



Shelf-Life and Food Safety of Eggs in Norway

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Scientific Opinion of the Panel on biological hazards of the Norwegian Scientific Committee for Food and Environment

The European Food Safety Authority (EFSA) assessed the shelf life of table eggs in 2014, and EU legislation currently sets a maximum shelf life of 28 days. The Norwegian Food Safety Authority asked VKM to assess shelf life under Norwegian conditions to determine whether a longer shelf life may be permitted for Norwegian eggs. VKM concluded that, because *Salmonella* Enteritidis is not relevant in Norwegian production chain and Norwegian temperature control significantly reduces microbial risk, the scientific basis for EFSA's 28 day limit does not apply to Norway. A 35-day shelf life remains safe and justified, provided the cold chain is maintained.

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Shelf-Life and Food Safety of Eggs in Norway

Preparation of the opinion

The Norwegian Scientific Committee for Food and Environment (Vitenskapskomiteen for mat og miljø, VKM) appointed a project group to draft the opinion. The project group consisted of four VKM members and two VKM staff. Two referees commented on and reviewed the draft opinion. The Committee, by the Panel on biological hazards assessed and approved the final opinion.

Authors of the opinion

The authors have contributed to the opinion in a way that fulfils the authorship principles of VKM (VKM, 2023). The principles reflect the collaborative nature of the work, and the authors have contributed as members of the project group and/or the VKM Panel on Biological Hazards, appointed specifically for the assignment.

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The expertise of VKM experts

Individuals working for VKM, either as appointed members of the Committee or as external experts, do this by virtue of their scientific expertise, not as representatives for their employers or third-party interests. The provisions on impartiality in the Norwegian Public Administration Act apply to all work carried out by VKM.

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Summary

Background

The Norwegian Food Safety Authority (NFSA) requested a scientific assessment of whether the assumptions behind EFSA's 2014 opinion on egg safety and shelf-life apply to Norwegian conditions, and whether Norway could justify a longer shelf-life than the EU's required 28 days. EFSA's original risk model is heavily focused on *Salmonella* Enteritidis, assuming significant vertical transmission (defined as pathogen transmission from infected hens to yolks) - a contamination route that is not relevant under Norwegian conditions due to near-absence of the pathogen.

The NFSA therefore asked Norwegian Scientific Committee for Food and Environment (VKM) to assess:

1. Whether EFSA's assumptions match Norwegian production.
2. The food safety significance of enzymes, microbial growth, AMR, and consumer behaviour under Norwegian conditions.
3. How long raw, non-heat-treated eggs stored under Norwegian conditions remain safe.

Methods

The assessment used a qualitative methodology, combining:

- Review of EFSA's 2014 opinion and extraction of underlying assumptions.
- Targeted literature searches on bacterial contamination, enzymatic activity, spoilage organisms, and antimicrobial resistance (no Norwegian-specific studies found for most topics).
- Analysis of consumer behaviour data from the EU-funded SafeConsume survey, including 954 Norwegian respondents.
- Predictive microbiology: growth/no-growth modeling (gamma-based) combined with known cardinal values for key microbes to assess likelihood of growth at $\leq 12^{\circ}\text{C}$ and at albumen pH values typical for eggs during storage (7.6 increasing to 8.9–9.4).
- Evaluation of Norwegian Table Egg Production Chain (TEPC) using legal documents, expert input, and surveillance data.

Special attention was given to:

- Stability of egg barriers (cuticle, shell membrane, vitelline membrane) over time.
- Conditions enabling horizontal contamination (defined as contamination from shell to egg interior).
- Differences in risk profile for *Salmonella*, *Campylobacter*, *Listeria monocytogenes*, *Bacillus cereus*, and *Staphylococcus aureus*.

Conclusions

1. Relevance of EFSA assumptions for Norway

- The biological structure and ageing processes of eggs are the same.
- EFSA's central assumption — significant *Salmonella* Enteritidis prevalence and vertical transmission — is *not valid* for Norway. Surveillance shows extremely low prevalence; vertical contamination can be ruled out.
- Other EFSA assumptions (barrier degradation, impact of temperature, spoilage organisms) *are valid*.

2. Food-safety significance of enzymes, pathogens, spoilage bacteria, AMR, and behaviour

- Enzymatic activity (lysozyme, pH rise, albumen viscosity changes) mirrors EU eggs; no Norway-specific differences found.
- Spoilage bacteria (e.g., *Pseudomonas*, *Bacillus*, *Acinetobacter*) behave similarly in Norway; spoilage typically begins only after ~28 days unless eggshell integrity is compromised.
- Pathogens other than *Salmonella* occur rarely and are inhibited at $\leq 12^{\circ}\text{C}$ and high albumen pH; *Listeria* and cold-adapted *Bacillus* may survive but cannot grow due to antimicrobial proteins in albumen.
- Consumer behaviour: Norwegians store eggs longer than other Europeans but still report very low incidence of egg-associated illness.
- AMR: data remain limited; no Norway-specific evidence of AMR transmission via eggs.

3. Time until raw eggs pose a health risk at $\leq 12^{\circ}\text{C}$

- Raw, non-heat-treated eggs stored at $\leq 12^{\circ}\text{C}$ do not pose a health risk before day 35 which is consistent with Norway's existing shelf-life.
- Microbes that might enter the egg cannot grow due to
 - low temperature,
 - high albumen pH, and
 - strong antimicrobial enzyme activity.

Overall conclusion

Because *Salmonella* Enteritidis is not relevant and Norwegian temperature control significantly reduces microbial risk, the scientific basis for EFSA's 28-day limit does not apply to Norway. A 35-day shelf-life remains safe and justified, provided the cold chain is maintained.

Sammendrag på norsk

Bakgrunn

Mattilsynet ba om en vitenskapelig vurdering av hvorvidt forutsetningene bak EFSAs 2014-uttalelse om trygghet og holdbarhet av konsumegg gjelder under norske forhold, og om Norge kan begrunne en lengre holdbarhet enn EUs krav på 28 dager. EFSAs opprinnelige risikomodel er sterkt fokusert på *Salmonella* Enteritidis, med antakelse om betydelig vertikal smitte fra infiserte høner til eggeplommer — en smittevei som ikke er relevant under norske forhold på grunn av tilnærmet fravær av patogenet.

Mattilsynet ba derfor Vitenskapskomiteen for mat og miljø (VKM) om å vurdere:

1. Om EFSAs forutsetninger samsvarer med norsk produksjon.
2. Mattrygghetsmessig betydning av enzymer, mikrobiell vekst, AMR og forbrukeratferd under norske forhold.
3. Hvor lenge rå, ubehandlede egg lagret under norske forhold forblir helsemessig trygge.

Metoder

Vurderingen brukte en kvalitativ metodikk bestående av:

- Gjennomgang av EFSAs 2014-uttalelse og identifisering av underliggende forutsetninger.
- Systematisk litteratursøk om bakteriell kontaminering, enzymaktivitet, bedervelsesorganismer og antimikrobiell resistens (ingen norske studier funnet for de fleste temaer).
- Analyse av forbrukeratferd fra den EU-finansierte SafeConsume-undersøkelsen, inkludert 954 norske respondenter.
- Prediktiv mikrobiologi: vekst/ikke-vekst-modellering (gamma-basert) kombinert med kjente kardinalverdier for sentrale mikrober for å vurdere sannsynlighet for vekst ved $\leq 12^{\circ}\text{C}$ og ved albumen-pH typisk for egg under lagring (7,6 økende til 8,9–9,4).
- Vurdering av norsk produksjonskjede for konsumegg (TEPC) basert på regelverk, ekspertinnspill og overvåkingsdata.

Særlig oppmerksomhet ble gitt til:

- Stabilitet i eggets barrierer (kutikula, skallmembran, vitellinmembran) over tid.
- Betingelser som muliggjør horisontal kontaminering fra skall til eggeplomme.
- Forskjeller i risikoprofil for *Salmonella*, *Campylobacter*, *Listeria monocytogenes*, *Bacillus cereus* og *Staphylococcus aureus*.

Konklusjoner

1. Relevansen av EFSAs forutsetninger for Norge

- Eggets biologiske oppbygning og aldringsprosesser er de samme.
- EFSA's sentrale forutsetning — betydelig *Salmonella* Enteritidis-forekomst og vertikal smitte — er ikke gyldig for Norge. Overvåkning viser ekstremt lav forekomst; vertikal smitte kan utelukkes.
- Andre EFSA-forutsetninger (barrierenedbrytning, temperatureffekt, ødeleggelsesorganismer) er gyldige.

2. Mattrygghetsmessig betydning av enzymer, patogener, ødeleggelsesbakterier, AMR og adferd

- Enzymaktivitet (lysozym, pH-økning, viskositetsendringer i albumen) er lik den som ses i EU; ingen norske særtrekk funnet.
- Bedervelsesbakterier (f.eks. *Pseudomonas*, *Bacillus*, *Acinetobacter*) oppfører seg likt i Norge; bedervelse starter vanligvis først etter ~28 dager med mindre skallet er skadet.
- Patogener andre enn *Salmonella* forekommer sjelden og hemmes ved $\leq 12^{\circ}\text{C}$ og høy albumen-pH; *Listeria* og kuldetilpasset *Bacillus* kan overleve, men kan ikke vokse på grunn av albumens antimikrobielle proteiner.
- Forbrukeratferd: Nordmenn lagrer egg lenger enn andre europeere, men rapporterer fortsatt svært lav forekomst av egg relaterte sykdomstilfeller.
- AMR: datagrunnlaget er begrenset; ingen norske funn av AMR-overføring via egg.

3. Tid før rå egg utgjør en helserisiko ved $\leq 12^{\circ}\text{C}$

- Rå, ubehandlede egg lagret ved $\leq 12^{\circ}\text{C}$ utgjør ingen helserisiko før dag 35, som er Norges eksisterende holdbarhetstid.
- Mikrober som eventuelt kommer inn i egget kan ikke vokse på grunn av
 - lav temperatur,
 - høy albumen-pH, og
 - sterk enzymatisk antimikrobiell aktivitet.

Overordnet konklusjon

Siden *Salmonella* Enteritidis ikke er relevant og norsk temperaturkontroll betydelig reduserer mikrobiell risiko, gjelder ikke det vitenskapelige grunnlaget for EFSA's 28-dagersgrense for Norge.

En holdbarhet på 35 dager er fortsatt trygg og faglig begrunnet, så lenge kjølekjeden opprettholdes.

Background as provided by the Norwegian Food Safety Authority

In 2022, the EU introduced an amendment to Regulation (EC) No. 853/2004 Annex III, stating that table eggs must be labelled with a best-before date no later than 28 days after laying. A similar provision had previously existed under Regulation (EC) No. 589/2008 which outlines marketing standards for eggs. However, the latter regulation is not part of the EEA Agreement. Thus, for EU Member States, there was no actual change in the requirements for labelling best-before dates—the requirement was merely transferred from one regulation to another.

For Norway, however, this change meant that the requirement now appeared in an EEA-relevant regulation, thereby becoming binding. As a result, Norwegian businesses faced a legal obligation to label table eggs with a best-before date no longer than 28 days after laying - that is shorter than the previous standard practice of 35 days.

The mentioned changes to the Animal Hygiene Regulation have not yet been incorporated into Norwegian law.

Norway has a *Salmonella* guarantee for table eggs. Annual control programs document an extremely low prevalence of *Salmonella* in laying hen flocks.

