggs and therefore the potential risk to the final consumers.

Table 2: Risk pathway depicting stages of egg production & risks associated with them in the UK adapted from (British Lion Eggs, 2021)

Stage of supply chain	Key risk (s)
On farm: Cage, Barn, Free-range including organic	Caged flocks can have higher prevalence of *Salmonella* Pests and wildlife can spread contamination within housed birds Infected feed/bedding/water/farm staff Introduction of infected birds/point of lay pullets Introduction of *Salmonella* via staff, farm visitors/ equipment such as lorries and catcher crews and egg crates for collection Insufficient cleaning may allow contamination to persist Continued production of Class B eggs by positive flock where there are other flocks on site not subject to restrictions
Transport of eggs to packing centre	Transport trays have been found to be contaminated with *Salmonella* Incorrect temperature controls can lead to condensation on the eggshells, which can encourage internalisation of *Salmonella.*

Stage of supply chain	Key risk (s)
Processing and packaging: Grading machine, dirt detector, crack detector, UV system, Weighing, blood detector	Areas where the eggs come into contact can transfer *Salmonella* for example, production line belts – this is more likely when the eggs are wet UV will potentially decrease *Salmonella* contamination levels; therefore, the lack of this step may increase risk Contaminated environment of packing centre Cross contamination from infected staff
Eggs shipped to retail	Temp control failure - Lion brand eggs must be kept at a constant temperature below 20 degrees.
Retail and consumer handling	Increase in temperature may increase *Salmonella* growth within the egg Cross contamination in processes such as whisking, and contamination of surfaces Raw egg products need to follow correct de-activation processes which may be difficult in-home kitchen Handling and cross contamination of cooking surfaces where external contamination exists on egg shell

3.2 On farm

3.2.1 On-farm detections and data trends

The ACMSF’s 2016 report provided a summary of long-term trends of Salmonella Enteritidis detections in broilers (Figure 1). A 70% decrease in detected S. Enteritidis in flocks occurred in 1994, and is thought to have followed wide-scale implementation of vaccination programs (Lane et al., 2014).

Figure 1: Trends in the reporting of incidents of Salmonella enterica serovar Enteritidis in chickens in Great Britain versus laboratory reporting of human S. enterica serovar Enteritidis infections, England and Wales, 1985–2011 (Lane et al., 2014).

The trend of low numbers of S. Enteritidis incidents has continued in recent years, with 27 isolations in 2018, 48 in 2019, 31 in 2020 and 9 in 2021 in UK chicken (APHA, 2022). A rise in Salmonella in laying hen flocks would lead to a rise in Salmonella detections in eggs and egg products (Lane et al., 2014).

Figure 2, Table 3 and Table 4 show the prevalence of Salmonella in laying hen flocks from 2009 to 2021.

During 2020, operators continued to take NCP samples as they usually do, and APHA official samples were also taken as usual. There may have been a reduction in BEIC surveillance and sampling due to the COVID-19 pandemic (APHA, 2021).

Since the ACMSF risk assessment in 2016, the overall prevalence of Salmonella in laying hen flocks remains the same, although there have been fluctuations year on year (Table 3, Table 4). The number of adult laying hen flocks that tested positive for any Salmonella was lowest in 2016 at 0.58% (22/ 3793). There was a peak in 2019 of 1.20% prevalence of any Salmonella spp., dropping down to 0.96% in 2021.

Figure 2: Prevalence of Salmonella in laying hen flocks tested under NCP in GB 2010-2021 (APHA, 2022).

Since the ACMSF report in 2016, there has been an overall increase in the proportion of regulated serovars and S. Enteritidis in laying flocks (Table 4). The increase in number of flocks testing positive for S. Enteritidis in 2019 and 2020 compared to previous years could also be influenced by the occurrence of risk-based enhanced sampling by APHA and BEIC on some premises (APHA, 2021). However, these remain well within the flock positive target of 2% under the NCP testing regulations.

