UNIVERSITY OF BIRMINGHAM

THE DETERMINATION OF SECONDARY SHELF-LIFE IN FOOD: A SYSTEMATIC REVIEW

A dissertation submitted by

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Abstract

Food waste is acknowledged as a critical challenge in the food supply chain, particularly in domestic households, where food is often discarded due to confusion around durability labelling. The Secondary Shelf-Life (SSL), typically indicated as ‘use within x days of opening’, is food labelling used to instruct safe consumption after package opening. However, legislation and knowledge on SSL remains scarce. As no systematic review concerning SSL has currently been published, this study aimed to assess the validity of SSL determination and analyse the possibility of SSL extension through a systematic review. The search term “Secondary Shelf-Life” was conducted on the databases Web of Science, Google Scholar, Scopus, ProQuest and PubMed, producing 599 studies. Following the identification and screening process, 36 studies were included in the final review. Results identified that temperature, a_w and packaging were critical factors influencing the SSL of food, and current SSL date labelling shows high variability and limited accuracy. Whilst SSL determination using modelling and SSL extension methods using preservatives showed significant results, environmental contamination and consumer storage practices were identified as the main risks of SSL determination. These results can support the development of clearer SSL definitions in legislation and recommend methods for SSL determination in practice, both of which may contribute towards food waste reduction. Despite promising results and recent publications, SSL remains a scarce topic, and the necessity for SSL labelling remains undefined. Further research is therefore required in all areas of SSL to increase the validity of the conclusions.

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Glossary

ASLT: Accelerated Shelf-Life Testing

a_w: Water activity

ESFA: European Standards Food Agency

LAE: Ethyl Lauroyl Arginate

MAP: Modified Atmosphere Packaging

PPDS: Pre-Packaged for Direct Sale

PSL: Primary Shelf-Life

RSL: Residual Shelf-Life

RTE: Ready-to-Eat

SSL: Secondary Shelf-Life

Tg: Glass transition temperature

VC: Volatile Compounds

1. Introduction & Literature Review

1.1. Introduction

The global food market has evolved drastically in recent years due to the modern fast-paced way of life (Silberbauer and Schmid, 2017). One change is the increased sale of ready-to-eat (RTE) food products due to their convenience, accessibility, and the little time needed for preparation (Silberbauer and Schmid, 2017; Mengistu and Tolera, 2020). RTE foods are classified as hot, chilled, or cooked foods that can be consumed without any further preparation (Mengistu and Tolera, 2020). This includes Pre-Packaged food for Direct Sale (PPDS) products like sandwiches, salads, and pastries, as well as minimally processed foods like fruits and vegetables (Santeramo et al., 2018; Food Standards Agency, 2020).

The public trust in food in the UK is heavily reliant on public confidence in food safety, standards, and regulations (GOV.UK, 2021). Most UK consumers trust that food is safe and labelled accurately, and it is reported that businesses show high levels of compliance with food safety regulations (GOV.UK, 2021). This level of consumer trust is critical, as loss can lead to reduced demand, significant negative economic impacts, and reduced protection in public health (GOV.UK, 2021).

Confidence in the UK food supply must therefore be supported for the ever-changing food market. Literature has shown that the current high demand for RTE food is related to public perception that the food is safe to eat (Santeramo et al., 2018). Consumers expect these foods to have a fresh appearance, to be microbiologically safe, and to have correct labelling with a suitable shelf-life during which the product remains acceptable (Silberbauer and Schmid, 2017). An example of promoting food safety in RTE foods in the UK is the recent change in labelling guidance on PPDS food products, also known as Natasha's Law (Food Standards Agency, 2021). This explains that a full ingredients list with highlighted allergens is mandatory on PPDS food, allowing consumers to make informed choices about the food they consume (Food Standards Agency, 2021).

However, there are challenges with the rise in RTE foods and concerns to food safety. The composition and storage conditions of RTE foods can provide an ideal medium for the growth of pathogenic microorganisms identified as a threat to public health (Mengistu and Tolera, 2020). Fruits and vegetables are particularly vulnerable to microbial growth due to their shorter shelf-life and lack of preservatives, and therefore require high safety standards (Santeramo et al., 2018). Whilst preservatives can be used in attempt to extend the products shelf-life and therefore reduce food safety risks, the use of specifically artificial preservatives is undesirable due to associations with health hazards like hypersensitivity, asthma and cancer (Kamala Kumari et al., 2019). Additionally, there is a growing consumer resistance towards the use of preservatives, and 'clean label' food products are growing in demand (Kamala Kumari et al., 2019).

Regarding recent food borne illness and food safety incident reports, the UK has shown increasing levels since 2010 and has remained stable from 2015-2019 (GOV.UK, 2021). The increase was not classified as a public health threat and was instead listed as better detection and higher levels of reporting (GOV.UK, 2021). Research has also shown an increase in food borne illness worldwide, particularly in developing countries, where it is one of the leading causes of illness (Mengistu and Tolera, 2020). However, the reason for this increase was reported as a public health concern and not from better detection or reporting (Mengistu and Tolera, 2020).

Therefore, both the safety and quality of foods globally needs to be a priority as food consumed in the UK is produced worldwide.

In recent years, food waste is also acknowledged as a critical issue in global food production. Food waste is defined as materials intended for human consumption that are lost, discharged, or contaminated in food production (Girotto, Alibardi and Cossu, 2015). Approximately one third of food produced for human consumption is lost or wasted, equivalent to 1.3 billion tonnes of food per year (Girotto, Alibardi and Cossu, 2015; Schanes, Dobernig and Gözet, 2018). As food production is resource intensive, food waste contributes to soil erosion, deforestation, and high levels of greenhouse gas emissions from food disposal and wasted food production (Girotto, Alibardi and Cossu, 2015; Schanes, Dobernig and Gözet, 2018).

In developed countries, domestic waste is the largest source of food waste, which is of particular concern as waste at final production stages are the most energy intensive (Aschemann-Witzel et al., 2015; Schanes, Dobernig and Gözet, 2018). A large fraction of domestic food waste is identified as 'sub-optimal foods,' which are edible foods classified as undesirable (Aschemann-Witzel et al., 2015). These are wasted due to visual perceptions, incorrect storage conditions, and confusion around food labelling, despite changes to PPDS foods in UK legislation (Girotto, Alibardi and Cossu, 2015; Food Standards Agency, 2021)

1.2. Labelling Legislation

Legislation regarding food labelling in the UK is enforced under Regulation 1169/2011, which details the principles, requirements, and the responsibilities for food labelling (GOV.UK, 2011). This ensures protection to consumers health and helps to maintain the high level of confidence currently in the UK food supply chain (GOV.UK, 2011; GOV.UK, 2021).

Chapter IV of 1169/2011 states mandatory food information required on labelling. This includes name of the food, list of ingredients including quantitative indications, identification of allergens, net quantity, durability dates, storage conditions, country of origin, and instructions for use (GOV.UK, 2011). The nutritional declaration including energy, fat, saturates, carbohydrates, sugars, protein, and salt is also mandatory for labelling (GOV.UK, 2011).

Legislation concerning the minimum durability date and storage conditions is located in articles 24 and 25 of 1169/2011 (GOV.UK, 2011). Where appropriate, the storage conditions and time limit for consumption should be indicated after package opening (GOV.UK, 2011). The durability date should also be replaced with a ‘use by’ date if the food is highly perishable and likely to constitute an immediate danger to human health (GOV.UK, 2011).

1.3. Secondary Shelf-Life

The Secondary Shelf-Life (SSL) is defined as the time interval after packaging opening during which the food maintains an acceptable quality (Nicoli and Calligaris, 2018; Nobile and Conte, 2023). The concept of SSL can be assimilated to “Period after Opening” (PaO), although PaO is typically used for cosmetics (Nicoli and Calligaris, 2018). This differs from the Primary Shelf-Life (PSL) or shelf-life, which is defined as the time interval after production during which the food maintains an acceptable quality under well-defined storage conditions (Nicoli and Calligaris, 2018). The differences between PSL and SSL are visualised in **figure 1.**

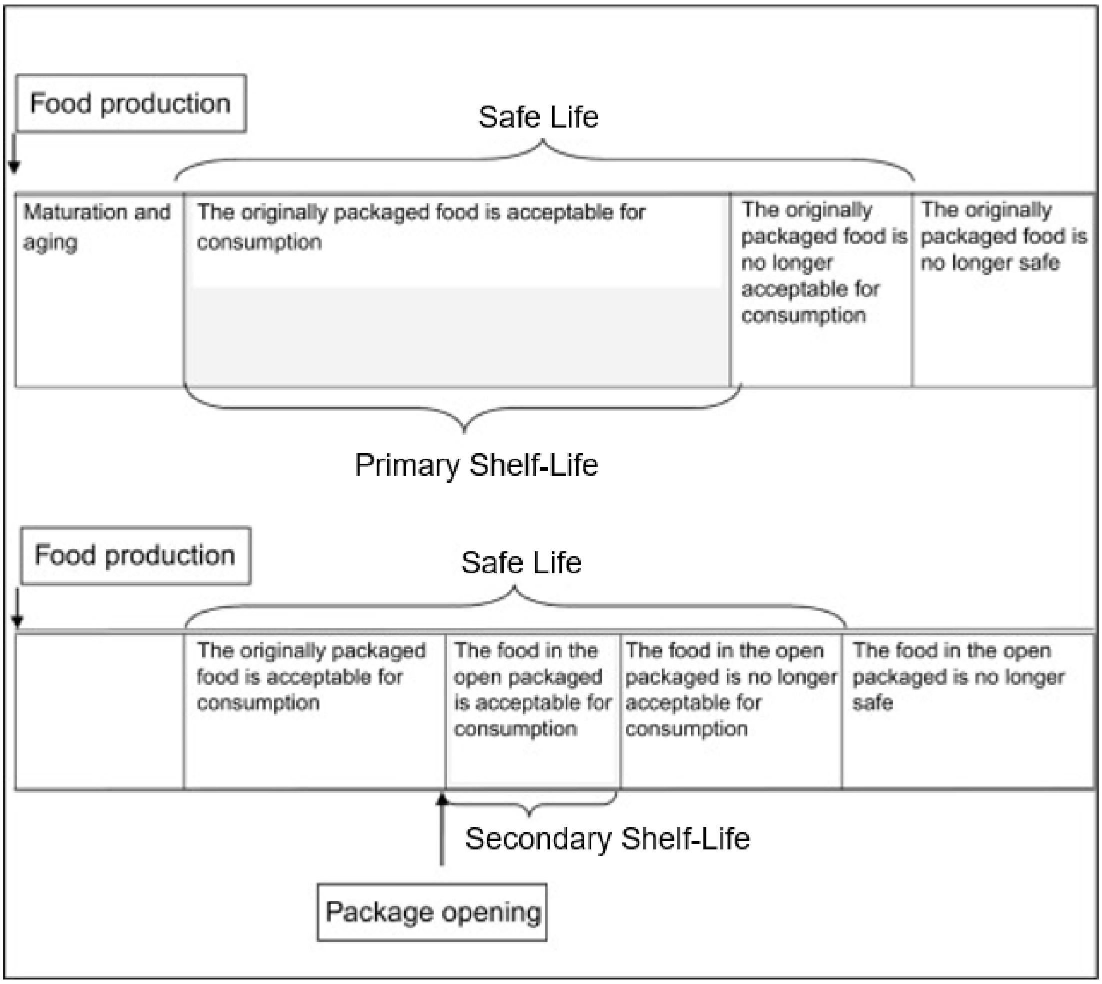

FIGURE 1 : THE DIFFERENCES BETWEEN PRIMARY SHELF-LIFE AND SECONDARY SHELF-LIFE (CALLIGARIS ET AL., 2019)

The PSL is shown on food labelling as ‘use-by,’ ‘best before’ or ‘best before end’ depending on the nature of the product. The information of SSL, referred to as the ‘time limit for consumption’ in article 25 of 1169/2011, is often expressed as ‘use within x days of opening’ on food labels (GOV.UK, 2011; Nicoli and Calligaris, 2018). This informs consumers on the appropriate use and storage of food after package opening (GOV.UK, 2011).

1.4. Legislation Gaps

Whilst regulation 1169/2011 states that the time limit for consumption should be indicated if appropriate, the choice of date for the SSL is the responsibility of the food manufacturer (GOV.UK, 2011; Nicoli and Calligaris, 2018). There are however no validated scientific methods, protocols or references for determining the SSL (Nicoli and Calligaris, 2018). There is also no guidance to manufactures on methods to determine SSL (GOV.UK, 2011; Nicoli and Calligaris, 2018).