In connection with regulatory developments under the European Commission, Norway has argued that the shelf life for table eggs should be longer in countries with low *Salmonella* prevalence. In principle, Norway believes that producers should be allowed determine the shelf life of eggs themselves, consistent with practices for most other food products. We have also argued that our national requirement for cooling table eggs throughout the supply chain contributes to extending the shelf life of table eggs further. Norway has currently not succeeded in gaining acceptance for these viewpoints and the regulations governing egg shelf life are therefore the same across all EU/EEA countries. Norway is currently working with Iceland to obtain an adaptation text that reflects national conditions in this area.

The European Commission's main rationale for not allowing producers to assess the shelf life themselves is the risk of *Salmonella* Enteritidis in table eggs, as outlined in EFSA's assessment (EFSA Journal 2014;12(7):3782).

Terms of reference as provided by the Norwegian Food Safety Authority

The Norwegian Food Safety Authority seeks a knowledge synthesis and risk assessment related to table eggs and requests answers to the following questions:

1. To what extent are the assumptions underlying EFSA's 2014 assessment of table eggs relevant to egg production in Norway?
2. What significance do factors such as enzymatic activity, the presence and potential growth of pathogenic agents and spoilage bacteria (time between laying and consumption, refrigeration and storage conditions), antibiotic resistance, and Norwegian consumer behaviour have for food safety?

3. How long will it take before non-heat-treated/raw eggs pose a health risk, provided the eggs are stored at a maximum of 12°C (regulatory requirement for businesses)?

The Norwegian Food Safety Authority will use the knowledge syntheses and risk assessment for a potential adaptation text/influence on new changes in the Animal Hygiene Regulations, by documenting that Norwegian conditions do not align with European conditions.

Introduction

This scientific assessment will address the relevance of the EFSA's Scientific Opinion on the public health risks of table eggs due to deterioration and growth of pathogenic microorganisms (EFSA Journal 2014;12(7):3782) in the Norwegian context. Specifically, it will examine the main rationale for prohibiting producers from determining the shelf life themselves, as well as the underlying assumptions and conclusions.

The following has been clarified with the requestor:

- ToR apply to table eggs from producers in Norway and sold in retail and directly from registered producers
- If the rationale, assumptions and conclusions in EFSA's Scientific Opinion on the public health risks associated with table eggs, due to deterioration and pathogen growth, are found irrelevant for Norway, then the shelf life of table eggs produced in Norway will instead be based on pathogens that are relevant under Norwegian conditions.
- Regarding ToR2 it is understood that spoilage bacteria are relevant only to food quality

Methodology and data

The overall approach for answering each AQ and SQ, as formulated in protocol for assessment¹, including uncertainty analysis (i.e., deriving from the use of a literature review, data from databases, expert judgement or primary data) collection was qualitative by using information obtained from hearing experts, data extracted from databases other than literature and from literature, and EFSA's Scientific Opinion. The exception is growth modelling that will be used to answer ToR3.

Data and information gathering

ToR1. The assumptions and prerequisites used in the EFSA's 2014 assessment were identified through a thorough review and summarised in a table.

ToR2. Data and information required to assess the significance of factors such as enzymatic activity, the presence and potential growth of pathogenic agents and spoilage bacteria (time between laying and consumption, refrigeration and storage conditions), antibiotic resistance, and Norwegian consumer behaviour was gathered through a literature search and from the SafeConsume survey. However, to avoid duplication of work, where the data and information presented in the EFSA assessment are deemed to be valid for both EU and Norwegian conditions in ToR1, they were accepted as valid for the Norwegian TEPC (Table Eggs Production Chain), and further gathering was not needed.

1

<https://vkm.no/download/18.4c8c352a1955de47fd550346/1741160053192/Protokoll%20konsumegg.pdf>

ToR3. To assess the time needed before non-heat-treated/raw eggs pose a health risk, provided the eggs are stored at a maximum of 12°C (regulatory requirement for businesses) we used the information gathered for ToR1 and ToR2.

Literature search and selection

Literature search

The project group had a meeting to identify the key words and combinations of those to be used in the literature search.

Literature search was divided by subject into strategy for:

Bacteria in eggs in Norway including pathogens and spoilage bacteria

Following was identified:

- Key words: Bacteria* OR Microbio* OR microflora AND egg AND hen OR layers AND Norway
- Inclusion criterion was that article is based on *Gallus gallus* eggs produced in Norway
- Exclusion criteria were method (development) articles, articles on hatching, egg products

PubMed search string was identified as relevant for finding studies on bacterial contamination of eggs in Norway:

((egg[tiab] or eggs[tiab]) AND (chick*[tiab] or hen[tiab] or hens[tiab] or turkey[tiab] or consum*[tiab] or food*[tiab] or table[tiab]) or "Eggs"[Mesh]) AND (Bacteri*[tiab] or Microb*[tiab] or Microflor*[tiab] or pathogen*[tiab] or microorg*[tiab] OR spoil*[tiab] OR rotte*[tiab])) AND norw*

The search in PubMed resulted in 51 articles, however title and abstract screening showed that none of those articles fulfilled the inclusion criterion and was therefore considered not relevant.

WoS (Web of Science) search string was identified as relevant for finding studies on bacterial contamination of eggs in Norway:

((egg* NEAR/5 (chicken* OR hen* OR poultry)) AND (bacteria* OR contamination OR pathogen*)) AND (Norway OR Norwegian OR Norge)

The search identified three articles; however, title and abstract screening showed that none of those articles fulfilled inclusion criterion and were therefore not considered relevant.

Enzymatic activity in eggs

Following was identified:

- Key words: Chemical AND spoilage AND Egg; and Viscosity OR pH change AND egg
- Inclusion criterion was that article is based on *Gallus gallus* eggs

- Exclusion criteria were method (development) articles, articles on hatching, egg products

PubMed search string was identified as relevant for the search:

((chemical[Title/Abstract]) AND (spoil*[Title/Abstract])) AND (egg*[Title/Abstract])

The search in PubMed resulted in 12 articles. However, title and abstract screening showed that five of these fulfilled the inclusion criterion but were excluded because they focused on egg products and were therefore not relevant.

WoS search string was identified as relevant for finding studies on enzymatic activity in eggs:

AB=(((egg* NEAR/5 (chicken* OR hen* OR poultry)) AND (chemical* OR spoilage OR viscosit* OR ph change)) AND (Norway OR Norwegian OR Norge))

The search identified no articles either in Core Collection or in all databases.

AMR in eggs in Norway

Following was identified:

- Key words: Antimicrobial AND egg AND Norway
- Inclusion criterion was that article is based on *Gallus gallus* eggs
- Exclusion criteria were method (development) articles, articles on hatching, egg products

PubMed search string was identified as relevant for the search:

((antimicrobial[Title/Abstract]) AND (eggs[Title/Abstract])) AND (Norway[Title/Abstract])

The search in PubMed resulted in one article. However, title and abstract screening showed that it did not meet the inclusion criterion and was therefore considered not relevant.

WoS search string was identified as relevant for finding studies on enzymatic activity in eggs:

AB=(((egg* NEAR/5 (chicken* OR hen* OR poultry)) AND (antimicrobial* OR resistance)) AND (Norway OR Norwegian OR Norge))

The search identified no articles in the Core Collection and two articles across all databases. However, title and abstract screening showed that none of these met the inclusion criteria and were therefore considered not relevant.

Contamination and growth assessment

Scenarios for microbial contamination from the eggshell surface into the egg albumen were assessed based on data on the stability of the membrane between eggshell and egg albumen. For microbes likely to be present in eggs produced in Norway, microbial growth was assessed using gamma-based models which apply cardinal values for minimum, optimum and maximum temperature, pH and water activity for growth.

Conditions below the minimum or above the maximum cardinal values predict no growth. Conditions between the minimal and maximal cardinal values indicate growth. The growth rate depends on how close the conditions are to the optimal cardinal value, whether the product supports proliferation, and whether there are antimicrobial components in the food matrix.

The purpose was to investigate whether the concentration of undesired microbes would increase in the egg under reasonably foreseeable conditions during storage conditions.

Assessment of validity of EFSA's 2014 assessment of table eggs for Norwegian conditions

Assumptions for EFSA's 2014 assessment of table eggs

Legal background for table egg production

Several relevant Regulations were identified in EFSA's report from 2014. Regulation (EC) No 589/2008 (EC, 2008) defined 'eggs' as eggs in shell - other than broken, incubated or cooked eggs — produced by hens of the species *Gallus gallus* and are considered suitable for direct human consumption or for the preparation of egg products. Only class A eggs are, however, regarded as table eggs, while class B eggs can only be sold to industry and must be marked accordingly. At that time the 'best-before date' for eggs marketed as class A was set at 28 days in Regulation (EC) No 589/2008, while a 'sell-by date' was established at 21 days from the laying. The Regulation also stated that eggs shall be graded, marked and packed within 10 days of laying and that *"eggs shall not be treated for preservation or chilled in premises or plants where the temperature is artificially maintained at less than 5 °C. However, eggs which have been kept at a temperature below 5 °C during transport for not more than 24 hours or on retail premises or in annexes thereto for not more than 72 hours shall not be considered as chilled"*. Furthermore, Regulation (EC) No 853/2004 (EC, 2004) states that eggs must be stored and transported until sale to the final consumer at a temperature, preferably constant, that is best suited to ensuring optimal conservation of their hygiene properties, unless the Competent Authority imposes national temperature requirements for egg storage facilities and for vehicles used to transport eggs between such facilities.

Table egg production chain

The structure of the egg production chain used in EFSA's report from 2014 is presented in **Figure 1**.