In 2016, 0/3793 NCP eligible laying flocks were positive for regulated serovars (including S. Enteritidis). In 2017, 6/3906 (0.15%) flocks were positive for regulated serovars, all of which were S. Enteritidis. In 2018, the proportions reduced, even with an increase in the number of eligible flocks tested, the number positive for regulated serovars was 4/4106 (0.09%), 3 of which were S. Enteritidis. In 2019, there was a peak where 16/4014 (0.40%) were positive for regulated serovars and 14 of these were S. Enteritidis. In 2020, 14/3959 (0.35%) were positive for regulated serovars and 11 of these were S. Enteritidis. In 2021, there was a slight reduction in the proportions testing positive for regulated serovars at 9/3977 (0.23%), with 3 of these testing positive for S. Enteritidis (Table 3).

Table 3: Adult laying flocks tested and positive for Salmonella, 2009 – 2021 (AHVLA, 2009, 2010, 2011, 2012; APHA, 2019b, 2019a, 2021, 2022).

Year	Total NCP eligible Flock # Adult Laying Hens	Positive for regulated serovars	Positive for SE	Positive total (adult)
2009	4197	10	7	67

Year	Total NCP eligible Flock # Adult Laying Hens	Positive for regulated serovars	Positive for SE	Positivetotal (adult)
2010	4099	11	6	41
2011	3865	7	5	29
2012	3777	3	1	32
2013	3,687	3	2	37
2014	3,704	2	2	36
2015	3,674	1	0	22
2016	3,793	0	0	22
2017	3,906	6	6	28
2018	4,106	4	3	26
2019	4,014	16	14	48
2020	3,959	14	11	42
2021	3,977	9	3	38

Table 4: A summary of NCP testing results for laying flocks broken down into two time periods – 2009-2016, as would have been observed in the ACMSF 2016 risk assessment, and 2017-2021.

2009-2016	All tested	All *Salmonella*	Regulated *Salmonella*	S. Enteritidis
Flocks	30,796	286	37	23
% of tested	100%	0.93%	0.12%	0.07%

2017 - 2021	**All tested**	**All *Salmonella***	**Regulated *Salmonella***	**S. Enteritidis**
Flocks	19.962	182	49	37
% of tested	100%	0.91%	0.25%	0.19%

FSA has been notified of several incidents of S. Typhimurium detection on layer farms in recent years – however, comparable data is not available prior to 2019, so a trend cannot be inferred.

3.2.2 Factors affecting *Salmonella* prevalence and levels in flocks

The ACMSF 2016 report concluded that the factors affecting levels of *Salmonella* were the introduction of National Control Programs, the combination of vaccination, rodent control and improved farm hygiene standards, together with the removal of traditional battery cage systems, which resulted in virtual eradication of infection. It highlighted that the introduction of vaccination for *Salmonella* Enteritidis in the egg industry was associated with a large reduction in human cases. A search of PubMed was completed in order to identify new evidence for factors that affect the prevalence and levels of Salmonella in flocks and also to provide context for the levels of *Salmonella* seen in the UK. Since 2016 the oldest flocks have increased from 60/70 weeks to 80/90 weeks old with a move to free-range egg production compared to caged hens (APHA, personal communication).

3.2.2.1 General

In Crabb et al., 2019, the overall finding from across multiple flocks was that the risk of contamination declined as the flocks aged. The environmental prevalence of Salmonella spp. remained similar as the flocks aged, but the prevalence in eggs varied significantly. The study also looked at pooling egg samples and found that a high prevalence in pooled eggs did not guarantee the detection of positive individual egg components in that subsample. This outcome indicates that factors other than simple environmental cross contamination are important in contributing to egg contamination and that physiological status of the hens such as variation in body weight and egg production was contributing to egg contamination (Crabb, Gilkerson and Browning, 2019). The birds were monitored up to 50 weeks in age and the vaccination status of the flocks included is not known.

3.2.2.2 Housing

There are diverse and sometimes conflicting results on how housing system of flocks may affect the prevalence of *Salmonella* but in general, lower levels of S. Enteritidis are associated with non-cage systems (EFSA BIOHAZPanel et al., 2019). It was also suggested that the change from conventional cages to enriched cages Council Directive 1999/74/EC could have been associated with the initial reduction of *Salmonella* prevalence in laying hens that occurred from 2009 until 2013 as this required the laying houses to be totally cleared for refurbishment, but no studies have specifically investigated this change. The literature reviewed in this EFSA document showed that stress inducing conditions, an increase in stoking density and larger farms resulted in an increased persistence and spread of *Salmonella* within laying flocks (EFSA BIOHAZPanel et al., 2019).