In 2021, the European Standards Food Agency (ESFA) released a study containing guidance on date marking and related food information (Koutsoumanis et al., 2021). A risk-based decision tree was designed to instruct food manufacturers on the products requiring SSL date labelling, shown in **figure 2** (Koutsoumanis et al., 2021). It concluded that unless SSL labelling is required for quality reasons, foods supporting the growth of pathogenic bacteria before and after package opening should have SSL date labelling added (Koutsoumanis et al., 2021). The time limit should be shorter than the ‘best before’ or ‘use by’ date (Koutsoumanis et al., 2021). However, no further guidance was given about methods for SSL determination, and SSL labelling for food quality reasons was not further discussed.

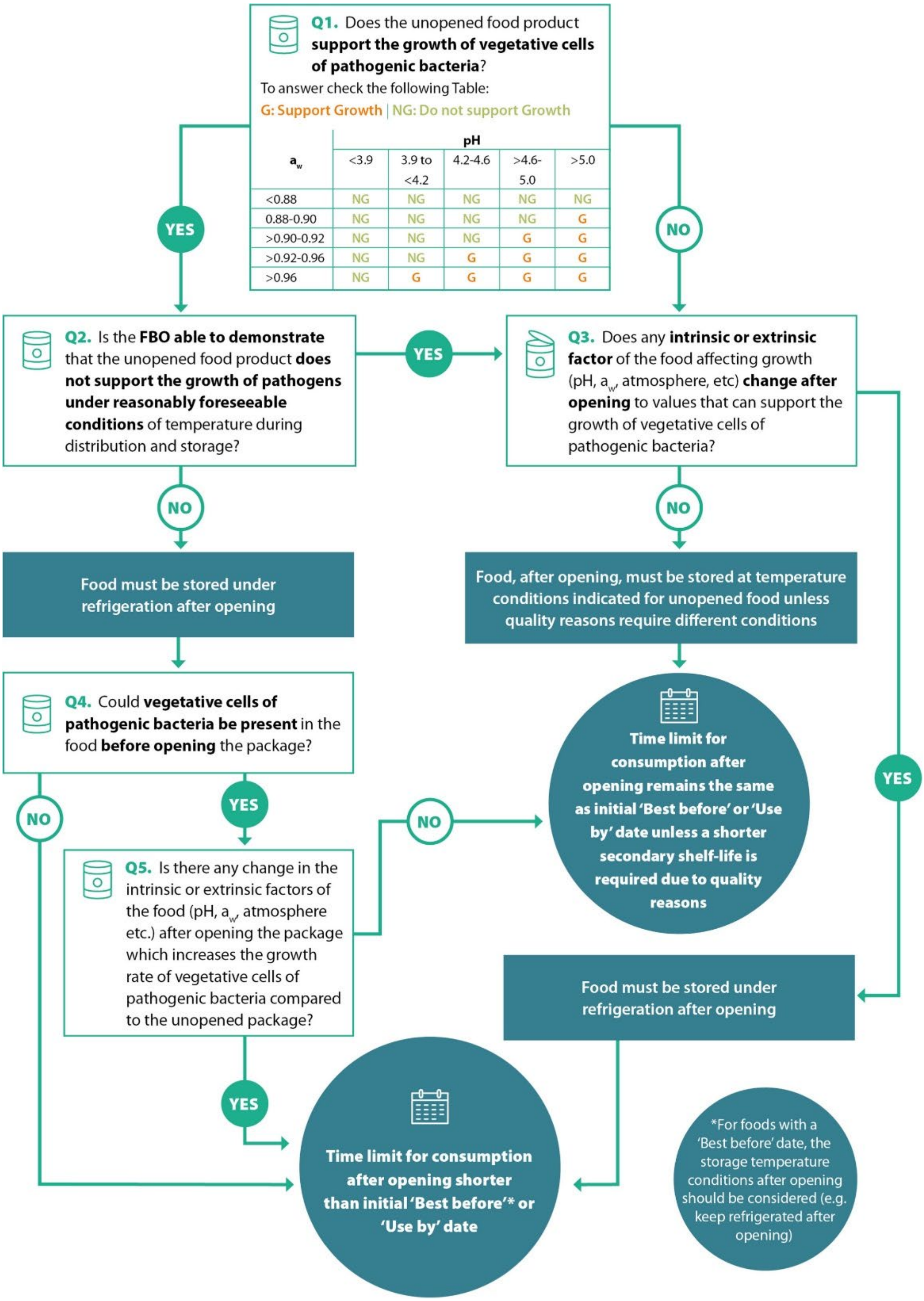

FIGURE 2: A RISK-BASED DECISION TREE IDENTIFYING THE PRODUCTS REQUIRING SECONDARY SHELF-LIFE LABELLING (KOUTSOUMANIS ET AL., 2021).

As previously discussed, SSL is assimilated with PaO (Nicoli and Calligaris, 2018). The legislation regarding PaO is located in directive 2003/15/CE which states that PaO indication is mandatory (GOV.UK, 2003). Similar to SSL, there are no validated scientific methods, protocols or references for determining PaO (Nicoli and Calligaris, 2018). However, guidance for PaO determination can be found in "Practical implementation of Article 6(1)(c) of the Cosmetics Directive (76/768/EEC)1: Labelling of product durability: period of time after opening" which lists relevant methods to assess the PaO (European Commission, 2015). This includes microbiological challenge tests, previous stability and analytical data, analysing consumer habits, and previous experience with similar products (European Commission, 2015). Whilst the methods listed above could be relevant for food manufacturers in regard to SSL determination, the guidance is relevant to cosmetics only, emphasising the legislation gap for SSL.

The legislation gaps therefore create problems with SSL determination and increase the risk for overestimation and underestimation. SSL overestimation is a significant food safety and food quality concern and could damage the reputation of the current food security standards (Nicoli and Calligaris, 2018; GOV.UK, 2021). SSL underestimation can promote domestic food waste in households, a significant contributor in overall food waste, worsening environmental impacts (Aschemann-Witzel et al., 2015; Schanes, Dobernig and Gözet, 2018). Research indicates that SSL is often underestimated for food safety purposes and could therefore contribute to increasing statistics of food waste (Nicoli and Calligaris, 2018).

1.5. Food Spoilage

Food spoilage is defined as any undesirable change to a food product that makes it unacceptable to the consumer (Gram et al., 2002). Food spoilage can appear both physically and chemically in appearance and off-flavours (Gram et al., 2002).

Although food spoilage occurs in all foods, the rate and type of spoilage is influenced by both intrinsic and extrinsic factors (Gram et al., 2002). Intrinsic factors concern the food itself and include nutritional content, pH, water activity (a_w), redox potential and the presence of antimicrobial components (Rolfe and Daryaei, 2020; Awilachew, 2021). Extrinsic factors are related to the environment the food is present in, where examples include temperature, relative humidity, light, gaseous environments, or the presence of competitor microorganisms (Choe and Min, 2009; Rolfe and Daryaei, 2020; Awilachew, 2021).

Food spoilage is a complex process and several reactions can occur, causing the food to undergo physical and chemical modifications (Gram et al., 2002; Nicoli and Calligaris, 2018). The expected deteriorative events are dependent on the food product and the conditions of storage, and examples of reactions are demonstrated in **table 1** below (Calligaris et al., 2019).

TABLE 1: DETERIORATIVE EVENTS THAT OCCUR IN DIFFERENT STORAGE CONDITIONS (CALLIGARIS ET AL., 2019)

Food	Deterioritive events
Chilled	○ Microbial growth ○ Enzymatic reactions ○ Senescence
Frozen	○ Oxidation ○ Enzymatic reactions ○ Re-crystallisation ○ Surface drying
Ambient	○ Oxidation ○ Non-enzymatic browning ○ Structural collapse ○ Caramelisation

Oxidation in food includes multiple reactions leading to the formation of highly reactive products, reducing acceptability (Choe and Min, 2009; Nicoli and Calligaris, 2018). It is described as the most frequent reaction that causes product unacceptability for ambient or frozen foods (Manzocco, Calligaris and Nicoli, 2010). Oxidation develops undesirable off-flavours and colours, destroys essential nutrients, and produces toxic compounds like dietary advanced lipid oxidation end-products (Choe and Min, 2009; Nicoli and Calligaris, 2018). Packaging is often used to prevent oxidative reactions occurring by protecting them from light and the gaseous environment, but this only provides a physical barrier that protects the product before opening (Choe and Min, 2009).

In highly perishable foods with a high a_w, the accumulation of moisture accelerates microbial growth and is listed as a key reason for food spoilage (Gaikwad, Singh and Ajji, 2018). In dried or semi-dried products, a change in moisture content can influence product acceptability (Nicoli and Calligaris, 2018). Low moisture foods are stored below their glass transition temperature (Tg) which is sensitive to moisture and can decrease rapidly (Nicoli and Calligaris, 2018). When food is above its Tg, structural changes like crystallisation, thickness and the agglutination of powders increase, affecting the texture and food appearance (Gaikwad, Singh and Ajji, 2018; Nicoli and Calligaris, 2018). The introduction of moisture to dry food can also make the food vulnerable to microbial and mould growth (Gaikwad, Singh and Ajji, 2018).

Although modern food processing and packaging are dependent on preservation techniques like Modified Atmosphere Packaging (MAP) to extend the PSL, highly perishable foods remain vulnerable to spoilage due to their intrinsic properties and are still prone to being wasted (Gram et al., 2002). Moreover, the MAP is depleted after package opening, allowing for the entrance of oxygen, moisture, and volatile compounds (VC) in the product, accelerating microbial growth and quality depletion (Nicoli and Calligaris, 2018). This reduces the SSL and increases the complexity of SSL determination, as the product is exposed to a variety of components the PSL would otherwise be protected from.

1.6. Shelf-Life Testing

As shelf-life indication is mandatory in European law, shelf-life testing is required to determine the time limit of product acceptability (Calligaris et al., 2019). As previously discussed, it is the responsibility of the food manufacturer to label foods with a ‘best before’ or ‘use by’ date, and it is critical to public safety that the shelf-life is determined accurately (GOV.UK, 2011; Nicoli and Calligaris, 2018; Calligaris et al., 2019). A brief outline of the shelf-life testing protocol is highlighted in **figure 3**.

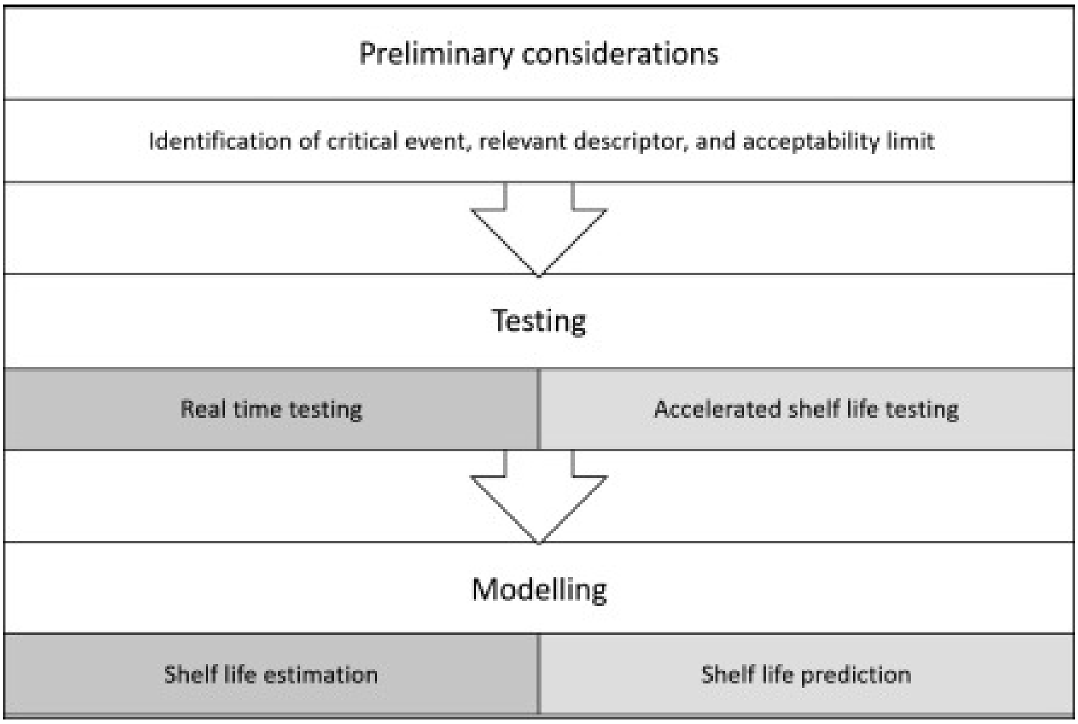

FIGURE 3: THE SHELF-LIFE TESTING PROTOCOL (CALLIGARIS ET AL., 2019)

The first phase of shelf-life testing protocol is identifying the factor that has the largest effect on food quality, referred to as the critical factor (Calligaris et al., 2019). This is dependent on the product being tested (Calligaris et al., 2019). For example, frozen foods are not as vulnerable to microbial growth as chilled foods, but are critically limited by enzymatic and chemical reactions, as observed in **table 1** (Calligaris et al., 2019). The decided critical factor is often then selected for monitoring food quality during the shelf-life assessment (Calligaris et al., 2019).