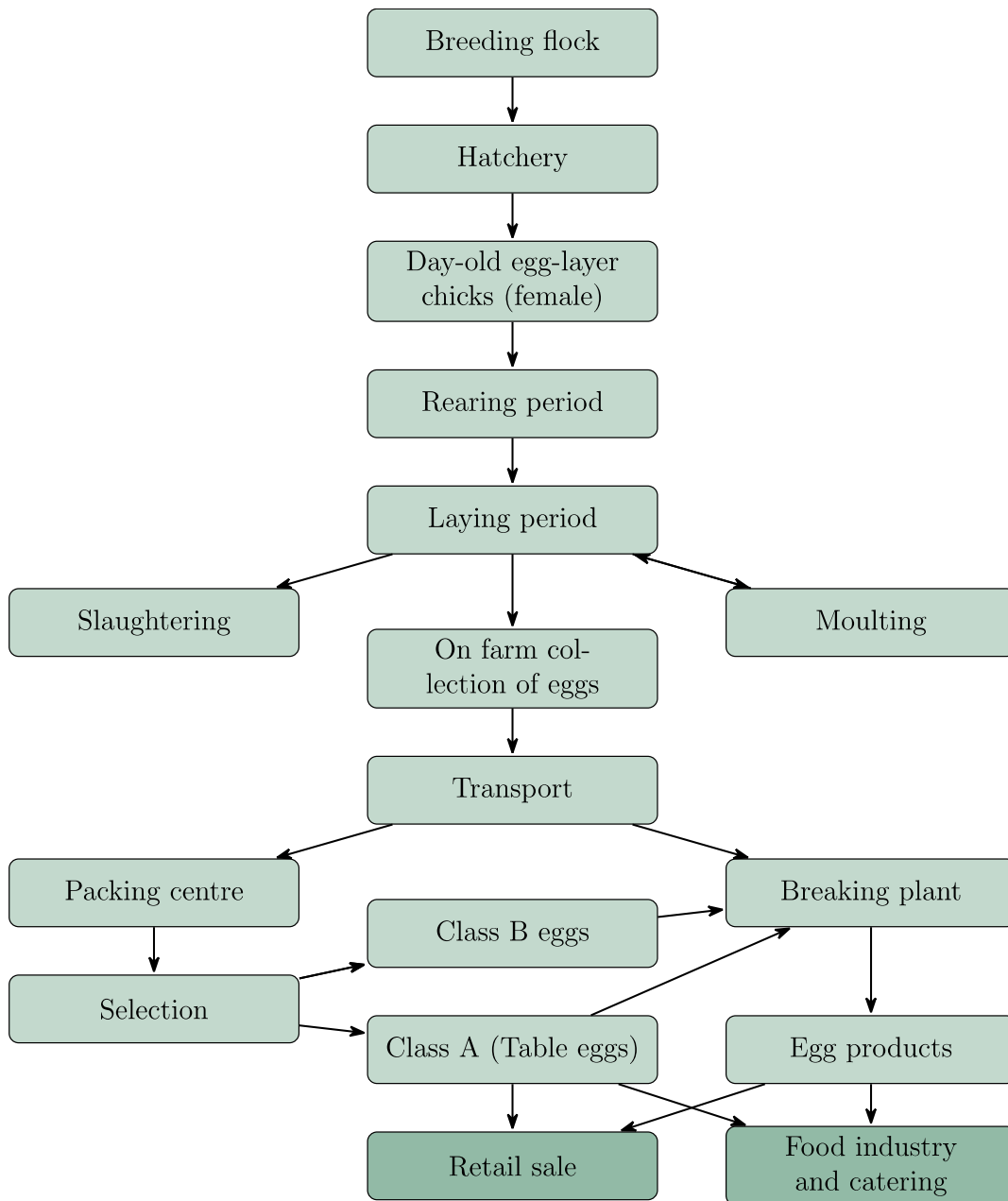


Figure 1. The structure of egg production in EU as defined in EFSA's report (EFSA 2014).

The structure of the egg production chain is described in Chapter 2.2 of EFSA's report (see Appendix I, **2.2 Structure of production**) and the legal framework described in this chapter defines the temperature conditions of the food chain with the possibility for the national requirements. Washed table eggs may only be put on the market in the MSs in which such practice is authorised.

Pathogens

Public health relevance of microorganisms transmissible through eggs was in EFSA's report assessed based on data gathered on food-borne outbreaks reported in zoonoses report which has been mandatory since 2005 (EFSA 2014). The relevance of *Salmonella* was assessed based on confirmed cases of human salmonellosis that were reported from the 27 EU MSs through the European Surveillance System (TESSy) in 2012.

Main egg-associated pathogens

Salmonella spp. (*S. Enteritidis*, *S. Infantis*, *S. Virchow* and *S. Typhimurium*) was responsible for 85% of human outbreaks associated with egg and egg products in the EU (2012) with *S. Enteritidis* responsible for >65%. A total of 5.4 million human salmonellosis cases were registered in the EU in 2010, of which 17% were attributed to laying hens and 57% to broiler reservoirs (+2.6% and 11% of cases attributed to turkey and pig, respectively) (See annex I).

Salmonella Typhimurium is in EFSA's report associated with duck eggs.

Epidemiological aspects of *Salmonella* in laying hens are extensively described in EFSA's report and cover patho-biology of different strains in layers and the dynamics of infection within laying hen flocks.

Other egg-associated pathogens

Two human disease outbreaks caused by *Bacillus cereus* toxins in eggs and eggshells were reported in 2011. Although the bacterium often causes mild and rapidly resolving clinical symptoms, it has also been associated with severe, and even fatal, illness. The EFSA report identifies several instances of food-borne illness in different countries caused by *B. cereus*, even though the contamination of eggshells was shown to be of a low frequency and influenced by the hygiene practices on the farms. *B. cereus* can also cause spoilage of egg products due to production of spoilage enzymes (lipases, proteases and phospholipases) even at low temperatures.

Staphylococcus aureus, a food poisoning bacterium producing enterotoxins, has been implicated in disease outbreaks associated with eggs. According to the EFSA (2014) report, it has been isolated from shells, yolk and albumen. Contamination of egg contents could result from the penetration of the shell by bacteria deposited on the shell surface during passage through the cloaca or after the egg has been laid.

Potential pathogens present but eggs not reported as being a cause of outbreak

Listeria monocytogenes has not been found on eggshells but has been identified in caged hen flocks in France. Thus, the bacterium may contaminate eggshells and be transferred to egg products. Consequently, in the EFSA's report, it was assessed primarily in relation to egg products rather than table eggs.

Campylobacter spp. is very common in laying hen farms but most frequently associated with poultry meat. While primarily found in caecum contents, these bacteria can also colonize other organs (ovarian follicles, reproductive tract, liver-gallbladder). However, there is no evidence of vertical transmission, and contamination of eggshells is considered to be very rare (EFSA, 2014).

Escherichia coli has not been associated with any reported outbreaks linked to eggshells or egg contents. However, the EFSA report finds a possibility that *E. coli* O157:H7 may be capable of penetrating the shell under high contamination levels, even at a storage temperature of 10 °C.

Cloxiella burnettii was detected in eggs but there is no evidence of Q fever outbreaks due to egg consumption.

Potential zoonotic pathogens not detected in eggs

Chlamydia psittaci is a zoonotic agent. The EFSA's report identifies one relevant study, in which the bacterium was not detected on eggshells and membranes.

Arcobacter spp. is a potential zoonotic agent but EFSA's report states that there is no evidence for transfer to eggs.

Spoilage bacteria

The EFSA report lists numerous bacterial genera that may be involved in different types of egg spoilage: *Achromobacter*, *Acinetobacter*, *Aeromonas*, *Alcaligenes*, *Bacillus*, *Citrobacter*, *Cytophaga*, *Enterobacter*, *Escherichia*, *Flavobacterium*, *Moraxella*, *Proteus*, *Pseudomonas*, *Stenotrophomonas*. The fungal genera *Alternaria*, *Mucor* and *Penicillium* are also reported to occasionally spoil eggs. The initial quantity and type of spoilage bacteria present on the eggshell can affect the rate at which bacteria penetrate the shell, invade the egg, and cause spoilage. Egg spoilage is primarily characterized by noticeable changes in odour, colour, or viscosity, making the egg unsuitable for consumption.

The effect of the barriers on microbial activity

The EFSA report highlights the cuticle, shell, shell membranes, albumen and vitelline membrane barriers of the egg as the primary defence against microbial contamination from the surface, and as the most important factors limiting the growth of microbes already present in the egg, both generally and within specific compartments. The membranes inside the eggshell can be trusted as a barrier for transfer of microbes from the shell until day 28 (EFSA 2014). After this time, microbes present in the shell, particularly those capable of growing there, may penetrate the egg and contribute to spoilage. Spoilage caused by microbes already present inside the egg can start from day zero depending on temperature, while spoilage microbes present on the shell will contribute later, once the integrity of the shell barrier declines.

The effect of temperature and storage on microbial activity

According to the EFSA report, high storage temperatures and extended storage periods negatively impact the quality of eggs and accelerate the development of visible changes, especially if the eggs are contaminated with spoilage bacteria. The impact of storage temperature on bacteria on the shell surface varies depending on several factors. Higher temperatures and prolonged storage times weaken the egg's natural defence mechanisms, increasing the risk that spoilage bacteria will multiply within the egg contents. Therefore, storing eggs at chilled conditions helps preserve their physicochemical and microbiological quality. The likelihood of egg spoilage is heavily influenced by the hygienic conditions during egg production and handling practices, including storage time and temperature.

AMR

Two pathogens were identified as having potential for transmission of AMR (antimicrobial resistance) through eggs and egg products; extended-spectrum beta-lactamase-producing *E. coli* (ESBLEC) and antibiotic-resistant *Staphylococcus* strains. However, the report cites only one study on ESBLEC, which found very low contamination levels (less than 1 log₁₀ CFU/mL) on the shells of eggs purchased from supermarkets and grocery stores in Spain. No ESBLEC was found after 24- and 48-hours of incubation on eggshells.

Enzymatic activity

Egg white, or albumen, plays a vital role in protecting the egg from harmful microbes. According to EFSA's 2014 assessment of table eggs, this protective effect is due to a natural mix of antimicrobial substances in the egg white that work together to prevent bacterial growth and spoilage. One of the key players is the enzyme lysozyme, which attacks bacteria by breaking down their cell walls by hydrolysing glycosidic bonds in the peptidoglycan.

As the egg ages, the pH of the albumen rises, from about 7.6 to 8.9-9.4 after several days of storage at ambient temperature, to alkaline conditions that further limit bacterial growth, but also leading to thinning of the egg white. The rate of pH increase is positively correlated with temperature. After two weeks of storage at 32 °C, the egg albumen pH is around 0.4 units higher than at 15 °C. This process is believed to result from structural changes in the glycoprotein ovomucin and its interaction with lysozyme (Mertens et al., 2010; Sauveur, 1988). The same difference was highlighted for storage at 5 °C vs. 22 °C, regardless of the duration of incubation (14, 24 and 42 days) (Aygun and Sert, 2013). As the albumen liquefies, it loses its ability to anchor the yolk firmly in place, allowing the yolk to gradually drift toward the egg's blunt end.

As described earlier, the integrity of the shell is critical: cracks facilitate bacterial penetration and accelerate spoilage. Once bacteria penetrate the shell, they can overcome the albumen's antimicrobial defences and begin metabolizing its nitrogen and carbon sources. Hydrolytic enzymes, such as proteases and lipases, break down proteins and fats, generating metabolites that produce off-odours, discoloration, liquefaction and structural collapse of the egg contents. Certain spoilage bacteria, such as pigment-producing *Pseudomonas* spp., release chromogenic and hydrolytic enzymes that accelerate decomposition and lead to characteristic rot, including green, black or blue discoloration.

The natural antimicrobial system of the albumen, including lysozyme, provides effective protection against microbial growth during the early stages of storage. Over time, however, the temperature dependent rise in albumen pH and the structural weakening of proteins reduce this protective effect, making the egg contents more susceptible to microbial growth and spoilage.

The speed at which these changes occur depends strongly on storage temperature. At higher storage temperatures, egg quality declines more rapidly, with faster liquefaction of the albumen and weakening of internal structures. Temperature also determines the rate at which bacteria multiply, influences the effectiveness of the albumen's natural antimicrobial enzymes, and accelerates internal quality deterioration, leaving the egg contents more vulnerable to enzymatic spoilage. In contrast, refrigeration slows down these processes and helps maintain the quality for a longer time.

Although higher temperatures accelerate deterioration and increase susceptibility to enzymatic spoilage, the egg white itself is naturally equipped with a range of protease inhibitors that block microbial enzymes. These inhibitors help slow down spoilage and preserve the internal integrity of the egg.

To our knowledge there is no evidence to suggest that the enzymatic activity in eggs produced in Norway differs from that in eggs produced in the EU. However, unlike in many EU countries, eggs in Norway are kept chilled throughout storage and distribution, which further helps preserve their quality.

Conclusions of EFSA's 2014 assessment of table eggs

Conclusions of the report are given according to the answers to the ToRs. (term of reference)

EFSA ToR 1 - Public health risk posed by relevant pathogens and in particular by *Salmonella* in the consumption and handling of table eggs

To address the first ToR, the BIOHAZ Panel used a quantitative model to describe the behavior of *S. Enteritidis* following vertical transmission. This serovar is the primary pathogen associated with egg-borne diseases due to its ability to contaminate the interior of intact eggs during their formation in an infected hen.