There are numerous methods employed to control Salmonella in laying flocks which revolve around maintaining clean henhouses. One method is cleaning flock housing between flocks, but the effectiveness of this cleaning is very variable (Whiley and Ross, 2015). Another is the control of pests and wildlife as these can transmit Salmonella between flocks and can re-contaminate clean hen housing. Biosecurity measures and the design of housing systems can mitigate this spread via wild animals (APHA, 2021).

Due to a recent avian influenza outbreak, an Avian Influenza Prevention Zone came into force across England on 3 November 2021, and additional housing measures came into force across the UK on 29 November 2021 which were further updated on 29 March 2022 and 2 May 2022. These measures meant that it was a legal requirement for all bird keepers across the UK (whether they have pet birds, commercial flocks or just a few birds in a backyard flock) to keep their birds indoors or fully netted area and follow strict biosecurity measures to limit the spread of and eradicate the disease. This may have an effect on the *Salmonella* spread in flocks. The Avian Influenza Prevention Zone was lifted on 16 August 2022.

3.2.2.3 *Salmonella* vaccination of hens

Salmonella vaccination of hens increases their immunity to *Salmonella* (Arnold et al., 2012), prevents and reduces the intestinal colonisation of bacteria, and results in reduced faecal shedding and eggshell contamination (EFSA, 2004). It also acts to reduce bacterial colonisation in reproductive tissues (EFSA, 2004). In the UK, there is evidence that the introduction of vaccination in the broiler/ breeder sector, along with improved hygiene and biosecurity, has been crucial in breaking the cycle of persistent farm hatchery contamination and spreading of S. Enteritidis infection (ACMSF, 2016).

The vaccines currently licensed for use in GB are split into live-attenuated and inactive (Table 5). Since the ACMSF report in 2016 there have been two new vaccines licensed for use in the UK including the live vaccine Nobilis SE Live Lyophilisate for use in drinking water in 2018. The onset of immunity is 14 days after the first vaccination and 4 weeks after the third with the duration of immunity lasting for 60 weeks after completion of the 3 vaccine schedule (Veterinary Medicines Directorate, 2021b). The second is the inactive vaccine Nobilis Salenvac ETC suspension for injection for chickens, licensed in 2020. This can be injected into the birds from 6 weeks of age with the onset of immunity after the second vaccination being 4 weeks. The duration of immunity after the second vaccine varies between strains but for S. Enteritidis duration is 48 weeks (evidenced by challenge) and 90 weeks (evidenced by serology) (Veterinary Medicines Directorate, 2020).

A study by Arnold et al. (2014) found that vaccinated flocks continue shedding *Salmonella*, and nearly all the birds had positive cloacal swabs regardless of vaccination after a challenge dose. However, vaccination did decrease the amount of Salmonella found on the eggshells, and resulted in a 55% and 21% reduction for the two monophasic strains of S.?Typhimurium and a 28% reduction for the S. Enteritidis strain (Arnold et al., 2014). A study by Crouch et al., (2020) investigated the efficacy of the inactive trivalent vaccine Nobilis Salenvac ETC in broiler breeder hens. Under field conditions, this vaccine induced an immune response, producing specific antibodies against the three component serovars (S. Enteritidis, S. Infantis and S. Typhimurium), persisting at high levels until the hens were at least 56 weeks of age (39 weeks after second vaccination). There was a significant reduction in colonisation of the organs and intestines after a challenge dose (108 colony-forming units, CFU/ bird) with a reduction of 63.2% faecal shedding and 44% organ invasion of S. Enteritidis (Crouch et al., 2020).

Table 5: Currently approved Salmonella vaccines for use in poultry populations in GB adapted from source (Veterinary Medicines Directorate, 2021a).