This identification stage is connected to the shelf-life acceptability limit, defined as the food quality level separating acceptable products from unacceptable products (Manzocco, Calligaris and Nicoli, 2010; Calligaris et al., 2019). The shelf-life assessment therefore aims to correctly determine the time required to reach the acceptability limit (Calligaris et al., 2019). There are several ways of identifying the shelf-life acceptability limit, including researching relevant legislation, identifying the shelf-life of similar products, and performing sensory analysis tests (Manzocco, Calligaris and Nicoli, 2010). However, the acceptability limit should allow a safety time interval, during which the product retains quality characteristics and there is no risk to public health (Calligaris et al., 2019).

Shelf-life can be assessed by Accelerated Shelf-Life Testing (ASLT) or real time testing (Manzocco, Calligaris and Nicoli, 2010). Real time testing involves monitoring food quality changes under environmental conditions that mimic what is experienced on the market shelf, whilst ASLT applies environmental conditions that allow the product to deteriorate faster (Calligaris et al., 2019). Real time testing is often used for highly perishable foods, whilst ASLT is used for the prediction of products with a longer shelf-life, such as ambient and frozen foods (Manzocco, Calligaris and Nicoli, 2010; Calligaris et al., 2019). During real time testing, it is best to test the product in the environment typically experienced during storage (Calligaris et al., 2019). However, as temperature fluctuations occur in storage, shelf-life testing can be performed in the worst situation the product might be expected to experience during storage (Calligaris et al., 2019). In ASLT, all compositional and packaging related factors that can affect the shelf-life remain constant, and one environmental factor like temperature, light, oxygen or relative humidity, is chosen as the critical factor to accelerate the reaction rate (Calligaris et al., 2019).

An alternative to physical shelf-life testing is shelf-life modelling, which is defined as the use of a mathematical model to either estimate or predict the shelf-life (Piergiovanni and Limbo, 2019). Whilst physical testing is ideal for observing quality changes and quality decay, a mathematical model is less costly, more time efficient, and allows for the testing of other factors (Piergiovanni and Limbo, 2019).

However, shelf-life assessments are generally applied to packed foods that have not been opened (Nicoli and Calligaris, 2018; Calligaris et al., 2019). Therefore, shelf-life testing often does not factor in the SSL and may be underestimated to maintain the safety time interval. Furthermore, food manufacturers cannot guarantee that the consumer will store the food product according to the labelling instructions, adding further barriers to SSL estimation.

1.7. Research Gap

Despite recent publications of literature regarding SSL, research is generally scarce. Studies are primarily focused on factors influencing SSL, the accuracy of SSL labelling, the use of modelling in an attempt to predict the SSL, and novel methods of SSL extension. There is also currently no systematic review regarding any part of SSL, which this study aims to fulfil.

A systematic review would highlight recent research, determine the best practises and policies for SSL, and suggest ideas for future research based on identified research gaps. Additionally, strengthening the research in this domain would provide guidance to food manufacturers about SSL labelling, consumers on the storage of food products, and policy makers on Regulation 1169/2011.

1.8. Aims, Objectives and Research Questions

1.8.1. Aim

To assess the overall validity of secondary shelf-life determination and the possibility of secondary shelf-life extension in food.

1.8.2. Objectives

To identify the factors affecting the secondary shelf-life of food.

To determine the accuracy of current secondary shelf-life labelling for food.

To assess the efficacy of modelling to predict the secondary shelf-life of food.

To identify the risks of secondary shelf-life extension on food.

1.8.3. Research Questions

What are the factors that affect the secondary shelf-life of food?

To what extent is the secondary shelf-life date on food accurate?

How could the secondary shelf-life of food be determined?

What are the risks of secondary shelf-life extension?

2. Methodology

A systematic review was decided as the best approach as the research questions and objectives address general SSL literature. The systematic review will identify relevant literature and assist in the formation of stronger conclusions. It is also important to note that this systematic review does not have any ethical implications.

2.1. Eligibility Criteria

The inclusion and exclusion criteria were established to guide the study selection. As no systematic review has been completed regarding SSL, a decision was made to include literature from any year, any food product and quantitative and qualitative studies of any type. This will therefore not overlook relevant literature in the already scarce topic (Randles and Paul, 2023). Grey literature discussing SSL was included due to the low volume of research available and the complexity of the outcomes (Benzies et al., 2006). Whilst studies should address at least one of the research objectives, literature was included if a recurring theme is present that was not listed in the objectives. This further ensures that relevant literature is not overlooked.

2.2. Search Strategy

The databases Web of Science, Google Scholar, Scopus, ProQuest and PubMed were used for the literature search, which were accessed via Findit@Bham. An initial search was completed on the 30th April 2025, where literature was exported to Mendeley and then uploaded to Covidence.

The keyword search only included the term "secondary shelf-life", where the quotations were used to eliminate regular shelf-life studies. Whilst the acronym "SSL" could have also been used in the search strategy, this could cause confusion with other terms that share the same acronym. The inclusion of other search terms “period after opening” OR “shelf-life” factor* OR “shelf-life” risk* were considered as “secondary shelf-life” alone may produce scarce results. However, PaO refers to cosmetics, not food, and the shelf-life searches do not consider SSL. These searches would therefore not be relevant and would produce limited results.

2.3. Data Collection and Analysis

After studies were uploaded to Covidence, duplicates were removed manually and by Covidence. The remaining studies were then manually screened by reading the titles, abstracts and searching for the term ‘secondary shelf life’ in the paper (Polanin et al., 2019). The study was excluded if the term was not found in the research paper and the abstract was not relevant to SSL.

After screening, the remaining studies were reviewed and critically appraised during the full text review. Papers were excluded if the mentions of SSL were not relevant to the overall aim of the study, for example if SSL definitions were included in research about regular shelf-life testing. Studies were also discarded if there was limited access to the article. The reasons for exclusion as well as the number of studies present during each stage of the screening process was recorded to be displayed in a PRISMA chart. This is because PRISMA charts ensure transparency, which is critical for systematic reviews (Randles and Paul, 2023).

Covidence was used for data extraction and analysis. Due to the variety of the research, a method of extraction considering research questions, methods, and outcomes was manually developed and used (Randles and Paul, 2023).

As research included both qualitative and quantitative studies, literature was firstly divided by research type and labelled accordingly. Quantitative studies were then further classified by:

- The method used to assess the SSL:
    - Microbiological analysis
    - Sensory analysis
    - Physiochemical analysis
- The objectives established in section 1.7:
    - The factors affecting the SSL of food.
    - The accuracy of current SSL labelling for food.
    - The efficacy of modelling to predict the SSL of food.
    - The risks of SSL extension on food.

The number of studies in each category was recorded to be displayed in a flowchart. It is important to note that research may contain more than one of the methods to assess the SSL and may answer more than one of the objectives. Additionally, any topics observed in research that did not fit the objectives were recorded.

Qualitative research was divided by only objectives, as the methods used to assess the SSL are more relevant to quantitative literature. The key themes and findings were extracted, and the outcomes were recorded (Randles and Paul, 2023).

A narrative synthesis was used to combine obtained data. This is because the topic has produced studies diverse in design, interventions and outcomes, which would not be suitable for a meta-analysis (Cochrane Consumers and Communication Review Group and R, 2013) This means that a statistical analysis on the results was not conducted (Randles and Paul, 2023).

2.4. Critical Appraisal and Risk of Bias

As systematic reviews can be affected by bias, a critical appraisal was completed using the CASP checklist, to ensure a more systematic approach to examining research (Randles and Paul, 2023). The full checklist is shown in **appendix 1.**

2.5. Limitations

A limitation is that single screening was used. It is generally recommended that a systematic review is conducted by 2 independent reviewers, as single screening can increase the risk of missed studies (Waffenschmidt et al., 2019). Additionally, the use of grey literature in a study is difficult to locate and to analyse the credibility of the source (Benzies et al., 2006). The access issues present may also miss valuable information on the scarce topic.

3. Results

The results will firstly discuss the data collection and analysis from the identification and screening process. Each objective will then be analysed based on the results of the available literature.

3.1. PRISMA chart and data grouping

During data collection, the majority of literature was obtained from Google Scholar, with the remainder of the databases providing less than 50 papers. A large portion of the studies were also removed during duplicate identification and screening. Whilst this is expected for a systematic review, it could demonstrate that SSL is not often the main research objective when discussed in research.

After the identification and screening process, 36 studies were included in the review. A full list of the studies is displayed in **appendix 2.** The identification and screening process is displayed in a PRISMA chart, shown in **figure 4**.

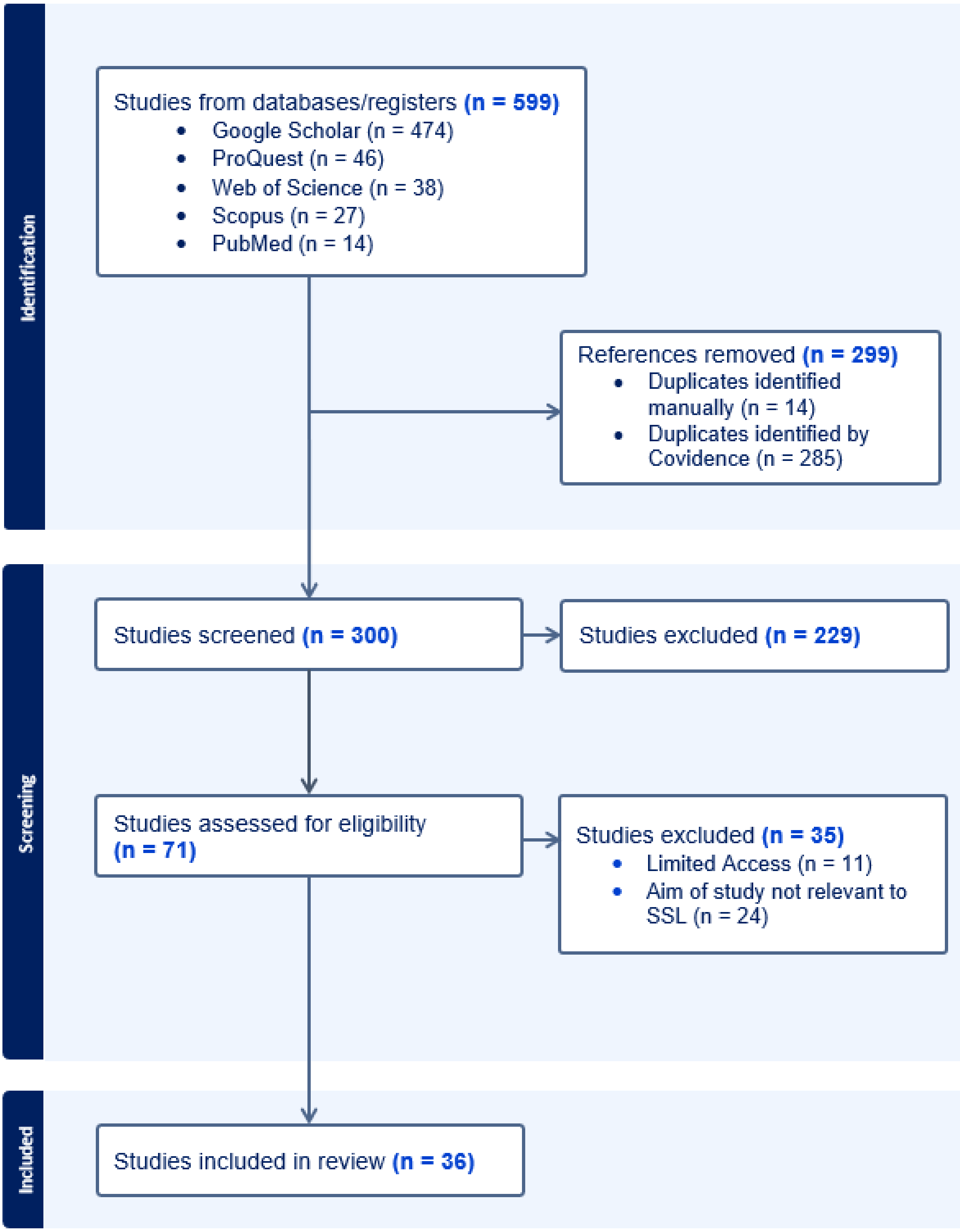

FIGURE 4: THE PRISMA CHART FOR THE SYSTEMATIC REVIEW

The publication dates from the included literature are shown in **figure 5** below.