The impact of extending the shelf-life of eggs on other *Salmonella* serovars and pathogens was evaluated qualitatively. No serovar other than *S. Enteritidis* was deemed to pose a significant risk of egg-borne salmonellosis in the EU, although *S. Typhimurium* has caused small outbreaks linked to duck eggs. The effect of extended shelf life on trans-shell contamination (secondary contamination) was considered minor under modern hygienic egg production conditions. The role of external shell contamination in public health risk remains uncertain due to insufficient data.

The model results indicated that extending the storage time for table eggs increases the number of illnesses per million servings, except when eggs are well-cooked (Table 1). The increase in risk depends on the additional storage time at both retail and household levels. Refrigeration at both stages can effectively minimize this risk.

Table 1. Relative risk for public health of uncooked and lightly cooked eggs at different sell-by and best-before dates (EFSA 2014).

Scenario	Relative Risk (Uncooked)	Relative Risk (Lightly Cooked)
Baseline (21 days)	1.0	1.0
Sell-by date extended to 28 days	1.4	1.5
Best-before date extended to 35 days	1.6	1.7
Worst case (Sell-by: 42 days, Best-before: 70 days)	2.9	3.5*

* The observed higher relative risk for lightly cooked egg meals as compared to uncooked egg meals, is considered to be a result of a less efficient log reduction because of the higher content of *S. Enteritidis* in the eggs before lightly cooking them. In other words, the change in dose between lightly cooked and uncooked egg meals differs, resulting in a higher relative risk for lightly cooked eggs. The absolute risk is obviously still higher for uncooked egg meals (EFSA 2014).

The absolute risk, however, was higher for uncooked meals compared to lightly cooked meals.

Refrigeration at retail, with temperatures ranging from 0 to 12 °C, helps limit the increase in risk. Extending the sell-by date by up to three weeks and the best-before date by one or two weeks (for sell-by dates of 35 and 28 days, respectively) reduced the risk if refrigeration is consistently applied. However, if these dates are extended beyond three weeks, the risk increased, even with refrigeration, assuming consumer refrigeration practices remained unchanged.

EFSA ToR 2 - Public health risk deriving from deterioration

To address ToR 2, a review of the organisms involved in the spoilage of table eggs was conducted. During storage, gaseous exchange between the egg content and the atmosphere, as well as exchanges of water and minerals between the egg albumen and egg yolk, lead to decreased egg albumen defence mechanisms and weakening of the vitelline membrane. This increases the risk of bacterial invasion of the egg's internal compartments.

High storage temperatures and/or long storage periods have a clear negative effect on internal egg quality and the development of macroscopic changes, especially if eggs are contaminated by spoilage bacteria. The effect of storage temperature on surface bacteria levels varies based on conditions. Temperature, time, and humidity are crucial parameters that affect egg quality during storage, increasing the risk of trans-shell microbial invasion.

Chilled storage temperatures help maintain the overall physicochemical and microbiological quality of eggs. Egg-spoilage events depend heavily on the hygienic conditions of egg production and handling practices, including storage times and temperatures. Spoilage is mainly characterized by macroscopic changes in odour, colour, or viscosity, which would prevent the egg from being used.

EFSA ToR 3 - Possible consequences for public health of an extended shelf-life of table eggs for the specific freshness criteria for egg products as laid out in the hygiene package.

Answers to the ToR 3 are not relevant as egg products are outside the scope of this assessment.

Conditions for Norwegian table egg production

Legal background

Norway has strict regulations to prevent the introduction and spread of certain infections in animals and humans. Food industry employees and healthcare personnel are not permitted to work with food while experiencing symptoms of infections that can be transmitted through food. After clinical improvement and before returning to work, they should provide two consecutive negative faecal samples for certain pathogens, particularly *Salmonella* spp. (other than *S. Typhi* and *S. Paratyphi*) (NVI et al., 2024.). According to the Food Law (LOVDATA, 2024), FBOs are responsible for implementing measures to prevent the occurrence or spread of contagious disease in animals, and to notify the NFSA (Norwegian Food Safety Authority) about any suspicion of contagious disease in animals that has potential to cause significant negative consequences for society. Notifiable diseases include *Salmonella* which must be reported in both humans and animals and is monitored through a surveillance programme covering feed, animals and food (LOVDATA, 1995.). All layer flocks are sampled twice during the rearing period and every 15 weeks during the egg laying period using 2 pairs of boot swabs analysed as

one pooled sample. Cage birds are sampled using faecal samples (2x150 g) (NVI et al., 2024.). If *Salmonella* is detected in animals in Norway, restrictions are imposed on the infected animal or animal holding, and measures are implemented to eradicate the infective agent (LOVDATA, 1995.). The Feedstuffs Regulation is a Norwegian national regulation governing the production, import, sale, labelling, use, and safety of feed for animals, including livestock (LOVDATA, 2002). The regulation contains limits and monitoring requirements for pathogenic microorganisms and requires absence of *Salmonella* in feedstuffs.

Table-egg production chain

The information on TEPC in Norway was gathered from a hearing expert and legal requirements and guidance documents (DEBIO, 2025; LMD, 2006; NFSA, 2025).

The structure of egg production used in EFSA's report, and presented in **Figure 1** and described in **2.2 Structure of production**, is relevant also for Norwegian conditions with two exceptions:

- Moulting is not considered good practice in Norway and is not used
- The egg product part of that flow-chart is outside of the scope of this assessment.

Only holdings with 200 or more animals need to be registered and are monitored by NFSA. Smaller holdings and backyard flocks are not monitored, so the data for temperature control, as well as the prevalence of pathogens and spoilage bacteria, are not available. Thus, the results of the shelf-life assessment for table eggs in this report might not be applicable to them.

There are three different types of egg production systems in registered holdings in Norway, 4.5% are held in environmental cages (enriched cage), 88% as free range (indoor) and 7% defined as organic (free range with access to outdoor roaming) (Animalia, 2024). The proportion of free range is increasing (Matprat, 2024). The number of layers in organic production increased from 2011 but has since declined. In 2023 there were 286,600 layers registered in organic farming, producing 4,500 tons eggs or just under 7% of the total egg production delivered to packaging (SSB, 2024).

There are 580 registered egg producing farms in Norway with approximately 4,3 million layers producing 68 million kilograms egg or approximately 200 eggs per capita (SSB, 2018).

Organic egg production

Free movement and housing

Hens must be kept free-range and not in cages. In multi-tier systems, there can be a maximum of three levels, including the floor. Nests with a perch in front are not considered a separate level. There should be a system for manure collection, such as a manure belt. The poultry house must have perches or platforms that meet specific requirements for quantity and size.

Light and flooring

The house should have access to natural light. At least one-third of the floor area should be solid and covered with bedding, such as straw, wood chips, sand, peat, or other material.

Outdoor areas

Hens should have access to outdoor areas when the weather permits, ideally for at least one-third of their lives. A minimum of 4 m² of outdoor area per hen is required. Exit openings to the veranda or outdoor area should be at least 2 meters wide per 100 m² of indoor usable area. In adverse weather conditions, the exit openings can be closed, but some should remain open to ensure animal welfare and indoor climate. Outdoor areas should be mainly covered with vegetation, provide shelter, and have easy access to food and water. Different flocks should be kept separate in the outdoor areas.

Feed and feeding

The farm should be as self-sufficient as possible with organic feed, with at least 30% coming from the farm or region. The hens should be fed organic concentrate feed and roughage such as hay or root vegetables.

Conventional egg production

Conventional production takes place in closed houses without the requirement for outdoor access. There are no specific requirements for housing systems or feed types, including the use of roughage.

Table 2. Comparison between organic and conventional egg production in Norway.

	Conventional	Organic
Max number of layers in the flock	7500	3000 per department (6000 in total)
Density	9 layers per m ² (850 cm ² per layer in enriched cages)	6 layers per m ²
Nest density	No specific requirements	One per 7 layers min
Free Movement	Free-range (indoors), enriched cage	Free-range, no cages
Outdoor Area	Not required	Min. 4 m ² per hen, weather permitting
Housing	No specific requirements	Perches (min 18 cm per layer), natural light, bedding
Feed	No requirements for type or origin	Min. 30% local organic feed, roughage

Pathogens

The Zoonoses Report covering the prevalence of pathogens in, among other foodstuffs, table eggs, is published annually in Norway in accordance with the requirements of the EU Council Directive 2003/99/EC. The NVI (Norwegian Veterinary Institute) is responsible for collecting and reporting of data.

The data presented in Zoonoses Report are obtained through national surveillance programmes, projects, diagnostic investigations and various inspections performed by public authorities and private companies (NVI et al., 2024.). Following data are collected:

- data on detected notifiable diseases and data from public surveillance are reported with the NFSA deciding which infectious agents are notifiable and which surveillance programmes should be carried out
- data from diagnostic investigations and data from internal control systems of food-, and feed producing companies are also included in the Zoonoses Report. Data from internal control of companies are not always available, with the exception of *Salmonella* control in feed-producing companies, where data from most of the internal controls are made available and is presented.

The surveillance programme for *Salmonella* covering eggs includes testing of live poultry. All breeder flocks and commercial production flocks are included in the surveillance programme. All breeder flocks are certified, and the sampling is done from day-old chicks, four weeks, and two weeks before they are moved. All layer flocks are sampled twice during the rearing period and every 15 weeks during the egg-laying period. The results of the surveillance program for the period 2015-2024 are summarized in Table 3.

Table 3. Surveillance programme results for *Salmonella* in layer flocks for the period 2015-2024.

Year	Layer flocks sampled	Positive flocks
2024	1201	0
2023	863	2 ⁴
2022	887	0
2021	910	1 ¹
2020	882	0
2019	874	0
2018	847	2 ²
2017	814	1 ²
2016	845	1 ³
2015	995	0

¹ *S. diarizonae* 61:k:1,5,7; ² *S. diarizonae*; ³ *S. Typhimurium*; ⁴ *S. ent. subsp. diarizonae* serovar 61:k:1,5,7

NIPH (National Institute of Public Health) is responsible for collecting and reporting of the outbreak data in Norway that has been reported to Vesuv (Vevbasert system for utbruddsvarsling). The overview of outbreaks caused, or suspected caused, by eggs or egg products in Norway in the period 2011-2021 are summarised in Table 4. Due to reporting requirements, it is not possible to differentiate outbreaks caused by eggs from outbreaks caused by egg products.

Table 4. The number of human salmonellosis outbreaks caused, or suspected caused, by consumption of eggs or egg products in Norway in the period 2011-2021.

Year	Outbreaks	Cases
2011-2015	1	22
2015-2018	1	2
2018-2021	1	2

However, no surveillance programmes are in place for other potential egg-associated pathogens, like *Bacillus cereus*, *Staphylococcus aureus*, *Campylobacter* spp. and *Listeria monocytogenes*.

Enzymatic activity

The literature search did not retrieve any results to point to enzymatic activity specific throughout Norwegian TEPC. In addition, the food chain and the structure of the production in the EU and Norway are similar. Therefore, the findings in EFSA's report are being accepted as relevant for Norwegian conditions too.

Spoilage bacteria

The literature search did not retrieve any results that indicate spoilage bacteria specific to Norwegian conditions. In general, the bacteria stated in the EFSA report as being associated with spoilage are those bacteria commonly found in many types of environments, and it is unlikely that their presence in Norwegian environments differs significantly from the rest of Europe. The production chain and the structure of production in the EU and Norway are also similar. There may however be a difference in concentration of the microbes. Those that are adapted to cold conditions may be found in higher concentrations in Norway than in warmer countries, particularly if the storage temperatures for eggs are higher in countries with a warmer climate than in Norway. Therefore, the findings in EFSA's report listing *Achromobacter*, *Acinetobacter*, *Aeromonas*, *Alcaligenes*, *Bacillus*, *Citrobacter*, *Cytophaga*, *Enterobacter*, *Escherichia*, *Flavobacterium*, *Moraxella*, *Proteus*, *Pseudomonas*, *Stenotrophomonas* are being considered as relevant for Norwegian conditions too.