Name	Active substance	Live/inactivated	Target species	Date of issue
Nobilis Salenvac	S. Enteritidis	Inactivated	Chickens	1995
Nobilis Salenvac T suspension for injection for chickens	S. Enteritidis and S. Typhimurium	Inactivated	Chickens	2000
AviPro *Salmonella* Vac T	S. Typhimurium	Live	Chickens	2002
Cevac Salmovac Lyophilisate for use in drinking water	S. Enteritidis and S. Typhimurium	Live	Chickens	2003
Gallimune SE + St, Water-in oil emulsion for injection	S. Enteritidis and S. Typhimurium	Inactivated	Chickens	2007
AviPro Salmonella Duo Lyophilisate for use in drinking water	S. Enteritidis and S. Typhimurium	Live	Chickens, ducks and turkeys	2011
Nobilis SE Live Lyophilisate for use in drinking water	S. Enteritidis and S. Typhimurium	Live	Chickens	2018
Nobilis Salenvac ETC suspension for injection for chickens	S. Enteritidis, S. Infantis and S. Typhimurium	Inactivated	Chickens	2020

3.2.2.4 Feed

Feed can harbour *Salmonella*, which can contaminate the eggs, either via the layer or through the environment. Since the 2016 ACMSF report was published, a ban on the use of formaldehyde-based products in animal feed was implemented in 2018. This has been suggested as a possible contributor to the increased isolations of *Salmonella* in the broiler sector which was up by 27% in

2020 compared with 2019. The NCP data for layers, however, has shown a decrease in *Salmonella* positive flocks in 2020 and 2021 compared with 2019 (APHA, 2021), though this could have confounding factors such as an avian influenza season causing birds to be kept indoors. Further information is needed to confirm if the removal of formaldehyde were the cause, as there may have been a replacement to the formaldehyde which would maintain low levels of *Salmonella* in feed.

A study by Brooks et al., (2021) comparing the rate of infection in broiler chicken tissue after the consumption of feed inoculated with *Salmonella*, found that both serovars used, S. Enteritidis and S. Heidelberg, were able to infect the tissues. S. Enteritidis infections were more prevalent than S. Heidelberg at 68% and 9% respectively, infecting at least one tissue. S. Enteritidis infected a larger proportion of tissues at 13.1% compared with 0.7% with S. Heidelberg (Brooks et al., 2021). This study suggests that contaminated feed could potentially cause Salmonella infection in chickens (uncertainty).

3.2.3 UK assurance schemes

Lion Code and Laid in Britain are currently the only egg assurance schemes in the UK, and under the FSA advice, the only eggs that are suitable to be consumed less-than-thoroughly cooked by vulnerable groups. The Lion Code and Laid in Britain codes of practice have been updated since 2016 and are outlined in Section 7.1.

Since 2016, changes have been put in place by British Egg Industry Council (BEIC) and APHA in response to incidents, and the COVID-19 pandemic. Changes in practice for assurance schemes include (personal communication, FSA, 2022):

- improving the efficiency of vaccines. Over time this could reduce the Salmonella prevalence in flocks and reduce the risk of contamination in or on eggs
- implementing enhanced sampling for flocks over the age of 72 weeks
- all Lion Code flocks sampled over a 9-months programme, working with producers and Defra approved labs to increase the quality of sampling and the sensitivity of detection
- circulating a new instruction to depopulate Lion Code laying flocks when found with a regulated serovar
- extending the sampling to the environment of packing centres that are now used as a sentinel of Salmonella presence
- taking rapid restrictive action in packing centres in a case of a positive detection while waiting for further tests.

In 2020, during the COVID-19 pandemic, BEIC stopped live visits to sites and adopted remote video audits with trained auditors who were familiar with the sites. Operator official NCP samples and APHA official samples were taken as normal (personal communication, APHA, 2022).

3.2.4 Transmission routes of *Salmonella* into eggs

Salmonella transmission in eggs can be vertical or horizontal. In vertical transmission, *Salmonella* is introduced from ovaries or oviduct tissue that are infected to eggs, prior to the formation of the shell. Certain *Salmonella* serovars have the potential to colonise and infect hen ovaries or oviduct tissues. This could result in *Salmonella* being transferred to the yolk or albumen before the shell or membranes are formed (Hudson et al., 2015). The *Salmonella* serovar that typically exhibits vertical transmission is S. Enteritidis, although it is still considered a rare event. Other serovars such as S. Heidelberg, S. Infantis, and S. Typhimurium may also be vertically transmitted to some extent, but this is very variable according to strain and the management of laying flocks (ACMSF, 2016).