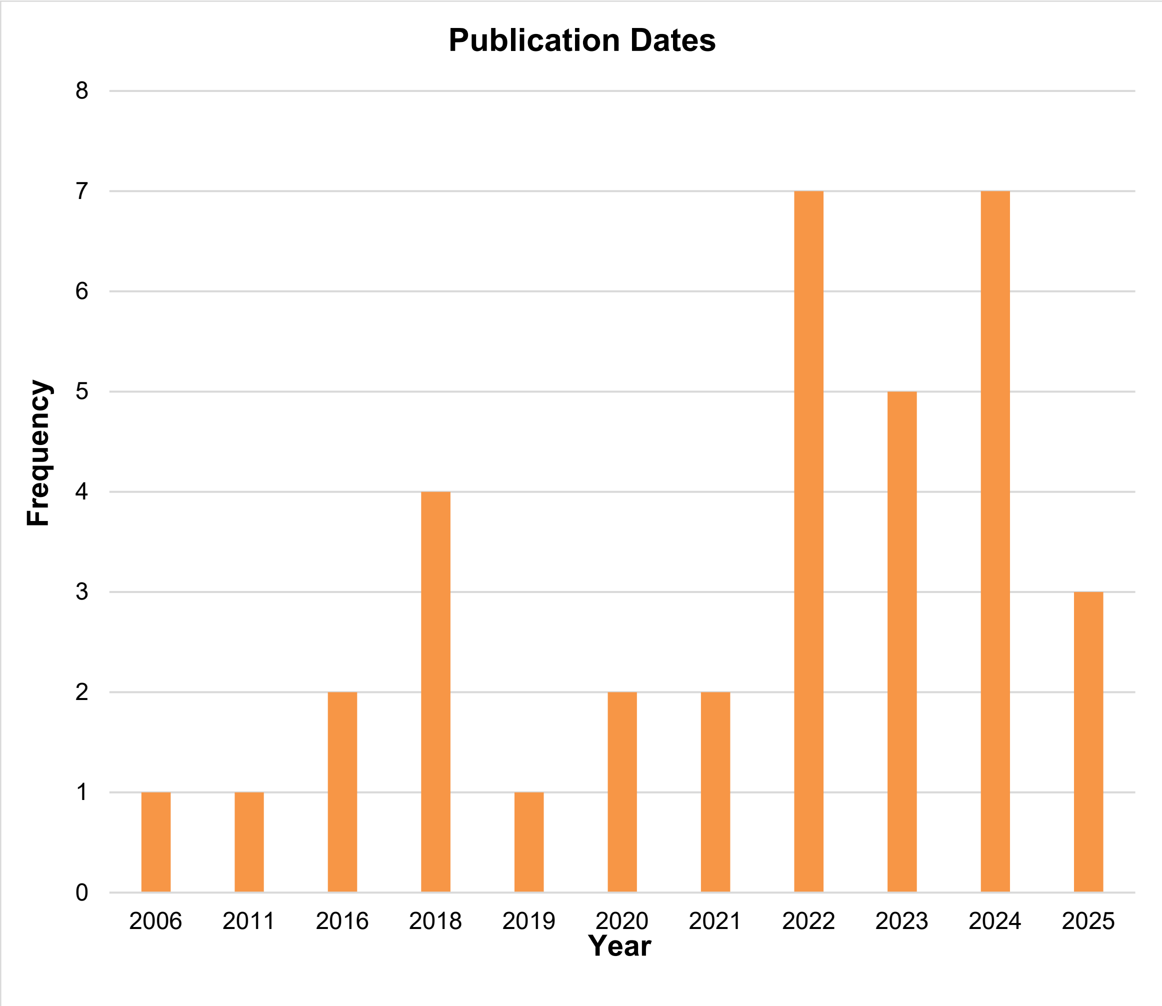

FIGURE 5: THE PUBLICATION DATES FOR INCLUDED LITERATURE

Research has overall been completed in recent years, with the majority of studies published after 2020. This shows that SSL is a newly emerging area of research and interest in the topic is increasing. There are also high numbers of publications from this current year (2025) showing that research on SSL is continuing to develop. This further emphasises the importance of a systematic review, as research gaps and the best practices can be highlighted for future research.

The flowchart from the division and classification of data is displayed in **figure 6** below.

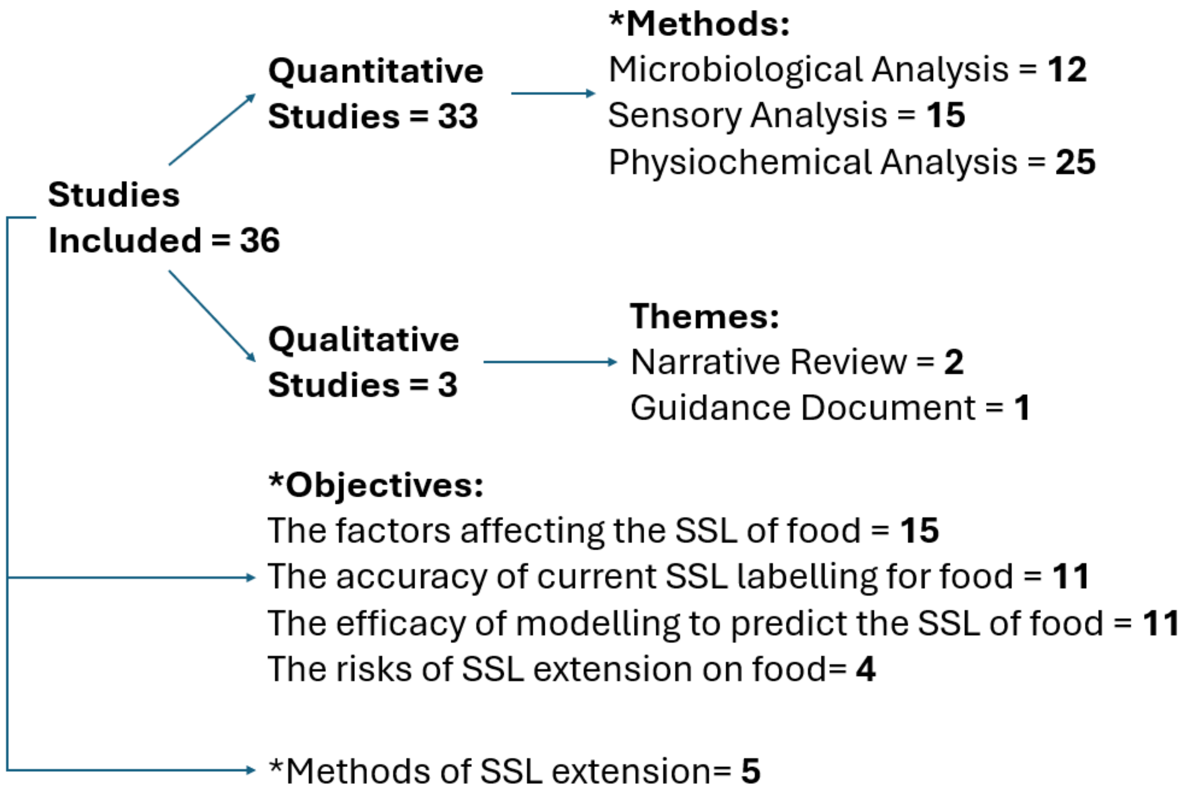

FIGURE 6: THE GROUPING CRITERIA FOR THE INCLUDED LITERATURE. HEADINGS MARKED WITH AN ASTERISK (*) WILL TOTAL TO MORE THAN 36.

The majority of the studies included were of quantitative research, with a small fraction containing qualitative methods. This is expected as SSL date labelling is expressed as numerical time durations.

With the exception of the risks of SSL extension objective, there was an overall balance of literature for each objective. This balance was not observed when extracting the methods used in quantitative research. Physiochemical analysis was the most popular method and was observed 52% and 40% more than microbiological analysis and sensory analysis, respectively.

Research on methods of SSL extension was also observed in the literature. Despite SSL extension methods being excluded from the objectives, the studies were recorded as the probability for SSL extension can be identified and analysed.

3.2. The Factors Influencing the Secondary Shelf-Life of Food

From the included studies, a significant proportion assess the factors influencing the SSL. The quantitative literature targeted towards this objective is shown in **table 2** below, where the factors assessed and the methods used are highlighted.

TABLE 2: DETAILS OF RESEARCH ASSESSING FACTORS INFLUENCING THE SECONDARY SHELF-LIFE

Reference	Food	Factors assessed	Analysis used	Method details	Conclusions
(Orfanou, Dermesonlouoglou and Taoukis, 2019)	Coffee	**Temperature** 25°C, 35°C and 45°C **a_w** 0.15, 0.22, 0.33 and 0.52	Sensory	10 trained panellists assessed aroma intensity, aroma quality, aftertaste and off-flavour on a 9-point magnitude scale	a_w and temperature are key factors influencing SSL of coffee. Sensory analysis can measure quality loss.
			Physio-chemical	Storage temperature (°C) and a_w	
(Trenzová et al., 2024)		**Packaging** -Glass container -Steel can -Paper sachet -Composite pouches	Physio-chemical	Moisture, water content, and VCs by GC/MS	Packaging does not prevent the loss of VCs and degradation products from oxidation.
(Tušek, Benković and Bauman, 2015)		**Packaging** -Tin can -Triplex bags	Physio-chemical	Colour by a Spectro-photometer	Colour change indicates food degradation; tin can packaging was the most effective.

(Anese, Manzocco and Nicoli, 2006)		**a_w** 0.09, 0.17, 0.23, 0.36, and 0.44	Sensory	Survival analysis testing. Stopped when ½ of panellists deemed unacceptable.	VCs remained stable at a_w values lower than 0.3, loss was observed once a_w is higher. End of SSL was 20 days at a_w values lower than 0.36. Decreased to 13 days with a_w values of 0.44.
			Physio-chemical	Total solid content, a_w, and VCs.	
(Makri et al., 2011)		**Temperature** 25°C, 35°C and 45°C **a_w** 0.15, 0.22, 0.33 and 0.52	Sensory	8 trained panellists rated aroma intensity, aftertaste, off-taste, overall impression and sample acceptability.	Increased temperature (45°C) and a_w (0.52) decreased SSL from 92 days to 20 days. Aroma is a good indicator for coffee staling in sensory testing.
			Physio-chemical	Measured VCs by GC/MS	
(Smrke et al., 2022)		**Packaging** -Airtight canister -Sealed with tape -Sealed with clip -Integrated screw cap	Physio-chemical	Measured VCs by GC/MS	Integrated screw cap was the most effective. Sensory testing should be completed in addition to determine an acceptable threshold.
(Bianchi et al., 2022)	Wine	**Packaging** -Natural cork -Polymeric -Stelvin -Crown cap -Tetrabrick	Physio-chemical	pH, alcohol content, volatile acidity, total polyphenols, proanthocyan-idins, total SO_2 and free SO_2	Polymeric stopper was useful for repeated opening. Cork stopper was not suitable. Other packaging showed critical issues.
(Bianchi et al., 2023)		**Packaging** -Screw cap -Natural cork -Crown cap -Tetrabrick -Polymeric	Sensory	10 panellists measured quantitative parameters, hedonic parameters, and overall hedonic index	The SSL is dependent on several factors. SO_2 and sensory decay are indexes of wine depletion. Polymeric cap performed the

			Physico-chemical	pH, alcohol content, volatile acidity, total polyphenols, proanthocyan-idins, total SO_2, free SO_2, anthocyanidins, colour intensity and tonality.	best, whilst other closures were not suitable for SSL.
(Wang et al., 2023)	Infant Form-ula	**Temperature** 25°C and 37°C **Humidity** 32%, 57% and 75%	Physio-chemical	Colour, lysine, maillard reaction products and pH	Maillard reaction products can predict the SSL and temperature decreased SSL.
(Calligaris et al., 2022)	Olive Oil	**Temperature** 25°C, 40°C, 50°C and 60°C	Physio-chemical	Fatty acid composition, total phenolic compounds, tocopherols, pyropheophytin a (PPP)	10°C increase leads to four times reduction of SSL. Peroxide values and PPP were the best indicators of product quality. Primary oxidation and antioxidant content did not significantly change during storage.
(Lacivita et al., 2023)	Gnocc-hi	**Temperature** 4°C and 20°C	Micro-biological	Plate count technique which tested total mesophilic bacteria, coliforms, yeasts, moulds, lactobacilli and *staphylococcus*	Visible moulds were observed, and samples were rejected after 21 days for 4°C and 4 days for 20°C.
			Sensory	7 panellists judged parameters from 1 to 9, where 5 was deemed unacceptable.	
			Physio-chemical	pH and moisture content.	