AMR

The International Egg Commission (IEC) recognizes that AMR is an issue of global concern for animals and humans, and states in a position paper from 2018 that they "will encourage the egg layer industry to reduce the use of antimicrobials, especially those for which resistance could pose the greatest animal and human health global risk"². However, the literature search did not retrieve any results regarding AMR specific to Norwegian TEPC.

² <https://www.thepoultrysite.com/news/2018/09/global-egg-industry-adopts-formal-position-on-antimicrobial-resistance-amr>)

Consumer behaviour

There are only a few sources on Norwegian consumers' behaviour regarding the handling of eggs. An online food safety survey was conducted between December 2018 and April 2019 with participants from 10 European countries: Denmark, France, Germany, Greece, Hungary, Norway, Portugal, Romania, Spain, and the UK (Langsrud et al., 2023). The survey included modules on hygiene and food handling practices for various food categories. One section was related to eggs, and a total of 9,390 participants reported eating eggs regularly at home, including 954 from Norway.

Previously published results

A number of descriptive statistics were published earlier by Cardoso et al., 2021. The authors report percentages of respondents giving a certain answer. Their reported numbers thus ignore (i) survey weights for individual respondents (and their households) and (ii) the fact that not all survey participants were asked all questions. Hence, the previously published results are not representative of respective populations, but rather only of individual question respondents. We address these weaknesses in our analysis, as discussed in the following subsection.

When respondents were asked "Where do you typically get the whole, raw eggs you eat at home?", 87.4% Norwegian respondents reported obtaining their eggs from stores, 18.1%—from farms/home production, and 4.3%—from markets (e.g., farmers markets, Cardoso et al., 2021). Norway was the country with the highest proportion of respondents buying eggs from stores, the lowest were Hungary (61.5%) and Spain (64.6%). For several countries, the proportion of respondents buying eggs from farms/own production or markets was much higher than in Norway. In Romania, 55.4% of respondents obtained eggs from farms/home production and 40.5% of respondents in Hungary obtained eggs from markets.

62.2% of Norwegian respondents reported that they did not clean eggs (Cardoso et al., 2021). Norway was the country with the lowest reported rate of cleaning of eggs. Only 8.4% of Norwegian respondents reported cleaning eggs every time they were used, the corresponding numbers were higher for all the other nine countries, with Hungary (45.2%) and Romania (36.2%) having the highest scores.

Regarding storage time of eggs, only 19.7% of Norwegian respondents reported eating the eggs within the best-before-date. Of the 10 countries, Norway had the lowest proportion of respondents eating eggs within the best before date, with Portugal (43.5%) and the UK (38.5%) having the highest proportion. At the same time, Norway had the highest proportion of respondents that reported eating the eggs within 2-3 weeks (16.1%), and after more than 3 weeks (15.8%) after obtaining the eggs. In Greece, Portugal, Romania and Spain only 1-2% reported eating eggs more than 3 weeks after obtaining them (Cardoso et al., 2021).

In a survey about food safety myths, with a total of 3,110 respondents from Norway, Germany, and the UK, 32%, 43%, and 42%, respectively, agreed with the statement "Eggs should not be washed as the bacteria on the outside will then get more easily inside the porous shell" (Veflen and Teixeira, 2022). 24%, 32%, and 32% of the respondents in Norway, Germany, and the UK, respectively, agreed with the statement "Eggs should be washed before storage". Only 17% of Norwegian respondents agreed with the statement "Eggs stored in the refrigerator are less safe than eggs stored at room temperature". The corresponding numbers for Germany and the UK were 15% and 28%, respectively (Veflen and Teixeira, 2022).

Our analysis of survey data

It is important to understand actual consumer behavior to assess overall risks of exposure to something harmful while handling and/or consuming eggs. In order to understand consumer behavior, that might impact food safety of eggs, for both Norwegian consumers and other Europeans, we have analyzed survey data related to handling and consumption of eggs as well as a number of questions covering general food-handling behaviors. The data come from the research project SafeConsume, supported by the Horizon 2020 program of the European Union.

We performed two types of analysis, graphical representation of responses to individual egg-relevant questions and regression analysis covering egg consumption, storage, and bad-stomach-bug event outcomes. For full details of analysis, see Online Appendix, Egg Consumption Graphs and Tables. Here, we present a brief summary of the findings.

We documented distributions of responses to egg-relevant survey questions. Uncertainty in response values is captured by bootstrapping survey responses (for technical details, see Section Technical Details on Bootstrapping Procedure of the Online Appendix), while using respondent household weights (estimated by survey organizers). In addition, we have taken into account that not all respondents were asked all questions. This way, we captured population-based distributions for each survey question and each surveyed country, while reporting uncertainties in estimated response frequencies.

We found that Norwegian respondents are similar to other European respondents when it comes to egg-related food consumption habits, even when it comes to consumption of raw or lightly-cooked eggs (see Section Survey Response Distributions: Graphical Analysis of the Online Appendix). Norwegians do, however, differentiate themselves when it comes to certain food-related habits:

- Norwegian consumers have the highest incidence of buying eggs from a shop (81.7%) and the lowest incidence of buying eggs at a market (2%) or getting them from backyard hens (3%)
- Norwegian consumers clearly store eggs at home longest compared to their other European counterparts (only 18.9% are guided by the use-by date, while 12.8% eat eggs also after more than 3 weeks after purchase)
- Norwegians are least likely to wash hands with soap after touching raw eggs (19% Norwegians do it at least 4 out of 5 times, compared to Denmark with 38.1%) and least likely to clean eggs before using them (56.6% never clean, while 10.1% clean every time, compared to Hungary with 12.4% and 43.5%, respectively)

Regression analysis allows to identify patterns in food-related behaviors and health outcomes. The survey design does not allow to quantify exposure quantities, as portion sizes are not covered by the survey, but rather frequencies of various choices made. Complete regression results are presented in the Online Appendix, Section Regression Analysis of Consumer Behavior.

We first analyze how egg consumption patterns vary across countries as well as gender, age, and educational level of respondents. Respondents reporting more frequent egg consumption (both total and lightly-cooked/raw) are younger, male and with higher educational level. Interestingly, households with a pregnant member as well as those with member(s) with diabetes and/or immune impairment report higher egg consumption frequency, also for

lightly-cooked/raw eggs. Second, for egg-storage durations, older and female respondents report longer storage durations, and this evidence is stronger for Norway than for all countries. Educational level has no effect in pan-European regressions, but, for Norwegian respondents, higher education (a graduate degree) is associated with shorter storage durations. Households with pregnant members, members with diabetes and/or immune impairment report shorter storage durations, but this effect is statistically insignificant for Norwegian respondents. Finally, younger respondents, male respondents, larger households, and households with children younger than 6-years old report more stomach bug events, but this effect is only significant for the pan-European regression. Of these, only age has a significant association for Norwegian respondents. Households with pregnant/diabetic/immune impaired members report more bad stomach events, but these have insignificant effects for Norwegian respondents. European respondents that assign responsibility for safeguarding the health to self rather than to shops or markets, report fewer stomach bug events, but not Norwegian respondents for whom the effect is insignificant.

Cumulative frequency of consuming dishes with lightly-cooked/raw eggs has a strongly significant positive association with the number of reported stomach bug events, for all respondents and for Norwegian respondents. It should be emphasized, however, that the significant association is not a proof of causation. Rather, it is likely that frequent lightly-cooked/raw egg consumption is an instrument that allows to identify respondents that are less cautious when making food-related choices. Interestingly, there appears to be no evidence that respondents that are less strict with egg storage durations experience more bad stomach events. In fact, respondents that report eating eggs within one day report also the highest incidence of bad stomach events (having controlled for all other independent variables). This is true for both the pan-European regression and for the regression for the Norwegian respondents.

The purely cross-sectional nature of the survey data does not allow us to make any conclusions about how consumers adjust their food-related behaviors in response to changing levels of risks of food-borne illnesses. However, the degree of similarity between countries with different levels of Salmonella incidence in eggs (as well as dissimilarities between countries with similar levels of Salmonella incidence) is suggestive of persistence in consumer behavior, where little may change in response to changing risks, such as, for example, in response to egg import from markets with higher levels of Salmonella incidence.

Summary and conclusions

Assessment of the TEPC conditions

The EFSA report's assessments of pathogens, spoilage bacteria and enzymatic activity in eggs are largely relevant to Norwegian conditions, as the production chain and legislation are comparable. Norway does, however, differ in several respects: moulting is not practiced, there are stricter requirements for temperature during storage and transport and there is a high proportion of free-range (mostly indoor) and organic production. Small-scale and unregistered producers are not covered by monitoring programs.

Risk related to pathogens

Salmonella Enteritidis is the main pathogen associated with egg-borne diseases in the EU and is also the most relevant for EFSA's shelf-life assessment. Norwegian surveillance data show

absence/low prevalence of *Salmonella* spp. in commercial flocks, making *Salmonella* Enteritidis less relevant when assessing the shelf-life of table eggs produced in Norway.

Surveillance data are, however, lacking for other relevant pathogens such as *Campylobacter* or *Listeria*.

In general, the risk of disease caused by pathogens increases with extended storage time, especially at higher temperatures, and when there is insufficient heat treatment at the consumer step. However, high albumen pH reduces bacterial growth in eggs.

Spoilage and enzymatic degradation

Spoilage bacteria such as *Pseudomonas*, *Bacillus*, and *Acinetobacter* are also relevant in Norway. Spoilage starts from day 0 for bacteria already inside the egg, and from day 28 for bacteria that penetrate a weakened shell barrier.

Enzymatic activity in the egg contributes to protection but weakens over time. No documentation has been found indicating that enzymatic activity in Norwegian eggs differs from that in EU eggs.

Temperature and storage

Temperature and storage time are critical factors for both food safety and quality. Cool storage (below 12 °C) reduces the risk of both pathogen growth and spoilage. Extended shelf-life may be justifiable if the cold chain is maintained throughout, including at the consumer's level.

Antimicrobial resistance (AMR)

There are no specific Norwegian data for AMR in the egg chain beyond what is reported in NORM-VET for poultry production, but ESBL-producing *E. coli* and resistant *Staphylococcus* spp. are mentioned as potential risks in EFSA's report.

Conditions in small-scale production

There is uncertainty related to hygiene conditions and temperature control among small producers and backyard holdings in Norway.

Conclusions

Conclusions are based on comparison of the assumptions in EFSA 2014 assessment of table egg shelf-life and assessment of comparable assumptions under Norwegian conditions. Relevance of assumptions taken in EFSA's report for Norwegian conditions is summarised in Table 5.

Table 5. Comparison of relevance of assumptions in EFSA's report and Norwegian conditions.

Assumptions for food safety	Included in EFSA's 2014 assessment	Relevance for Norwegian conditions
<i>Salmonella</i>	Y	N
Enzymatic activity	Y	Y
Spoilage bacteria	Y	Y
AMR	Y	?

Assessment of contamination and growth

MAESM (Modified Australian Eggs Storage Model) model used in the EFSA assessment is a quantitative risk assessment model adapted from the Australian Egg Corporation Limited model (Thomas et al., 2006) to fit EU conditions and estimates how storage time and temperature affect the growth of *S. Enteritidis* inside eggs from lay to consumption (EFSA 2014).