In hens, the intestinal, urinary, and reproductive processes all share a common orifice and therefore the egg can get contaminated (typically faecal) when laid. Horizontal transmission is typically a result of this faecal contamination on the shell surface, or contamination through environmental vectors, such as farm environment. Shell damage, such as cracks, can accelerate this process.

Vertical transmission is considered to be the major route of *Salmonella* contamination and is more difficult to control, while horizontal transmission can be effectively reduced by adequate disinfection of the environment (WHO/ FAO, 2002).

Since 2016 there has been no evidence or research found to show that new serovars of *Salmonella* have been linked to the contamination in or on shell eggs (uncertainty). However, in 2020, S. Mikawasima (a single isolate that was not related to the human outbreak strain), S. Ramatgan and S. Stanleyville were isolated from chickens in GB for the first time. Other unusual serovars included S. Bredeney (from laying hens), which was last isolated from chickens in GB in 2003; S. Stourbridge (from broilers), which was last isolated from chickens in 2014 and S. Schwarzengrund (from laying hens) and S. Braenderup (from broiler), neither of which had been isolated from chickens in GB since 2015 (APHA, 2021). There is no evidence that these serovars can infect or persist in the egg and therefore the risk to consumers of LTTC eggs are unknown (uncertainty).

3.2.5 Penetration of eggshells by *Salmonella*#

Penetration of eggs with *Salmonella* is complicated, with a wide range of factors affecting the penetration throughout the egg supply chain. The major extrinsic factors are bacterial strain, temperature differential, moisture, number of organisms present, and storage conditions. The main intrinsic factors are shell defects. Cuticle and porosity had been considered major factors though current evidence suggests that bacteria are checked in their movement by structural modifications in the mammillary layer (Messens, Grijspeerdt and Herman, 2005). Microorganisms may enter the egg through pores or fissures in the shell, potentially contaminating the contents (Hudson et al., 2015).

Horizontal transmission can occur when eggs are placed in an environment which can create a negative gradient, drawing any fluids or micro-organisms across the surface of the shell and into the egg. Other transmission routes for micro-organisms are cracks or shell damage that are small enough to go unnoticed. Bacteria that enter the shell in this way are likely to be trapped by the shell membrane and will only multiply in adequate conditions. Should this occur, it would be expected that spoilage of the egg contents would be noticed (visual or olfactory abnormalities) but it could be that the bacterial density is insufficient for spoilage to be obvious (uncertainty) (ACMSF, 2016).

In a study by Messens et al. (2007), eggs from free-range hens (6%) and generic white eggs (16%), were better at resisting *Salmonella* penetration than generic brown eggs (30%), and organic and omega-3–enriched eggs (34%). A second experiment in this paper looked at effect of two types of feed on eggshell penetration (standard feed and a feed with a corn-cob mix). Eggs from hens kept in aviaries and fed corn-cob mix were more frequently penetrated (62%) than eggs of hens given standard feed (48%) (although this was not significant). Further work is needed to confirm that feed can play a role in penetration of *Salmonella* (Messens et al., 2007). No newer papers on these topics were found, therefore we do not know if these rates would be comparable to current egg production (uncertainty).

Indirect contamination of the egg contents has the highest incident between 15 minutes and 3 hours post laying when at 25°C. Experimental refrigeration of eggs at 4°C significantly decreased penetration by *Salmonella* (Miyamoto et al., 1998). Lower temperatures increase survival of S.

Enteritidis on eggshells, but also limit internal growth (Khan et al., 2021). Fluctuations in temperatures cause rapid increases in *Salmonella* (Okamura et al., 2008). Incorrectly controlled changes in temperature may lead to condensation forming on the egg, which in turn increases the likelihood of *Salmonella* internalisation within the egg (Gradl et al., 2017).

A study by Lin et al., (2021) found that a novel serovar, *Salmonella* Hessarek, has emerged in salmonellosis linked to eggs and egg products in Australia and other parts of the world. As there is limited research on this serovar, their study focused on the penetration of S. Hessarek into table eggs at different temperatures. Penetration into egg contents was significantly higher in cold (eggs stored at 5°C) compared with warm conditions (eggs stored at 25 degrees) (Lin et al., 2021).