(Bianchi et al., 2024)	Bread	**Formulation** -flour type -leavening agent **Packaging** -MAP with air or MAP with argon	Sensory	10 panellists ranked 7 parameters and gave an overall hedonic index on a scale of 0-10	No statistical significance on packaging as the MAP is depleted, but differences occurred in leavening agent type. The hedonic index can mark SSL acceptability.
(Manzocco et al., 2020)	Cracker	**Temperature** 20°C, 40°C and 60°C **Oxidation** Oil with peroxide values of 5,11 and 25 $mEqO_2/kg_{oil}$	Physio-chemical	Moisture, colour, peroxide value	Oil with peroxide values from 5-15 $mEqO_2/kg_{oil}$ shortened SSL by 50%, irrespective of temperature. Rancid odour was an effective method to detect unacceptability.
			Sensory	30 panellists sniffed the product and marked the aroma intensity from 1 to 7.	

Coffee was the most researched product with 6 studies, followed by wine with 2 studies. With the exception of gnocchi, the foods assessed would overall be classified as shelf-stable ambient products vulnerable to contamination or food quality loss after package opening.

Temperature, packaging, and a_w were the dominating factors assessed in research. Physiochemical analysis was the most popular assessment method, where pH, a_w, and VC concentration were the most frequent properties measured. The measurement choice was however dependent on the product, as quality indicators can vary based on the food. An example is the measurement of total and free SO_2, which was only used to in wine to assess the oxidation rate (Bianchi et al., 2023).

Although not as frequently used, sensory testing was highlighted as important for marking product unacceptability (Manzocco et al., 2020; Smrke et al., 2022; Bianchi et al., 2024). Similar sensory testing occurred across literature, where the use of trained panellists, measuring aroma intensity, aftertaste and off-flavours, and giving an overall hedonic index on a numerical scale were observed (Makri et al., 2011; Orfanou, Dermesonlouoglou and Taoukis, 2019; Manzocco et al., 2020). The marker for unacceptability was also similar across studies, where testing often finished after a significant number of panellists deemed the product as unacceptable (Anese, Manzocco and Nicoli, 2006).

As previously discussed, the indicators of product unacceptability were dependent on the food and varied from peroxide values in oil to colour change and the loss of VCs in coffee (Anese, Manzocco and Nicoli, 2006; Tušek, Benković and Bauman, 2015; Manzocco et al., 2020; Calligaris et al., 2022). Overlapping methods were however observed in different products. It was identified that aroma was an effective method to detect unacceptability in both oil and coffee, which indicates that it could be an acceptability marker in products (Makri et al., 2011; Manzocco et al., 2020)

Although quantitative literature was the dominant form of research, qualitative studies identified and discussed the factors influencing SSL. The ESFA guidance document identified that intrinsic, extrinsic and implicit factors influence the SSL once the packaging is opened and accelerate product unacceptability (Koutsoumanis et al., 2021). Key factors listed include the depletion of MAP during opening, temperature changes during domestic use, a_w, and pH (Koutsoumanis et al., 2021). Likewise, a separate study identified pH and a_w as major factors that can determine the rate of spoilage (Nicoli and Calligaris, 2018). This study also identified factors that affect SSL in foods with a longer shelf-life, including oxidation, crystallisation and moisture changes (Nicoli and Calligaris, 2018).

Overall, research identified temperature as one of the main factors influencing SSL. A study assessing temperature changes in oil stability during its SSL concluded a 10°C increase in storage temperature led to a four-time reduction of shelf-life (Calligaris et al., 2022). Visible moulds were also observed on Gnocchi after 21 days when stored at 4°C, but only 4 days when stored at 20°C (Lacivita et al., 2023).

Higher a_w values were associated with a shorter SSL in studies, although this research was primarily targeted towards coffee. It was identified that VCs will remain stable at a_w values lower than 0.3, but a loss is observed once the a_w is higher (Anese, Manzocco and Nicoli, 2006). The end of the SSL was approximately 20 days at a_w values lower than 0.36, which decreased to 13 days when the a_w reached 0.44 (Anese, Manzocco and Nicoli, 2006). A similar conclusion was observed in a separate study, which identified both temperature and a_w as the key factors influencing the SSL of coffee (Orfanou, Dermesonlouoglou and Taoukis, 2019).

Although different packaging methods were frequently assessed, mixed results were observed. It was concluded that the polymeric cap was the most suitable for wine subject to repeated opening, whilst literature assessing the packaging influence on the SSL of bread showed no significant differences as the MAP was depleted once the analysis took place (Bianchi et al., 2022; Bianchi et al., 2023; Bianchi et al., 2024). It was observed that packaging is generally poor at preventing degradation in coffee and wine after opening, showing that packaging is more effective for extending the products PSL (Bianchi et al., 2022; Trenzová et al., 2024).

However, SSL assessments were only completed on a few select foods. These foods were not diverse, and the majority of research was focused on coffee. To further expand research, factors like temperature, a_w and packaging should be assessed on a wider range of foods.

3.3. The Accuracy of Current Secondary Shelf-Life for Food

In addition to the factors influencing SSL, literature assessing the accuracy of SSL labelling in food was a notable area of research. The quantitative research regarding the accuracy of current SSL labelling is shown in **table 3** below.

TABLE 3: DETAILS OF LITERATURE ASSESSING THE ACCURACY OF SECONDARY SHELF-LIFE LABELLING

Reference	Food	Analysis used	Method details	Conclusions
(Sousa et al., 2016)	Ham	Micro-biological	Challenge tests: Products inoculated with *Listeria* and stored at 12°C for 3 days. Assessed growth potential of *Listeria* where a value of 0.5log^{10} CFU indicated no significant growth.	The 3-day SSL was considered valid for product A as it did not support *Listeria* growth. The SSL for product B could not be validated as microbial growth was observed 24 hours after opening.
(Spampinato et al., 2022)		Micro-biological	Measured total aerobic bacteria, LAB, enterobacteria, fungi and putative staphylococci.	Negatives changes were observed after 8 days, and the product was unacceptable after 12 days. Overall acceptable past the advertised 1–3-day SSL.
		Sensory	Trained panellists evaluated the products odour, colour and texture on a 0-5 scale.	
(Nicosia et al., 2021)	Pesto	Micro-biological	Measured total aerobic mesophilic and *Clostridium spp.*	Highest microbial load was 3 orders of magnitude lower than the acceptability limit. Product was acceptable after 20 days, could extend SSL from 5 days to 20 days.
		Sensory	Triangle test was completed on 12 panellists; acceptability was marked on a 0-10 scale.	
		Physio-chemical	Measured colour, a_w, pH and VCs.	

(Nicosia et al., 2023)	Bolog-nese sauce	Micro-biological	Measured aerobic mesophilic count, yeasts and mould.	The SSL could be extended to 13 days compared to the 5 days indicated on the label, although results should be further confirmed by further studies.
		Sensory	10 panellists assessed the product on a 0-10 scale, unacceptable at 40% rejection.	
		Physio-chemical	Measured pH.	
(Díaz, 2016)	Pâte	Physio-chemical	Measured moisture, pH and colour.	Concluded an SSL date of 8 days for pâte, although they must be stored at 4°C during the SSL.
		Micro-biological	Measured total aerobic microorganisms and enterobacteria.	
(Nicosia et al., 2022)	UHT Milk	Micro-biological	Measured aerobic mesophilic bacteria, lactic acid, yeasts, moulds and pseudomonas. Acceptability limit of 6log10 CFU.	Regarded as microbiologically unacceptable after 7 days, which was characterised by a low pH and high microbial load. SSL could be reassessed to 6-7 days from the 1-2 days on labels.
		Sensory	12 panellists conducted 2 separate tests: triangle test when unacceptability was marked as 8/12 guessing correctly, and acceptability tests where 40% rejection marked the product as unacceptable.	
		Physio-chemical	Measured colour and pH.	
(Isasi, 2017)	Cheese	Micro-biological	Measured staphylococcal enterotoxins, *Salmonella* and *Listeria monocytogones.*	The SSL on cheese A was correct as the product remains acceptable after 5 days. Cheeses B and C did not indicate their SSL on the labelling and their estimated SSL is less than 3 days.
		Sensory	Panellists used descriptive sensory testing and recorded the texture, sound, odour and taste.	

		Physio-chemical	Measured a_w and pH.	
(Condurso et al., 2020)	Infant Formula	Physio-chemical	Measured VCs, Maillard reaction products and lipid peroxidation products.	The SSL is dependent on the composition of infant formula, so should either be amended or removed from the labelling.
(Li et al., 2024)		Physio-chemical	Measured VCs including aldehydes, ketones, alcohols, furans, sulphides, esters and terpenoids.	The VCs changed significantly within 7 days of the SSL, and the odour changed significantly within 3 days of the SSL.
		Sensory	24 panellists conducted a triangle test 0,3 and 7 days after opening.	
(Volpe et al., 2020)	Croiss-ants	Sensory	Completed a survival analysis using check all that apply questions.	Croissants A and B had an SSL of 22±2 and 11±2 hours respectively. Product B had a shorter SSL due to the high fat content.

A greater variety of foods and a higher proportion of quantitative studies was observed in these studies compared to the research assessing the factors influencing SSL. Microbiological analysis was the most popular method used to determine the SSL, with 7 out of the 10 studies listed in **table 3** conducting some form of microbiological experiment. The studies often measured pathogens such as *Listeria monocytogones*, *Salmonella spp.* or *Clostridium spp.*, as well as total aerobic bacteria, total mesophilic bacteria, lactic acid, yeasts and moulds. An acceptability limit of 6log10 CFU was also established in a study (Nicosia et al., 2022). The use of microbiological analysis contrasts with results on the factors influencing SSL, where microbiology was only used in one study.

In addition to microbiological analysis, sensory analysis was a popular method choice, where the triangle test and marking for unacceptability were the most common methods used. A 40% panellist rejection was overall used in unacceptability tests, and 75% of panellists correctly guessing the sample was used as the acceptability limit in triangle tests (Nicosia et al., 2022; Nicosia et al., 2023). The majority of studies however used a combination of physiochemical, sensory and microbiological methods to measure the SSL labelling accuracy.

To reflect the real-world conditions that products may typically experience during the SSL, a domestic simulation was often used. This included opening the samples at room temperature, leaving the package open, removing product, closing packaging, then placing back in the refrigerator. Domestic refrigerators were also used during this simulation, where the temperature fluctuations were recorded. This method therefore considers the variability of consumers behaviour during product storage.

Several papers concluded that the assessed SSL in the experiment was greater than indicated on the label, and an SSL extension in labelling is possible. Research concluded that pesto presented an SSL of 20 days compared to the 1-3 days on the label, Bolognese sauce demonstrated a 12-day SSL compared to the advertised 5 days, and UHT milk was given an SSL of 6-7 days compared to the 1-2 days on the labelling (Nicosia et al., 2021; Nicosia et al., 2022; Nicosia et al., 2023). It is important to note that these experiments were conducted by the same authors, and that results should be confirmed in further studies by different authors to see if similar results are obtained (Nicosia et al., 2023).

Results from studies analysing the same food product however showed mixed results. A study on ham in one experiment concluded an SSL of 8 days was suitable, compared to the advertised 1-3 days on the labelling (Spampinato et al., 2022). On the other hand, a different study regarding ham confirmed an SSL of 3 days was suitable for sample A, but the SSL could not be confirmed for sample B as microbial growth was observed after package opening (Sousa et al., 2016). Ham is regarded as a highly perishable product, and these mixed results could indicate that an SSL extension may not be suitable and may instead pose a risk to food safety. However, the source of the microbial growth may not be from environmental contamination and could be due to other processes, so attention is therefore required at all stages of food production.