The TEPC described in Norway reflects the EU TEPC (Figure 1).

The egg characteristics, including the physiological changes in barriers between compartments as well as the conditions in the eggshell, albumen, and yolk are relevant for assessment of the behaviour of microbes in eggs in general.

The EFSA assessment focuses on *S. Enteritidis*, introduced vertically, i.e. when the microbe is transferred from the hen to the egg while in the oviduct. The microbe is then likely to be present in the egg yolk, where proliferation can start immediately after the microbe has entered the egg interior. This contamination route is not relevant for eggs produced in Norway, as transmission of *S. Enteritidis* to egg is very rare, and if it happens, a horizontal transmission route is more likely than vertical transmission. According to the EFSA assessment, the initial concentration of microbes is lower by horizontal transmission than by vertical transmission, and the microbe will need to pass membranes and overcome the antimicrobial activity in the albumen before it starts to grow.

Approach, assumptions and scenarios

Approach and assumptions

For our assessment, the following assumptions apply:

- Contamination of the egg comes from outside the egg after the eggshell is established, either inside the hen or after the egg is laid.
- Penetration of the membrane between the shell and albumen can happen in case of sudden disruptions of the membrane, degradation of the membrane, or reduced mechanical stabilisation of the membrane from the eggshell due to loss of turgor pressure because of water evaporation and volume reduction of the egg interior.
- The concentrations of microbes immediately after contamination are low as the survival rate of microbes in the eggshell is low.
- To have an impact on changes of the food safety of eggs during the shelf life, the microbes entering the egg from the shell must pass the barriers and be able to grow in the egg white or egg yolk.

Contamination

Contamination from the production environment into eggs will depend on whether the microbes are present in the production facilities, whether they are able to survive and/or grow

in the eggshell, and finally whether they can penetrate membranes. It is documented that Gram-negative bacteria more easily penetrate the membranes than Gram-positive bacteria, but we have not differentiated between bacteria in this assessment. The time until contamination is assessed based on these aspects:

- The stability of eggshell and membranes. As described below, the membranes are stable for a few weeks, but sudden movements or irregularities in the eggshell may tear them and cause weak points and even disruptions. The most critical phases for disruptions are when the egg is laid, in particular if the hen is sneezing, and during transport under bumpy conditions. The membrane between albumen and the egg yolk is more protected than the membrane between albumen and shell, as the viscous albumen serves as a buffer.
- The conditions at the farm, during the transport, and finally at the point of consumption of eggs. The egg surface is by nature contaminated by the same microbes as in the hen faeces, and also from the place where the eggs are laid. The more moisture and dirt, the more material will be on the egg surface, and the more likely microbes will be able to proliferate. According to the information from the trade and standards for egg production, the eggs are kept in dry areas, collected daily, and dirt is removed from the surface so proliferation of microbes during the first days after the egg is laid is limited. For eggs packed in boxes, contamination from the egg box or the consumer's refrigerator if taken out of the box will be limited.
- The survival and growth of microbes in the eggshell from contamination until the membrane is weakened. According to the EFSA assessment, the concentration of microbes on the eggshell is more likely to decrease than to increase during storage. A 2-log reduction has been observed for microbes like *Listeria* and *Bacillus*. Contamination of the egg interior during the first days of storage is therefore not likely as the membranes are stable the first days after the egg is laid. At later stages, when the membranes have been weakened, the microbes present from the beginning will be reduced in number.

The worst-case scenario for contamination from the eggshell is when hens are ill, the eggs have irregularities, are placed in dirty, moist areas for a long time before collection, and finally transported under bumpy conditions to the packaging house. However, packing houses will redirect or reject dirty eggs and eggs with irregularities in the shell to other purposes than table eggs.

Therefore, even though horizontal contamination cannot be ruled out, the concentration of microbes in the egg immediately after contamination will be low.

Stability of egg barriers and compartments

The egg structure and barriers described in the EFSA model (2014) is valid for Norwegian eggs. This implies that the barriers in the egg are:

1. Egg shell with cuticula,
2. The membrane between the eggshell and egg white, and
3. The membrane between egg white and egg yolk

A summary of the egg compartments, their conditions, and how they are separated is given in the Figure 2 below. The figure is based on the EFSA assessment and further developed by us.

Egg: a dynamic 5 compartment model

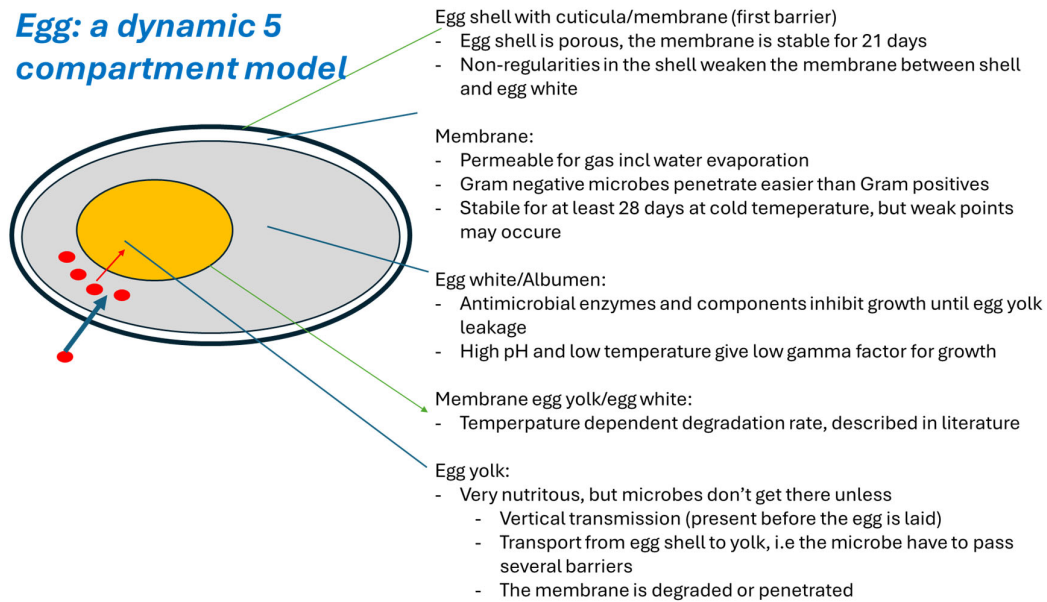


Figure 2. Egg, dynamic 5 compartment model

The egg is a 5 compartment, dynamic system, where the barriers are weakened over time, and where the conditions in the albumen and yolk also will change over time. This leads to four phases in the egg, as illustrated below in Figure 3.

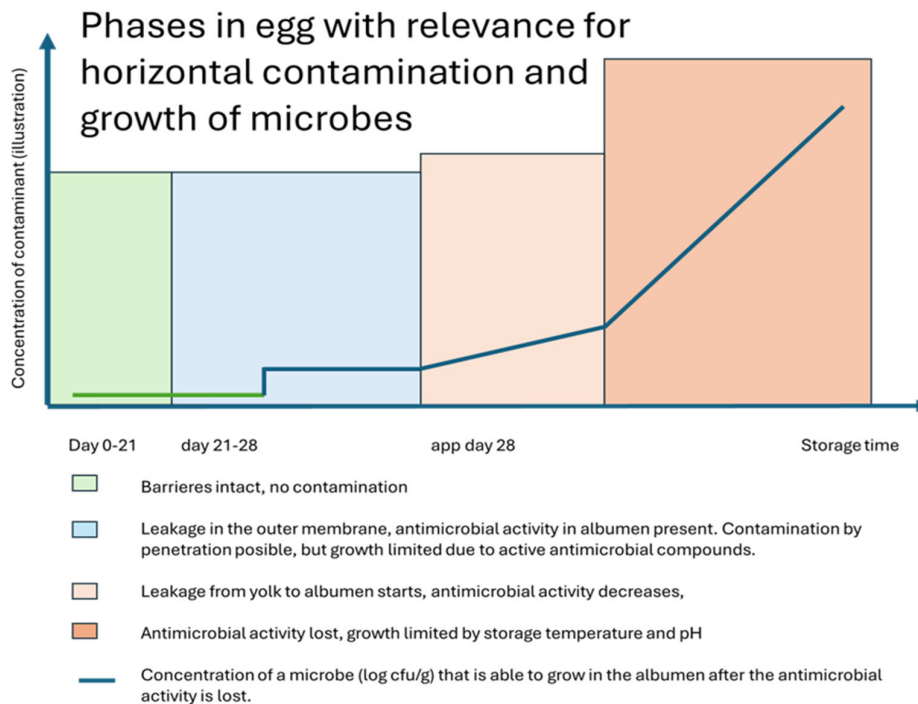


Figure 3. Phases in egg with relevance for horizontal contamination and growth of microbes.

The egg has an optimal design for formation of chicken, which means that protection against microbes and exchange of nutrition is stable until day 21 at nesting temperature. Afterwards, the egg degrades.

The first phase is when the eggshell and outer membrane are intact and penetration of microbes from the outside of the egg is not likely unless there is a damage to the egg membrane.

The second phase is when the membrane is weakened, and microbes may be able to enter the interior. In this phase, when the outer membrane is weakened, but as the membrane between yolk and albumen is still intact, microbial growth will be limited due to antimicrobial activity in the albumen. The proteins in the albumen start to degrade, which eventually leads to lower viscosity and an increased pH. This change in the albumen continues in the next phase.

The third phase is when the membrane between the egg yolk and albumen starts to leak nutritional compounds. At that stage, the antimicrobial activity in the albumen will be less effective. However, the pH in the albumen will have increased from approximately 7.6 to 8.9-9.4.

In the fourth phase, the antimicrobial effects are lost or at a minimum level.

The conditions for growth of microbes in the egg during storage

The growth of microbes depends on extrinsic, intrinsic, and implicit factors. Examples are storage temperature, pH and water activity in the egg compartment where the microbe is, and the antimicrobial enzymes and compounds.

A shift to higher storage temperature will favour growth of most microbes that can be expected to occur on eggs. In eggs, microbial growth is further influenced by storage-induced changes in egg white pH and water activity, for example due to evaporation of water through the eggshell, which can alter microbial competitiveness. Antimicrobial compounds may limit growth of some microbes but not others, for instance, lysozyme will inhibit growth of Gram-positives more than growth of Gram-negatives.

The conditions that regulate growth have been well investigated and implemented in predictive models for growth/no growth (growth boundary models) and for growth rate. The gamma concept models are the most applied models. These are based on theoretical minimum, optimum and maximum values of e.g. temperature for growth for specific microbes. The values are called cardinal values. These values are specific for each microbe and are stable in all systems. Conditions below the minimum or above the maximum cardinal values predict no growth. Conditions between the minimum and maximum cardinal values indicate growth. The growth rate depends on how close the conditions are to the optimal cardinal value. Predictions of growth rates at other temperatures than those used in experiments for documentation can be done as the temperature-relative growth rate is described mathematically as a continuous function, as shown below.

Gamma curves (Figure 4) for the different critical factors for growth can be combined: In a food product where the pH is between the minimum and maximum value for growth, but the temperature is below the minimum for growth, the predicted growth will be zero.

In the present assessment, the growth potential of microbes considered relevant for eggs produced in Norway is assessed qualitatively by comparing their pH and temperature range for growth with the conditions in the egg albumen.