3.3 Processing and packaging

The 2016 ACMSF report acknowledged that egg exteriors could be contaminated via either direct contact or indirectly by packaging materials. Since 2016 an increased number of packing centres have made a change from single use cardboard trays to transport eggs, to re-usable plastic trays, which should be disinfected between use. This could lead to cross-contamination between eggs if the plastic trays are not washed adequately and could be linked to outbreaks that have occurred at packing centres, but further investigation is needed to confirm this (uncertainty) (APHA, personal communication).

A study by Musgrove et al., (2009) showed that the transportation trays used to move the eggs from farm to packaging centre can become contaminated with *Salmonella* which could contaminate eggs. However, this study was performed in the USA where the vaccination of laying hens is not widespread so the extent this pathway may contribute to contamination in UK eggs is unknown (uncertainty). The study’s focus was on Enterobacteriaceae, but they also analysed isolates to determine the genre, and *Salmonella* along with other bacteria were identified in the isolates tested.

Other potential areas of risk are areas where the eggs are in close contact with each other such as during packing and in the egg grader and rollers where bacteria can be transferred from one egg to another. A study by Regmi et al., (2021) found that transfer of S. Enteritidis from the eggshell surface to the egg carton or packing material could occur (uncertainty). They inoculated wells of egg cartons with S. Enteritidis and uninoculated eggs were placed into the cartons at 4°C and 25°C. 8 eggshell samples tested positive for S. Enteritidis, 6 from polystyrene foam packaging and 2 from plastic cartons. This indicates a possible risk of contamination from packaging material to egg shell surface (uncertainty) (Regmi et al., 2021).

Investigations of two outbreaks of human S. Enteritidis cases in recent years in the UK has revealed that dissemination of the pathogen could occur at packing centres (Section 4.5).

3.4 Retail, catering and consumer handling

Food safety concerns at the retail, catering and consumer level highlighted by the ACMSF in 2016 include poor hygiene and preparation practices, failure to observe Best-before dates, and inappropriate storage that encourages condensation on eggshells.
External contamination present on the outer surface of the eggs poses risks in relation to cross contamination of the egg contents, the food handlers’ hands and the food preparation environment. Cross contamination can additionally occur during the breakage and processing of eggs. Research by Humphrey et al. (1994) showed that breaking inoculated eggs by hand led to contamination of the hands and whisking of eggs led to distribution of *Salmonella* over 40cm away from bowl, which survived for 24 hours (Humphrey, Martin and Whitehead, 1994). The

prevalence of this in domestic settings however is difficult to ascertain (uncertainty).

Effective food hygiene such as effective cleaning and the avoidance of cross-contamination within food processing environments is important for reducing the risk from cross-contamination. While much training focuses on food handlers in larger scale food processing and catering kitchens, good practice advice is likely to be of value to any and all domestic food handlers, especially if they are involved in the preparation of food for higher risk groups or individuals (ACMSF, 2016).

There has not been a significant change identified in consumer or retail handling since the ACMSF report in 2016. An outbreak of S. Enteritidis in Spain in 2021 involving two cases of illness suspected that cross-contamination with unclean eggs in the fridge was the source of infection (uncertainty) (European Centre for Disease Prevention and Control, European Food Safety Authority, 2022). This shows the importance of ensuring hygienic practices while handling eggs.

An FSA study on UK shell eggs in 2003 found a contamination prevalence with *Salmonella* of 0.34% (Food Standards Agency, 2004). No recent studies on the occurrence of *Salmonella* in UK retail eggs have been conducted.

3.5 Egg products

Egg products are defined as 'processed products resulting from the processing of eggs, or of various components or mixtures of eggs, or from the further processing of such processed products' (Retained Regulation EC No 853/2004). Processing can include heating, smoking, curing, drying, marinating, etc., to manufacture products such as refrigerated liquid egg, powdered egg, or frozen egg products. These are widely used in sauces, desserts, pasta, processed meats and fish.

The 2016 ACMSF report acknowledges that manufacturing of egg products can result in cross-contamination with a range of bacteria from the shells, and it can include the use of eggs that have been downgraded, such as cracked eggs or eggs contaminated with *Salmonella* (but not S. Enteritidis). Pasteurisation of liquid egg is an important step in preventing foodborne illness, as is effective refrigeration of pooled eggs.