Research overall concluded that due to the inaccuracy and variability regarding SSL date labelling, labels should be amended either by SSL extension or completely removing the SSL from labelling (Condurso et al., 2020). The extension or elimination of SSL was further suggested in a separate study (Mansor et al., 2023). This study described the benefits of SSL elimination, including a significant reduction in food waste, savings for domestic households, and increased competitiveness amongst manufacturers as consumers would choose products with a longer shelf-life (Mansor et al., 2023). However, further testing is required on different products to increase the reliability of this conclusion.

3.4. The Efficacy of Modelling to predict the Secondary Shelf-Life of Food

Modelling, despite being developed as a relatively recent method of shelf-life testing, was identified as a key area of research for SSL. The details and conclusions in the literature regarding SSL modelling are displayed in **table 4** below.

TABLE 4: DETAILS OF LITERATURE ASSESSING THE EFFICACY OF SECONDARY SHELF-LIFE MODELLING

Reference	Modelling details	Conclusions
(Foteini Orfanou, Dermesonlouoglou and Taoukis, 2019)	Used the Guggenheim Anderson-de Boer model for modelling the temperature and A_w change in coffee, kinetic models to determine the quality loss, and Weibull hazard analysis to predict the SSL.	Modelling is an effective tool for food waste reduction and could be used to take more variables into account.
(Tušek, Benković and Bauman, 2015)	Used first and zero order kinetic models to model colour changes in coffee.	Whilst both modelling methods were considered significant, zero order kinetics is recommended as it is easier to use.
(Benković and Tušek, 2018)	Used linear and nonlinear regression models to model colour changes in coffee.	Both models showed intrinsic and extrinsic factors influence coffee colour change. The nonlinear model was the most suitable as all parameters were significant.
(Lee, 2024)	Used first and zero order kinetic models to relate package opening time to food quality deterioration rate shift.	Modelling could work alongside other shelf-life predictors like ASLT but further data on food quality degradation during the SSL is required.
(Lacivita et al., 2023)	Developed a model on the dependence of the SSL on the RSL in gnocchi.	The model was acceptable despite its simplicity, and the SSL was most dependent on the gnocchi moisture.
(Manzocco et al., 2020)	Used zero order kinetic and one step nonlinear regression models to determine the SSL of crackers based on their oxidation rates	Indicators of SSL unacceptability can be used to develop self-life predictive models.
(Anese, Manzocco and Nicoli, 2006)	The Guggenheim Anderson-de Boer model was used to model the SSL depending on the A_w and temperature of coffee.	Although modelling can be used to predict SSL, it can be difficult to identify the main factor of decay, the point at which product unacceptability is determined, and the interference of other environmental factors.
(Dimopoulos et al., 2024)	The SSL of dehydrated spinach was modelled by microbial growth. Used the Gompertz model.	Modelling microbial growth is effective at determining product acceptability limits.
(An and Lee, 2024)	Used a mathematical model based on the sorption isotherm	Models are helpful for estimating SSL, but further research is

	and packaging moisture transmission of products.	required on different food products.
(Calligaris et al., 2022)	Used mathematical modelling based on the Arrhenius equation and a zero-order reaction model to show the influence of temperature in extra virgin olive oil.	Temperature is the most common factor affecting shelf-life and could be used as the critical factor in SSL modelling.
(Wang et al., 2023)	The Arrhenius model was used to predict SSL in infant formula.	The model only considered indicators related to non-enzymatic browning so has limitations.
(Nobile and Conte, 2023)	Modelled the dependence of SSL on RSL using first order kinetics.	More attention should be given to the main factors responsible for food quality decay after package opening.

Literature overall used a range of methods for modelling. First and zero-order kinetics were used in one study to model the colour change in coffee, where zero-order kinetics was recommended as the most suitable method (Tušek, Benković and Bauman, 2015). Linear and nonlinear regression models were used in a separate study to visualise colour changes in coffee, where the nonlinear model was regarded as the most suitable as all parameters were significant (Benković and Tušek, 2018). However, kinetics and regression models were used in a range of studies beyond modelling colour changes in coffee, demonstrating they can be used for a wide range of foods (Manzocco et al., 2020; Nobile and Conte, 2023; Lee, 2024).

Other common equations used in modelling included the Arrhenius equation, the Guggenheim Anderson-de Boer model, and the Gompertz model (Anese, Manzocco and Nicoli, 2006; Foteini Orfanou, Dermesonlouoglou and Taoukis, 2019; Calligaris et al., 2022; Wang et al., 2023; Dimopoulos et al., 2024). The SSL was also modelled in relation to the Residual Shelf Life (RSL) in some studies, which is defined as the time difference between the PSL and product unacceptability (Lacivita et al., 2023; Nobile and Conte, 2023). This shows that a variety of methods using a range of equations can be used to model a products SSL.

In research, the topic of modelling was often included alongside literature investigating the factors influencing SSL. In particular, research identifying the factors influencing the SSL of coffee often included some form of modelling to strengthen the conclusion. The models created were therefore simple in design and were only based on the variable assessed in research. Literature concluded that this form of modelling can be used as an effective tool for SSL prediction alongside ASLT and could contribute to food waste reduction (Anese, Manzocco and Nicoli, 2006; Lee, 2024). However, several variables influence SSL, increasing the complexity and limiting the application of modelling (Anese, Manzocco and Nicoli, 2006; Foteini Orfanou, Dermesonlouoglou and Taoukis, 2019; Lee, 2024)

Studies have overall suggested that further research is required on a wider range of foods, as well as on the main factors responsible for decay during the SSL, as it can be difficult to conclude the main factor of product decay (Anese, Manzocco and Nicoli, 2006; Nobile and Conte, 2023; An and Lee, 2024). A separate study identified temperature as the most common factor affecting SSL and suggested that temperature could be used as the main factor in SSL modelling (Calligaris et al., 2022). However, other studies have suggested several variables need to be considered due to the complexity of SSL (Benković and Tušek, 2018; Lee, 2024).

3.5. Methods of Secondary Shelf-Life Extension for Food

Although the methods of SSL extension were excluded from the research objectives of this systematic review, the topic was included in the results due to the relevance to food waste reduction and the significant presence of the topic in literature. Whilst fewer studies were overall relevant compared to the previous objectives, research has been published recently, with 3 out of 5 papers being published this current year. This demonstrates that the topic is a newly developing area of research.

Studies varied in design and included assessments on the foods as well as packaging. A compound used in 2 different studies was Ethyl Lauroyl Arginate (LAE), where it was concluded to be effective in microbial inhibition in both the packaging and in food (Nicosia, Pulvirenti and Licciardello, 2022; Nicosia, Pulvirenti and Licciardello, 2025).

A range of foods were assessed, with a primary focus on perishable products containing a shorter SSL. The SSL extension of meat and meat-based products was assessed in 2 separate studies, which analysed the use of an antioxidant gel and a phenolic extract from olive vegetation waters (Sordini et al., 2025; Pitirollo et al., 2025). The products overall were successful in SSL extension, preserved the meat from oxidation, and research on the phenolic extract concluded that olive vegetation waters could be a sustainable 'clean label' approach to preservative use (Sordini et al., 2025; Pitirollo et al., 2025). Beyond animal products, a separate study used dehydrated spinach, where it was concluded that osmotic dehydration combined with pulsed electric field treatment increases the SSL to 33 days under chilled storage (Dimopoulos et al., 2024).

The different methods overall produced significant results and were successful in demonstrating the possibility of SSL extension, particularly for highly perishable products. However, only 5 studies in the overall literature discussed SSL extension methods. Further research is therefore required on a wider variety of food products to determine successful methods.

3.6. The Risks of Secondary Shelf-Life Extension for Food

Despite the risks of SSL not being as prevalent as the other research objectives, literature concerning the subject was important to consider due to the consequences of SSL overestimation.

The results regarding the accuracy of current SSL labelling have demonstrated that SSL extension is possible, and the research concerning methods of SSL extension shows significant results in the reduction of oxidation reactions. However, it is critical to identify the risks of both SSL determination and extension to keep food safety a priority in manufacturing. Although the risks associated with SSL contained mostly qualitative literature and the topic was not as frequently discussed as the other objectives, the methods of contamination that reduce the SSL were highlighted. Risk-based decision trees were also used to identify the products that SSL labelling would be suitable for.

The ESFA guidance document identified that contamination could occur after package opening which can introduce pathogens into the food, either by environmental contamination or by pathogens like *Staphylococcus Aureus* from human handling (Koutsoumanis et al., 2021). This contamination route was identified in a different study, where it concluded that the potential routes of contamination should be considered during SSL determination (Nicoli and Calligaris, 2018). Consumer behaviour is acknowledged as an additional risk as there is a probability that the food is stored or handled incorrectly (Koutsoumanis et al., 2021).

Contamination after package opening should not be the only route of contamination considered during SSL determination. Research assessing the SSL of cooked ham observed a high microbial load despite acceptable scores in sensory testing, which was marked as a significant concern (Spampinato et al., 2022). It was noted that the microbiological growth was not due to contamination and was instead present before the pack was opened (Spampinato et al., 2022).

Regarding the risk-based decision trees, the decision tree from the ESFA displayed in **figure 2** concludes that not all products require SSL labelling, as the risk of the food is dependent on the individual products intrinsic, extrinsic and implicit factors before and after package opening (Koutsoumanis et al., 2021). Examples of foods that may require SSL labelling were given, including UHT milk in aseptic packaging, fresh meat and vacuum-packed meat in MAP, and a mixed salad in MAP (Koutsoumanis et al., 2021). However, a separate study concluded SSL labelling would not be required on highly perishable products as the SSL would contain a similar date to the PSL (Nicoli and Calligaris, 2018). Instead, it was suggested that SSL labelling should be listed on products with a longer shelf-life as the SSL is significantly reduced after package opening (Nicoli and Calligaris, 2018). The study further explained the reasoning and identified that whilst the changes that occur to shelf-stable foods after opening will mostly only affect food quality, some changes could lead to mould growth and mycotoxins (Nicoli and Calligaris, 2018). A risk-based decision tree was then designed, shown in **figure 7**.

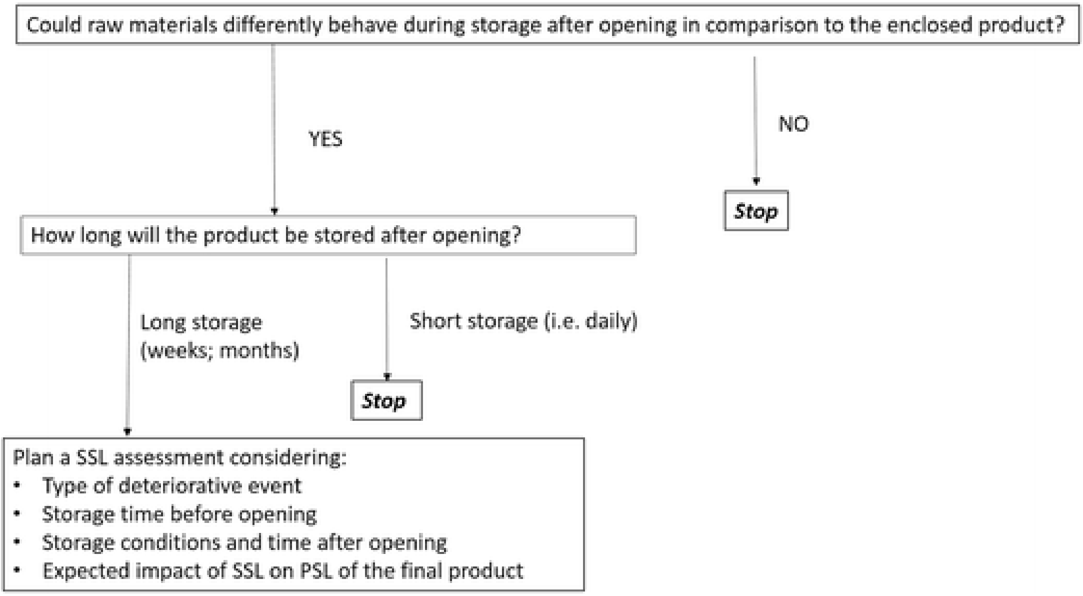

FIGURE 7: A RISK-BASED DECISION TREE IDENTIFYING THE PRODUCTS REQUIRING SECONDARY SHELF-LIFE LABELLING (NICOLI AND CALLIGARIS, 2018).