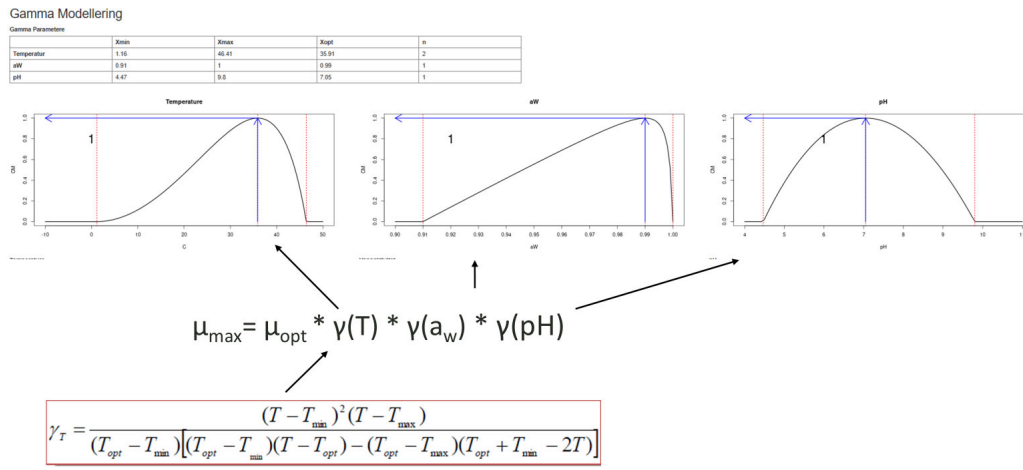


Figure 4. Gamma curves for the different critical factors for growth

In addition, the antimicrobial activity in the egg albumen is considered when assessing ability to limit growth of the relevant microbes.

To proliferate, the microbes entering the egg interior need to be able to grow in following conditions:

1. Temperature below 12 °C, as this is the established maximum storage temperature for eggs in Norway.
2. pH of 7.6 in the initial phase and within the range 8.9-9.4 in phase 2, 3 and 4. Owing to the loss of carbon dioxide through the eggshell pores, the pH of egg albumen increases from about 7.6 to 8.9-9.4 after several days of storage at ambient temperature. The rate of pH increase is positively correlated with temperature (page 50 in the EFSA report).
3. Grow or survive for more days in the presence of antimicrobial enzymes in the albumen until the activity of these is reduced or lost. This means that growth is unlikely in phase 1 and phase 2.

Microbes relevant for safety of eggs produced in Norway

The microbes listed below are considered to be the most relevant ones for eggs produced in Norway. Their optimal temperatures and pH values for growth as well as the ranges allowing growth are given. It should be noted that the cardinal values, as described above, are normally slightly lower/higher than the range where growth is observed in practical experiments. This is due to the fact that the cardinal values are theoretical limits in the mathematical equations that are adapted to experimental data using curve fitting. For temperature, the difference between minimum cardinal temperature for growth and the minimal temperature for growth is less than 2°C (Table 6).

Table 6. Cardinal values for bacteria relevant for conditions in TEPC in Norway (Guérin et al., 2017; Kranzler et al., 2016; Schelin et al., 2011)

Genus	Optimal Temp (°C)	Temp Range (°C)	Optimal pH growth	Growth pH Range
<i>Bacillus cereus</i>	Growth: 15-37 Emetic toxin production: 12 –37	Growth: 4–48** Emetic toxin production: 8-40	6.0–7.0	4.5–9.5
<i>Staphylococcus aureus</i>	Growth: 35–41 Enterotoxin production: 35 –44	Growth: 6.5 – 48.5*** Enterotoxin production: 10–46	5.3-7.0	4.8-9.3
<i>Campylobacter spp.</i>	30-45	42*	6.5-7.5	4.9-9.0
<i>Listeria monocytogenes</i>	30-37	0-44	7.0	4.3-9.6

*Strain dependent

**Psychrotrophic variants have shown slow toxin production at 8 °C while mesophilic variants have shown toxin production at 40 °C.

***Even though growth of *S. aureus* has been reported at temperatures below 10°C in some studies, none of the studies have been in eggs. The rule of thumb is that temperatures below 12°C do not allow for significant growth or toxin production.

Preparation and consumption habits

The habit of eating raw eggs or using raw eggs in desserts, cakes and other foods is common both in Norway and in other countries, even though the kind of dishes vary between countries. A difference between Norway and other countries is that eggs are consumed raw after a longer storage period than in other countries. Despite this practice, no outbreaks linked to table eggs have been reported.

Cooking practices such as preparing soft boiled eggs or frying eggs at a temperature where parts of the eggs remain raw, are common in Norway, but have not led to outbreaks except when spices in scrambled eggs have been contaminated.

Results and discussion

The assessment indicates that contamination of the egg interior from the eggshell and the surroundings of eggs is not likely. This is due to the low survival rate of microbes on the eggshell, combined with a stable membrane between the eggshell and albumen as well as regulations and practices for control and redirection of eggs with irregularities and damaged membranes that can lead to a weakened barrier.

The presence of microbes on the eggshell is highest during the first days after the egg is laid, but this is also the period when the barrier is most effective.

Even if microbes were able to enter the egg interior, the antimicrobial activity in the albumen will inhibit growth of all microbes and kill Gram-positive bacteria.

The probability of contamination increases slightly from phase 2. Growth of microbes after contamination.

The low temperature and high pH in the albumen are both effective hurdles for growth. Among the microbes found relevant for eggs in Norway, some are able to grow below 12 °C, and some are at the maximum of their pH range after the pH in the albumen has increased to 8.9-9.4

Table 7. Assessment of conditions for growth or toxin production for relevant pathogens in table eggs production

Microbe likely to enter the egg white	Minimum temp for growth unknown or below 12 °C? (all phases)*	Able to grow at pH 8.9-9.4 (phase 3-4)*	Able to grow at pH 7.6 (phase 1 and 2)
<i>Bacillus cereus</i> (toxin production)	Yes*	Yes*	Yes
<i>Staphylococcus aureus</i> (toxin production)	Yes (growth) No (toxin production)	No	pH range: yes
<i>Campylobacter</i> spp.	No	No	Yes
<i>Listeria monocytogenes</i>	Yes	Yes*	pH range: yes Growth in presence of antimicrobial enzymes: No

*At the limit of the range and far from optimum

**Lysozyme and other antimicrobial enzymes in the albumen have inhibiting effect on Gram positive microbes.

The outcome of our assessment (Table 7) is that eggs have triple protection against horizontal contamination.

Even though the protection is good, eggs produced in Norway do also get spoiled. Spoilage is normally only detected after many weeks of storage.

Contamination of the egg yolk has not been considered in our assessment. Even though vertically contamination of *Salmonella* is not relevant for eggs produced in Norway, other microbes may be introduced to the egg yolk from the hen. However, the fact that table eggs have not been connected to outbreaks or illness cases, even though it is common to eat eggs that have been stored for several months, indicates that this contamination route is of minor relevance for table eggs produced in Norway.

Uncertainties

The main uncertainties in our assessment are:

- whether cold adapted microbes behave as the microbes found in eggs in warmer areas

Cold adapted microbes might be able to grow in cold chain conditions even if the growth may be slower and would therefore increase food safety concerns with longer shelf-life. That would, however, have to be assessed in combination with pH range for cold adapted microbes as unfavourable pH in egg albumen would prevent growth that is already slower due to low temperatures. In that case food safety concerns with longer shelf-life may not be increased.

- when the leakage of nutritious compounds and compounds that reduce the antimicrobial activity of the egg starts.

If the time before the leakage is shorter than the one applied in our assessment, the microbes will still be inhibited by the low storage temperature and food safety concerns with longer shelf-life may not be increased.

Conclusions (with answers to the terms of reference)

ToR1. To what extent are the assumptions underlying EFSA's 2014 assessment of table eggs relevant to egg production in Norway?

- a. The assessment from EFSA describes the compartments of eggs, the barriers between shell, albumen and yolk, as well as predictions of loss of barrier function. Conditions like pH and antimicrobial activity is described.

The description is valid for eggs in Norway.

- b. The EFSA assessment is based on presence of *Salmonella* spp., the assumption that the prevalence is high and that contamination of eggs occurs vertically, i.e. from the hen into the egg yolk. There is less focus on horizontal contamination of eggs in EFSA's report.

This assumption is not valid for eggs in Norway, for the following reasons:

- There is a very low prevalence of *Salmonella* in eggs in Norway
 - The production of hens is controlled and vertical contamination (from hen to yolk) with *Salmonella* is unlikely.
 - Horizontal contamination of eggs from the production environment is also monitored in surveillance programs in Norway, and production houses where eggs or the faeces of hens test positive for *Salmonella* will be detected.
 - Organically produced eggs from units where the hens can go outside, and where they have areas where they prefer to rest, sleep and place their eggs are also monitored. Contamination of *Salmonella*, in particular of *Salmonella enteritidis* to eggs from surrounding nature is therefore not likely.
- c. The EFSA assessment of shelf life is based on quantitative predictions of the growth of *Salmonella* using well-established models and conditions like pH, temperature, and antimicrobial effects during storage. Other microbes that may be present and influence food safety and quality are assessed qualitatively or semi-quantitatively using the same descriptions of eggs.

As *Salmonella* is not relevant for eggs in Norway, the growth prediction of *Salmonella* in the EFSA assessment is not relevant for egg production in Norway.

The assessment of other microbes, which are all assessed to have minor relevance in EFSA's report, is relevant for egg production in Norway.

ToR2. What significance do factors such as enzymatic activity, the presence and potential growth of pathogenic agents and spoilage bacteria (time between laying and consumption,

refrigeration and storage conditions), antibiotic resistance, and Norwegian consumer behaviour have for food safety?

The physiological changes in eggs and the presence of spoilage microbes are the same in eggs produced in Norway as in the other countries of Europe.

Pathogens, other than *Salmonella*, are rare in eggs both in Norway and other parts of Europe. Presence of cold-adapted *Bacillus* spp. may however have a higher prevalence in Norway due to the colder climate. Even so, the barrier between eggshell and albumen will stay intact for weeks, and growth of microbes that may enter the albumen in case the membrane has weak points, will not occur due to antimicrobial activity and high pH in the egg albumen. This activity will remain until the membrane between egg yolk and albumen starts to leak.

The low storage temperature for eggs in Norway will limit the growth of the pathogens except for *Listeria* and cold-adapted *Bacillus*. These microbes will, however, not grow due to lysozyme activity in egg albumen, as the cell wall of Gram-positive bacteria will be degraded or not formed.

Spoilage microbes in eggs have an impact on egg quality. Their significance for food safety is mainly as indicators for long storage or abuse conditions where pathogen microbes may grow. Spoilage is not considered relevant before day 35 at 12°C, most likely much longer.

At the outset of the assessment, it was assumed that eggs are consumed raw more often in Norway than in other parts of Europe. A review of a large consumer survey showed that this is not the case.

ToR3. How long will it take before non-heat-treated/raw eggs pose a health risk, provided the eggs are stored at a maximum of 12°C (regulatory requirement for businesses)?

Raw eggs will not pose a health risk before day 35, i.e. the shelf life that has been set for eggs in Norway. The reasons are that the pathogen microbes that may be present on eggshells or in the production surroundings will not grow in egg albumen, not enter the egg yolk, and not be able to grow in the albumen either due to the antimicrobial activity or at storage conditions up to 12 °C.

Data gaps

Empirical knowledge indicates that survival of microbes that enter the egg interior by horizontal contamination will not cause a food safety issue. Documentation is, however, missing, for instance of the time until antimicrobial effects are lost.

There is a lack of directly comparable data on bacterial growth and toxin production, as studies differ in experimental design, matrices, and analytical methods.