The ACMSF also identified *Salmonella* outbreaks listed with egg products including – mayonnaise,(3 outbreaks, one of which states the mayonnaise was made with raw shell eggs), egg fried rice (5 outbreaks) and various egg dishes such as desserts, cress sandwiches, Yorkshire pudding, egg noodles and pasteurised liquid egg white. This association of salmonellosis with eggs products has continued (see Section 4.5).

When preparing mayonnaise, pH and temperature are the key factors in controlling *Salmonella*. A pH of 4.6 and a temperature of 37°C was the most effective at reducing S. Typhimurium (lost viability after 24 hours), and 23°C was less effective but still more effective than 4°C where S. Typhimurium survived for more than 10 days. There is a risk that if the pH is not accurately measured and controlled, then storage above 4°C could allow growth. The survivability in acidified environments at 4°C is also important in terms of cross-contamination within the kitchen environment (Keerthirathne et al., 2019). Homemade preparations are potentially more risky with consumers less likely to have easy access to pH meters and recipes may follow taste preference rather than a safe ratio of acid to egg (Cardoso et al., 2021).

3.6 Consumption of raw or undercooked eggs

Based on industry data, the consumption of eggs per person per year in 2021 was 202. This has increased from 171 eggs per person per year in 2004 and is a small increase from 195 in 2016 when the ACMSF risk assessment was written. The majority of UK eggs are sold through retail. The percentage sold at retail in 2021 was estimated at 65%, an increase from 48% in 2004. There was particularly strong growth between 2008 and 2021 where retail sale of eggs grew by 50% (British Lion Eggs, 2022). The ACMSF risk assessment did not report specifically on consumption of raw or LTTC eggs by vulnerable groups.

Data from the national diet and nutrition survey (NDNS) (DHSC, 2013, PHE and FSA, 2014, 2016, 2018, 2020) on the consumption of raw and poached (used as a LTTC equivalent and include those used in recipes) by vulnerable groups (under 5s and over 65s) are presented in Table 6. No specific information on immunocompromising conditions are given in the survey, therefore this group has not been fully represented in this data (uncertainty).

In the data from NDNS, over 40% of foods made with raw eggs contain less than 5% eggs in proportion of the whole food product. This indicates that in these cases, raw eggs are used in small quantities as an ingredient in a recipe containing other ingredients. The quantity of both raw and poached eggs consumed by under 5s is lower than that consumed by the over 65s.

Table 6: Data of amount of raw and poached eggs (with recipes) consumed by vulnerable groups from the NDNS data 2015-2020. For reference, a raw egg (without shell) weighs around 55 g.

Consumed including in recipes	Number of consumers: 4 to 18 months (2683 respondents)	1.5 to 4 years (1157 respondents)	65+ years (1538 respondents)	Mean acute consumption (g/person/day)*: 4 to 18 months	1.5 years to 4 years	65- yea
Raw eggs	21	39	74	1.3	4.3	3.2
Poached eggs	17	32	140	54	61	78
Both raw and poached eggs	38	71	205	26	31	52

* Rounded to 2 significant figures

Self-reported rates of consumption of eggs eaten raw, LTTC and thoroughly cooked indicated that, of the respondents that consume eggs at home, only a small percentage eat raw eggs once a week or more. A higher percentage eat LTTC eggs and thoroughly cooked eggs (wave 2 of Food and You 2 (FSA, 2021)). 61% of respondents never eat raw eggs, 22% never eat LTTC eggs and 8% never eat thoroughly cooked eggs (Table 7).

Table 7: Taken from Food and You 2 survey on the eating habits of UK consumers (FSA, 2021).

Frequency	raw (eggs that are uncooked for example, in homemade mayonnaise or homemade desserts like mousse or soft meringues)	LTTC (eggs that have a runny yolk for example, soft boiled)	cooked thoroughly (eggs that have firm yolk for example, hard boiled)
Every day	1%	1%	2%
Most days	2%	4%	5%
2 to 3 times a week	4%	12%	15%
About once a week	7%	24%	27%
2 to 3 times a month	4%	15%	16%
About once a month	4%	11%	15%
Less than once a month	14%	9%	11%
Never	61%	22%	8%