Microbiological risk assessments were completed in addition to decision trees. A separate research paper conducted a microbiological risk assessment for the growth of *Listeria Monocytogenes* on deli meats, as RTE foods like deli meat are high risk foods that can present an ideal environment for pathogenic bacteria (Maciejewska et al., 2024). It concluded that over the 5 days of the listed SSL, the listeriosis risk could be overestimated when excluding product spoilage (Maciejewska et al., 2024). This potential for overestimation was also identified in the guidance document, where it is stated that uncertainties considered during SSL assessments may overestimate the risk for products (Koutsoumanis et al., 2021).

Although further research is required regarding the products eligible for SSL labelling, the studies overall highlight the uncertainties that need to be considered during the SSL determination as well as the routes of contamination.

4. Discussion

The results from the systematic review can therefore be used to provide answers to the research questions. The knowledge identified during the introduction can also be further developed, as well as identifying research gaps, limitations and recommendations for research and future practices.

4.1. What are the factors that affect the Secondary Shelf-Life of food?

The results identify that the critical factors influencing the SSL of food are temperature, a_w, and packaging. These were assessed to the greatest extent in literature, where it was concluded a higher temperature and a higher a_w value decreases the SSL. This is because these conditions provide an ideal environment for the chemical reactions that lead to microbial growth and food spoilage (Nicoli and Calligaris, 2018). Packaging, regardless of the type, was overall considered ineffective in SSL preservation as the atmospheric conditions were depleted after package opening.

These results therefore suggest that like PSL, the SSL is influenced by both intrinsic and extrinsic characteristics. However, these factors will have a greater impact on the SSL, as the reactions that occur during food degradation are accelerated once packaging is opened.

On the other hand, the results summary excludes literature establishing that several factors influence the SSL. Whilst they may not be as critical as temperature, a_w and packaging, they can have a significant effect on the SSL. Examples identified in research include the risk of environmental contamination after package opening and incorrect storage conditions by the consumer after purchase (Koutsoumanis et al., 2021). This further increases the complexity of an accurate SSL determination, as food manufacturers need to consider all variables and uncertainties in addition to the mechanisms of food spoilage.

The summary also excludes a range of products, as the research is targeted towards ambient shelf-stable foods that undergo spoilage after opening. Although it is established that a_w is a critical factor in highly perishable food, it is difficult to conclude if the identified factors are critical to all foodstuffs (Gaikwad, Singh and Ajji, 2018). For example, frozen foods were not considered in the results, and due to the low storage temperature, are unlikely to have temperature as a critical factor.

The results consider the key deteriorative reactions that occur in food spoilage, shown in **table 1**. Some of the reactions listed for ambient products were measured in studies, such as the oxidation rate in crackers and non-enzymatic browning in the form of the Maillard reaction in infant formula (Manzocco et al., 2020; Wang et al., 2023). Microbial growth and the appearance of mould was also assessed in both chilled and ambient gnocchi (Lacivita et al., 2023). Research was however lacking in assessing other reactions observed in chilled and frozen foods such as oxidation.

Studies also build on the existing knowledge of shelf-life testing. As shown in **figure 3,** the determination of the critical factor is the first stage of shelf-life testing (Calligaris et al., 2019). As the results identified critical factors, the application could advance SSL testing. This would be beneficial because shelf-life testing is generally applied to packed foods, and the expansion could increase the accuracy of SSL determination (Calligaris et al., 2019).

After identifying the critical factor, shelf-life testing then requires an acceptability limit. Whilst this is typically completed by finding relevant legislation, identifying the shelf-life of similar products, and sensory analysis, the resources for this are lacking regarding SSL, especially in the legislation (Calligaris et al., 2019). The results from this systematic review suggest that sensory testing is effective at detecting product unacceptability, indicating methods used for PSL testing can be transferred to SSL. This could therefore provide guidance to food manufacturers in regard to SSL determination and could aid in closing the gap in SSL legislation. Acceptability limits however require a safety margin to ensure the product is not a risk to public health, which was not discussed in research (Calligaris et al., 2019).

The expansion of shelf-life testing knowledge can also benefit SSL modelling. Modelling is described as an alternative to ASLT and real time shelf-life testing but requires the identification of the critical factor to be reliable (Piergiovanni and Limbo, 2019; Calligaris et al., 2019). The results identifying critical factors increases the accuracy of modelling, leading to a more reliable SSL prediction.

Despite a high proportion of included studies focusing on the factors that influence SSL, there were limitations in the results. The products tested are limited in variety, as they were dominated by coffee and other shelf-stable products that can be stored at ambient temperatures, and did not contain RTE foods, a product rising in popularity in recent years. Further research on the critical factors should therefore be conducted on a wider variety of products, including frozen, RTE, and chilled foods.

Additionally, whilst it was acknowledged that sensory testing would be effective at determining the acceptability limit, there was a lack of research exploring other methods. Only 1 study included microbiological analysis in the method, which could be due to the dependence on physical measurements for this objective. Microbiological analysis was concluded to be beneficial as it could measure the rate of microbial growth in the product, and an acceptability limit could also be easily defined with colony forming units (Lacivita et al., 2023). Whilst safety margins should be considered, identifying the microbial load could be beneficial in shelf-life testing as the acceptability limit could be further defined.

Overall, the results identify critical factors influencing the SSL which can be beneficial to shelf-life testing and can provide further guidance to food manufacturers on methods of SSL determination. The limited scope of foods assessed however reduces the reliability of the results. Efforts are therefore required to expand the research to a diverse category of foods to provide further benefits.

4.2. To what extent is the Secondary Shelf-Life date on food accurate?

Studies assessing SSL labelling accuracy used a combination of sensory, microbiological and physiochemical analysis to identify the SSL. The date was compared to the SSL indicated on the label, if one was present. The results indicated that the labelled SSL was frequently underestimated, and the possibility of SSL extension should be considered.

The results therefore suggest that the SSL date on products is not accurate, even after considering variables like domestic use. It was overall concluded that revisions are required regarding SSL date labelling to provide the consumer with more accurate information (Condurso et al., 2020; Nicosia et al., 2023).

The studies can develop the current practices surrounding shelf-life testing. Currently, the determination of the accuracy limit in shelf-life testing is often identified through researching legislation or the shelf-life of similar products (Calligaris et al., 2019). Whilst the results demonstrate that there is currently limited data on the SSL of foods, this review could provide a source of reference for the products analysed. In addition, shelf-life testing is mostly applied to packaged foods (Calligaris et al., 2019). Using results from SSL studies could therefore introduce methods of SSL determination for food manufacturers, increasing the reliability of the ‘use within x days of opening’ labelling.

Additionally, the results from this review addresses SSL legislation gaps. There are currently no established methods, protocols or references in the legislation, despite the requirement of a time limit for consumption on appropriate foods (GOV.UK, 2011; Nicoli and Calligaris, 2018). The sensory, microbiological and physiochemical methods of analysis shown in the results are effective at demonstrating product acceptability and could therefore be used as established methods in legislation. Moreover, researching relevant legislation is used as a reference in shelf-life testing, and addressing legislation gaps for SSL would provide further benefits towards accurate determination.

As the results indicated that SSL extension could be possible, this could aid efforts to reduce food waste. The majority of food waste in developed countries is derived from domestic waste, which is often due to confusion around durability dates as well as the perception of sub-optimal foods (Aschemann-Witzel et al., 2015; Schanes, Dobernig and Gözet, 2018). The results have demonstrated the SSL is frequently underestimated and SSL extension should not be ruled out, therefore the correct application could prevent consumers from discarding edible food and could overall reduce food waste.

However, the results contained limitations that may reduce the overall validity and reliability of the findings. There were significant variations in the SSL within the same foods, most notably observed in ham (Sousa et al., 2016; Spampinato et al., 2022). Additionally, whilst research showed significant results, a large proportion of the research in this area was conducted by the same authors. This has the potential to increase bias in the results due to the similarities in the methodology. A greater variety of authors is therefore required to form more reliable conclusions.

Whilst the foods analysed were of a greater variety than the products used to analyse the factors influencing SSL, tests were still conducted on a limited number of products, and the majority of foods were only analysed in one study. Further research could therefore analyse the products listed in the results or introduce new foods, increasing the validity of the results.

Overall, the results have identified inaccuracies in SSL labelling, where it was concluded that underestimation is frequently observed. These findings could have positive influences on the SSL legislation gap as it provides methods of accurate determination, which could therefore contribute to reduced domestic food waste. Whilst the limitations of variability and author bias should be considered in the findings, the results highlight that change is required for SSL labelling so consumers can make informed choices in the foods they consume.

4.3. How could the Secondary Shelf-Life of food be determined?

The results focusing on methods of SSL determination are mostly concerned with SSL modelling. A variety of modelling methods were observed, including kinetics and regression models, which were analysed both theoretically and on food products. It was concluded that modelling was successful, with zero-order kinetics and nonlinear regression models demonstrating the highest success.

Results therefore indicate that modelling can be used as an effective tool for SSL determination for a variety of products, despite the requirement of further research to understand the factors influencing SSL. The results investigating the accuracy of

SSL labelling have highlighted the likelihood for SSL underestimation, which can promote food waste and lead to detrimental environmental impacts (Aschemann-Witzel et al., 2015; Schanes, Dobernig and Gözet, 2018). As the results concerning modelling indicate that it can be an accurate method for SSL determination, the application of predictive modelling in the food industry could therefore increase the accuracy of SSL labelling.

Additionally, modelling is described as an alternative to ASLT and real time testing. Whilst not traditionally used in shelf-life testing as it is a recent discovery in comparison to the other methods, the use provides benefits as the process is more cost effective, less time consuming, and considers other critical factors that can influence the SSL (Piergiovanni and Limbo, 2019). The application would overall provide further benefits to food manufacturers for the SSL determination on products that require such labelling.

Whilst results have demonstrated that modelling can be effective at determining SSL, there are limitations. With some exceptions, modelling was used in the results to assess one or two factors that influence the SSL. Limitations have already been established in the literature targeted towards factors influencing SSL, as the food products and methods of testing showed little variability. Further research is therefore required on understanding the factors influencing SSL to strengthen the validity of the results concerning SSL modelling.

Additionally, research is lacking in the application of real-time and ASLT testing for SSL. Whilst these methods have been compared in previous literature and used in studies to show the accuracy of SSL labelling, the validity of this method for specifically SSL testing was often not discussed in research. Further comparative research on the different methods of SSL testing would therefore be beneficial as this could emphasise the accuracy of SSL modelling.

Therefore, whilst SSL modelling has shown promise in a novel method of SSL determination, expanded research on the factors influencing SSL and the comparison of different shelf-life testing would help strengthen the results.

4.4. What are the risks of Secondary Shelf-Life extension?

The results on SSL labelling accuracy indicate that SSL extension whilst maintaining public safety is possible due to the current underestimation. Research on the SSL extension methods was scarce as publications were recent, but results demonstrated that preservatives can successfully be used in highly perishable products. LAE, antioxidant gel and a phenolic extract from olive vegetation waters was shown to be effective at reducing the oxidation rate, therefore extending the product's SSL. The results also identified the main risks of SSL determination. This includes high microbial loads in foods either from environmental contamination or previous food handling, mould growth and mycotoxins in shelf-stable products, and consumers not correctly following the labelled storage conditions.

These results indicate that SSL extension could be possible with the use of the correct preservatives, which could help reduce levels of food waste. However, the results also demonstrate that the factors of SSL increase the risk of the product and therefore increase the risk to the consumer.

Identifying the risks of SSL is essential as it protects public health, allows for a more accurate SSL prediction that considers additional variables, and identifies products that would require SSL labelling. However, the risks are unclear in current legislation as there are no methods, protocols or references regarding SSL, and there is no guidance on SSL estimation. The results for identifying foods requiring SSL labelling are mixed, with studies providing conflicting findings, and regulation 1169/2011 states that durability labelling should be provided ‘where appropriate’ but does not give any further clarifications (GOV.UK, 2011). This therefore increases the difficulty of determining SSL and weakens the necessity of SSL labelling on any food product.

Whilst results indicate preservative use is effective in SSL extension, this conclusion contradicts the current public demand of ‘clean label’ food products. Artificial preservatives in particular are met with consumer resistance due to the negative health associations (Kamala Kumari et al., 2019). However, the use of the phenolic extract from olive vegetation waters on meat pâte was a natural preservative assessed in a study, which was effective and concluded as a sustainable alternative (Sordini et al., 2025).