Eggs produced and sold directly from farm to consumer without quality checks of eggshell regularities and membrane stability are not included in the present assessment. Not removing eggs with irregularities will have an impact on the transfer rate of microbes over the membranes, but it is not documented how much the impact is on egg quality and safety.

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Appendix I – Relevant chapters from EFSA’s report

2.2 Structure of production

(Reproduced from EFSA 2014)

Grandparent and parent flocks are genetically selected on various criteria applicable for the parent and for the progeny (hatchability, number of eggs produced, colour of shell, suitability of progeny for the type of production (colony cages, alternative systems)). Aspects such as bone strength and resistance to certain diseases are also often subject to selection. Fertile eggs from these flocks are incubated and hatched under very good sanitary conditions to produce grandparent birds that produce parent birds which then produce the commercial generation of laying hens. This multiplication pyramid means that one elite breeding hen can be responsible for up to 300 000 commercial laying birds and over 90 million eggs. Female day-old laying hen chicks are selected, vaccinated and transferred to the rearing farm. During the rearing period, pullets are housed in floor-based systems or in cages for 16 to 18 weeks, then transferred to the laying phase; this transfer is an important stress factor for the pullets.

During the laying period, which is approximately 44 to 60 weeks in most cases, production of eggs increases progressively to reach peak production (0.9 eggs per day) 6 to 8 weeks after the onset of lay. The quality of the egg (colour, weight, size, and conformation) and eggshell also increase progressively during these first weeks of lay, and then deteriorates towards the end of lay, although egg size may continue to increase. At the end of the laying period, a moulting procedure is occasionally used to stimulate a new period of lay by means of nutrient and light restriction. This is a stressful process that can increase the risk of *Salmonella* shedding by latent carrier birds. More commonly, laying hens are transported to the slaughterhouse to be slaughtered after a single laying period.

During the laying period, eggs are collected every day, sometimes several times a day, using automated belts transporting the eggs from auto-nests or cage egg belts to a collecting room. On small farms, eggs may be collected manually into trays held on trolleys or buggies. Eggs are selected and stored in a storage area, which may sometimes be chilled, before transfer to the packing centre, which may be on the farm or a separate central facility, or to an egg processing (breaking) plant (see Figure 1 above).

Following the new EU Regulation concerning the minimum standards for the protection of laying hens (Council Directive 1999/74/EU13) banning conventional ‘battery’ cage production, alternative systems have replaced conventional cages in all MSs. This involves the use of enriched colony cages housing up to 80 birds per large cage area following new European standards, barn and aviary systems, which may be of multi-tier construction, or free range and organic production with outdoor access (Dekker et al., 2011). The choice of the type of production is clearly different between MSs, and each system has different advantages and disadvantages in terms of bird welfare and biological risk (Holt et al., 2011; Lay et al., 2011). The regulatory requirements have resulted in many small cage layer units going out of business.

3. Public health relevance of microorganisms transmissible through eggs

(Reproduced from EFSA 2014)

The zoonoses reports include data on food-borne outbreaks and have been mandatory for EU MSs since 2005. Since 2007 harmonised specifications for the reporting of these outbreaks at the EU level have been in use (EFSA, 2007a). In 2010, revised reporting specifications for food-borne outbreaks were implemented and the distinction between 'verified' and 'possible' food-borne outbreaks was changed to 'strong' or 'weak' based on the strength of evidence implicating a suspect food vehicle. Food-borne outbreak investigation systems at the national level are not harmonised between MSs. Consequently, the differences in the numbers and types of reported outbreaks, as well as the causative agents, may not reflect differences in food safety between MSs, but may be more indicative of differences in the efficiency and sensitivity of the national monitoring systems for identifying and investigating food-borne outbreaks. Nevertheless, this reporting of zoonoses represents the most comprehensive set of data available for the EU.

In 2012, as in previous years, the most common single foodstuff category reported as a food vehicle was eggs and egg products, responsible for 168 (22 %) out of 763 outbreaks. The majority of these outbreaks were associated with *S. Enteritidis* (67 %). Two outbreaks were caused by bacterial toxins (one each by the *Bacillus cereus* group and staphylococcal toxins). In addition, one calicivirus outbreak was attributed to eggs and egg products - see Figure 5). When eggs or egg products are used as ingredients data are insufficiently detailed to identify the specific contribution of the egg component in these outbreaks (EFSA and ECDC, 2014).

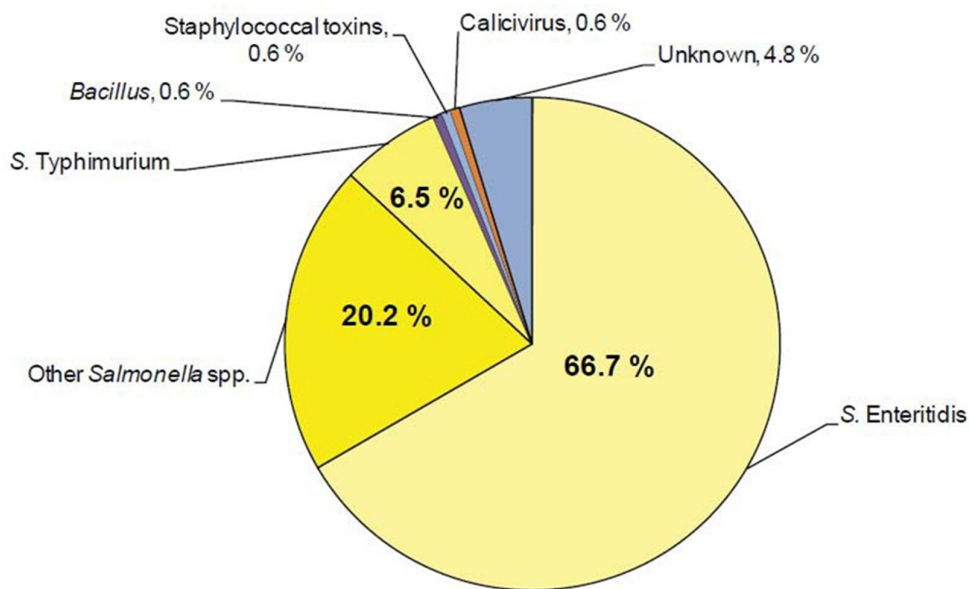


Figure 5. Distribution of strong-evidence outbreaks caused by eggs and egg products, by causative agents, in the EU, 2012. Data from 168 outbreaks are included: France (33), Germany (3), the Netherlands (1), Poland (51), Slovakia (3), Spain (74) and the United Kingdom (3) (EFSA and ECDC, 2014)

Appendix II - Critical steps in Norwegian TEPC and the relevance of each barrier

Table 8. Mapping of critical steps and the relevance of each barrier

Step in the farm-to-fork chain	Scenario	Barrier 1: Outer shell/cuticula	Barrier 2: Membrane between outer shell and egg white	Barrier 3: Membrane between egg yolk and egg white	Comment
Farm, in hen	Will the eggs be contaminated in the hen before the formation of the membranes and eggshell	Not relevant	Not relevant	Not relevant	Relevant for Salmonella and for ill hens. Not relevant for Norway
Farm, in hen	Can contamination from the oviduct before the egg is laid occur?	Yes, the oviduct is not sterile. Microbes will be partly held back by the cuticula, but can survive on the surface	No, eggs are adapted to optimal protection of the "chicken". Barriere is effective.	No, the barrier is intact	
Farm, after egg is laid	Can the shell and membranes be damaged when the egg is laid?	Yes, cracks may occur	Cracks in the outer shell may cause weaker spots in the membrane	No	Old literature: Avian influenza is a major risk
Farm	Can contamination from the surroundings of the newly laid egg occur?	Yes, on the surface, the cuticula will protect, at least partly, for transfer of surface contamination towards the inner membrane. Condense, moist and dust on the egg surface will increase the establishment of microbes in the eggshell	Not if the membrane is intact	No	Normally the hens will lay their eggs in the dry areas and shortly after waking up. This means that most eggs will be laid in suitable areas and rapidly collected even if the hen is free to walk outside.
Farm-transport-pack house	Is there any impact of the storage conditions the first hours and	No, unless new cracks are caused by handling	Yes, the temperature difference between egg and surroundings causes volume	No, or could there be release of nutrients from the egg yolk to the	Risk increase: rapid cooling. Contamination can occur.

	days after the egg is laid?		changes in the egg white. Underpressure is formed and microbes may penetrate the membrane	egg white at this stage? Note: the inner membrane is supposed to be stable until day 28, see the EFSA report	
Farm-pack house	Will cracks formed earlier or during transport to pack houses impact the risk of contamination and/or growth?	Yes, cracks make holes in the cuticula and “knives” towards the membrane.	Yes, in case of weakened areas. “wounds” may develop over time Antimicrobials will limit growth to a minimum.	No	
Sorting	Will eggs with cracks or membrane weaknesses be taken out/ will such damages be detectable?				Classification of eggs on the pack house
Transport, distribution, storage	Which changes occur during the first 3 weeks of storage, and how will they impact contamination?	The cuticula is intact until 21 days. The primary barrier to cross contamination lost after that.	The evaporation of water from the egg is limited at low temperature. Membrane not yet weakened	No relevant changes	In eggs with damaged membranes, there is a likelihood of contamination, but hardly in eggs with undamaged membranes.
	-and growth?	Growth of microbes in the porous eggshell may occur at high humidity if organic material is available.	Egg white contains antimicrobials (lysozyme, and others). pH up to 9. Microbial growth is controlled	The barrier is intact, no release of nutrients from egg yolk to egg white.	The growth is controlled
Storage	Storage for 28 days or longer	Barriere function lost	The barrier is weakened due to evaporation. The rate is temperature dependent. The egg white is liquified	The barrier is most likely intact	The lower temperature, the less evaporation.
			Antimicrobial functions are in place as long as there is no leakage of		

			nutrients from the egg yolk		
Storage	Longer storage		Evaporation continues, membranes weakened. Antimicrobial effects are reduced when nutrients from egg yolk enter the egg white Growth will start at some point	Evaporation and enzymatic degradation cause tension in the membrane. Nutrients from the egg yolk will be transferred to the egg white.	The lower temperature, the less evaporation and nutrient transfer Main question: how long it will take before...
Storage-late transport	Transport of eggs (from retail to home) after some storage		Sudden breakage may happen	More protected than the outer membrane, but the likelihood of transfer	The longer the egg is stored, the greater the likelihood of damage to the membrane. A last "sell-by date" makes sense.
Storage at home	Will consumer habits for storage and preparation have an impact on the safety	Microbes are present. "Eggevann og skjeggevann skal ikke brukes til annet» Cross contamination in the kitchen	In cracked eggs: Coagulation at xx C (low temperature) is not enough to kill most microbes. (Surprising?) Hard-boiled eggs:	Microbes may be present in "old eggs". Hard-boiling needed to kill microbes.	Storage at 0°C: no literature support for a more stiff and therefore brittle membrane.
Risk scenarios to include in the model:					
Farm	Rapid cooling		Higher probability of penetration		
Farm and storage	Eggs stored, in contaminated and humid surroundings	More microbes contaminated and more growth			
Handling-contamination	Cracks	Membrane lost	Membrane weakened		
Storage - growth	Abuse temperature		Evaporation increases the tension on the membranes Less antimicrobial effects	Evaporation increases the tension on the membranes. Higher probability for	

				leakage of egg yolk nutrients to the egg white.	
Storage-consequences of contamination	Long term storage	More microbes can enter the membrane surface	As above	As above	
	Transport of eggs after a storage period		Membranes weakened. Less protection		