The results however did not demonstrate the overall necessity of SSL labelling. It is understood that cases of food bourne illness are increasing in the UK, but the reasoning was concluded as better detection methods and increased reporting (GOV.UK, 2021). SSL labelling is however not recognised as a contributing factor. Despite the risks associated with SSL overestimation, it is difficult to conclude that SSL labelling in the form of ‘use within x days of opening’ is required for public safety when there is already mandatory information regarding product acceptability with the ‘best before’ or ‘use by’ date.

On the other hand, there is a research gap regarding the extension or exclusion of SSL labelling and the benefits towards food waste. Whilst it is suggested by several studies that a longer or absent SSL would promote reduced domestic waste, research is lacking on the public perception of SSL labelling and if the consumer follows the guidance. Qualitative research regarding customer attitudes would therefore be beneficial for the determination and requirement of SSL labelling.

Overall, whilst the potential of SSL extension and the novel methods that could be used are highlighted, durability extensions can be considered as high-risk as there are several factors that affect the SSL. Additionally, whilst literature concluded that revisions are required either in the form of SSL extension or SSL removal, the original purpose and necessity for SSL labelling is not clearly established or defined.

4.5. Limitations

Despite significant results identified from a variety of literature, this systematic review is subject to limitations in the results. Most notably, the overall topic of SSL contains scarce literature, reducing the reliability of the conclusions. Whilst the literature conducted has been recently published showing that SSL is an emerging area of research, additional work is required in all areas to draw further conclusions. This can then provide a stronger argument towards methods of food waste reduction.

In particular, the results concerning the factors influencing SSL are extremely limited and conducted on a narrow product range. Further research in this field is important as it can identify factors that affect chilled and frozen foods, as well as developing knowledge on other research objectives like the risks of SSL and SSL modelling.

Additionally, the results were not varied regarding publication authors, in particular for the accuracy of SSL labelling. Whilst SSL is a narrow research field and repeated authors are expected, the reliability of the results is reduced, and the risk of bias is increased. This topic therefore needs to be expanded to include more publication authors internationally, which can highlight legislation gaps beyond the UK, as well as consumer behaviour and food manufacturing practices.

Addressing these limitations through further research can therefore strengthen the knowledge surrounding SSL determination, which can provide benefits towards food waste reduction and add further guidance in legislation.

4.6. Recommendations for Policy, Practice and Future Research

Due to the limited scope of current SSL research, several recommendations can be made for policy, practice and future research. These recommendations aim to increase the reliability of the current findings, as well as identify methods that can contribute to food waste reduction.

4.6.1. Policy

Firstly, clearer regulation on the products that require SSL labelling is recommended, as current literature presents mixed results. This includes providing additional information on the ‘appropriate’ foods for SSL labelling in regulation 1169/2011 and clarifying when the labelling is required due to quality reasons. This would provide further information to food manufacturers on the products requiring an indication of the SSL. Clearer legislation could also be expanded beyond the UK to the EU, as EU legislation is retained under UK law.

Additionally, the methods of SSL determination could be provided as official guidance in legislation. Regarding cosmetics, guidance is available for the determination of PaO, a concept assimilated with SSL. Official SSL guidance could therefore provide similar benefits, as it informs food manufacturers about the available determination methods.

4.6.2. Practice

Whilst modelling is relatively recent compared to ASLT and real time shelf-life testing, the use of predictive modelling has shown to be successful at SSL determination. Modelling could therefore be a useful tool in practice, as the application is less costly and time consuming compared to traditional methods.

Moreover, shelf-life testing generally applies to the PSL of products. In practice, shelf-life testing could be expanded to the SSL. This systematic review has identified the critical factors influencing the SSL, as well as methods to determine the acceptability limit. Both of these findings would aid in the development of accurate and reliable SSL testing.

4.6.3. Future Research

Further research is firstly required on a wider range of foods, as the current scope of products analysed was narrow and excluded chilled and frozen foods. Increased research would expand on the current knowledge of food spoilage mechanisms and could also provide further guidance to the other research objectives like SSL modelling and the risks of SSL.

Research investigating the different spoilage mechanisms on foods after package opening, such as the growth of mould and mycotoxins on shelf-stable products is also recommended. This is to establish the products suitable for SSL labelling, which can be of benefit to policy makers and labelling legislation.

Finally, research comparing SSL modelling to ASLT and real time testing methods is advisory, as this can increase the validity of SSL date labelling. Further ASLT and real-time tests specifically concerning SSL instead would be beneficial as this can further develop knowledge on SSL testing.

5. Conclusion

This systematic review has analysed available literature concerning SSL and used the studies to assess the overall validity of SSL determination in food. Research overall indicates that whilst several factors should be considered during SSL determination, temperature, a_w and packaging are identified as the critical factors. The current SSL labelling on products shows high levels of inaccuracy and was frequently underestimated, suggesting that the extension on SSL date labelling is possible. Whilst novel methods including SSL modelling and SSL extension using preservatives showed promising results, further research is required to form stronger conclusions. Environmental contamination and consumer storage practices are identified as the main risks of SSL determination and extension and should be considered when discussing the possibility of SSL extension.

The results from this review can provide benefits towards legislation, shelf-life testing and the mechanisms of food spoilage. Whilst there is currently no documentation in legislation identifying methods of SSL determination, research has shown the combination of sensory, microbiological and physicochemical analysis to be effective at marking product acceptability. Additionally, the identification of the critical factors influencing SSL and the effective application of SSL modelling can expand on SSL testing, as well as reducing the time and costs in shelf-life testing.

Whilst this review underwent extensive searching to identify relevant literature, research regarding SSL remains scarce. The most notable research gap concerned the factors influencing SSL, as this was focused on a limited number of products. This limitation also reduced the strength of the conclusions for SSL modelling. Future research should therefore focus on SSL determination in a wide range of products.

Despite this, the requirement for SSL date labelling was not clearly established in research. Whilst research identified some products that may require SSL labelling, this literature conflicted, and further research suggested that SSL extension or even the complete removal of SSL could provide benefits for food waste reduction. Reforms are therefore required in the legislation regarding SSL determination and labelling so consumers receive accurate and reliable information that supports food safety and reduces food waste.

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Appendix 1

CASP Appraisal Checklist

Paper for appraisal and reference: **The Determination of Secondary Shelf Life for foods: A systematic review.**

Section A: Are the results of the review valid?

Did the review address a clearly focused question?		
	Yes	☑
	Can't Tell	
	No	

Comments:
The overall aim, objectives and research questions are clearly defined in section 1.7 of the introduction.

Did the authors look for the right type of papers?		
	Yes	☑
	Can't Tell	
	No	

Comments:
The papers were identified by searching for the term "secondary shelf life" where quotations were used to differentiate results from regular shelf-life studies.

Is it worth continuing? Yes

Do you think all the important, relevant studies were included?		
	Yes	☑
	Can't Tell	
	No	

Comments:
Research was extracted from a variety of databases including Web of Science, Google Scholar, ProQuest, Scopus and PubMed. Grey literature was considered, and studies were included that were not in English. There were limitations as some studies were not accessible past the abstract, and single screening was used to identify relevant studies.

Did the review's authors do enough to assess quality of the included studies?	Yes	☑
	Can't Tell	
	No	

Comments:
Whilst research was extracted from relevant databases, the data may not be of high quality because grey literature was included. This was written in the methods section and in the limitations and will be discussed further during section 4 of the paper.

If the results of the review have been combined, was it reasonable to do so?	Yes	
	Can't Tell	
	No	

Comments:
Not applicable for this review

Section B: What are the results?

What were the results of the review?

Comments:
The research produced both quantitative and qualitative results and were varied in design and topic. Results are shown further in section 3 of the paper.

How precise are the results?

Comments:
There was not enough research on a particular topic to draw an overall conclusion, and most of the research papers included concluded that further research is required on the secondary shelf-life topic.

Section C: Will the results help locally?

Can the results be applied to the local population?

Yes	☑
Can't Tell	
No	

Comments:
As the population will purchase food with secondary shelf-life labelling on, the correct labelling could affect the levels of domestic food waste, which has been established as the largest form of food waste.

Were all important outcomes considered?

Yes	
Can't Tell	☑
No	

Comments:
Although research about any part of secondary shelf-life was considered, it is difficult to include if all the outcomes were considered as the research is scarce. For example, there are many foods with secondary shelf-life labelling that were not included in any study conducted.

Are the benefits worth the harms and costs?		
	Yes	☐
	Can't Tell	☑
	No	☐

Comments:
Food waste is currently a critical issue that is one of the largest sources of greenhouse gas production, has risen in recent years and no intervention has shown to be successful in reducing this. Whilst the extension of secondary shelf-life may reduce domestic food waste, it is critical that the extension does not put food safety at risk. Although there are conflicting reasons as to why, food bourne illnesses are rising, and it is not ideal to contribute to this statistic by extending a date relevant to food safety.

Appendix 2

Full list of included literature from the systematic review

Title	Authors
Secondary Shelf Life of Foods: State of the Art and Future Perspective	Alessandro Del Nobile, Matteo Conte, Amalia
Challenge tests para avaliar o período de vida útil secundário em fiambre fatiado pré-embalado (Challenge tests to evaluate secondary shelf-life of pre-packed sliced ham)	Sousa, André Bonito, Conceição Costa Sousa, Isabel Toscano, Maria Manuel Moura, Isabel Bastos Lopes, Teresa Teixeira Pena, Cláudia Cunha, Isabel Campos Saraiva, Margarida Calhau, Maria Antónia
Microbiota Survey of Sliced Cooked Ham During the Secondary Shelf Life	Spampinato, Gloria Candeliere, Francesco Amaretti, Alberto Licciardello, Fabio Rossi, Maddalena Raimondi, Stefano
Control of the Maillard reaction and secondary shelf-life prediction of infant formula during domestic use	Wang, Sihui Wang, Mengqi Wang, Ying Wu, Zhengyan Yang, Jingjing Li, Hongjuan Li, Hongbo Yu, Jinghua
Effect of Different Packaging Strategies on the Secondary Shelf Life of Young and Structured Red Wine	Bianchi, Alessandro Taglieri, Isabella Macaluso, Monica Sanmartin, Chiara Zinnai, Angela Venturi, Francesca
Exploratory use of nisin and ethyl lauroyl arginate for the inhibition of spoilage microflora during secondary shelf life	Nicosia, Carola Secchi, R Pulvirenti, Andrea Licciardello, Fabio

Role of a Natural Preservative in the Secondary Shelf-life of Ready-to-Use Meat Pâté	Sordini, Beatrice Esposto, Sonia Bonucci, Arianna Dottori, Ilenia Daidone, Luigi Urbani, Stefania Veneziani, Gianluca Selvaggini, Roberto Servili, Maurizio Nucciarelli, Davide
Guidance on date marking and related food information: part 2 (food information)	Koutsoumanis, Konstantinos Allende, Ana Alvarez-Ordóñez, Avelino Bolton, Declan Bover-Cid, Sara Chemaly, Marianne Davies, Robert De Cesare, Alessandra Herman, Lieve Hilbert, Friederike Nauta, Maarten Peixe, Luisa Ru, Giuseppe Simmons, Marion Skandamis, Panagiotis Suffredini, Elisabetta Jacxsens, Liesbeth Skjerdal, Taran Da Silva Felício Maria Teresa Hempen, Michaela Messens, Winy Lindqvist, Roland
Application of accelerated shelf-life test (ASLT) procedure for the estimation of the shelf-life of extra virgin olive oils: A validation study	Calligaris, Sonia Lucci, Paolo Milani, Andrea Rovellini, Pierangela Lagazio, Corrado Conte, Lanfranco Nicoli, Maria Cristina
Effects of different coffee storage methods on coffee freshness after opening of packages	Smrke, Samo Adam, Jan Mühlemann, Samuel Lantz, Ingo Yeretzian, Chahan

Domestic use simulation and secondary shelf life assessment of industrial pesto alla genovese	Nicosia, Carola Fava, Patrizia Pulvirenti, Andrea Antonelli, Andrea Licciardello, Fabio
Antecedents and barriers to sustainable food waste practices among lower-middle income households in malaysia	Mansor, Fazreena Ahamd, Siti Hasziani Yaacob, Noor Junani Arwin Ali, Roslina Kamaruddin, Nurul Izzat
Development of solvent-cast antimicrobial PHBV films for the inhibition of spoilage microflora	Nicosia, Carola Pulvirenti, Andrea Licciardello, Fabio
Assessment of the secondary shelf life of Bolognese sauce based on domestic use simulation	Mezza, I Nicosia, Carola Pulvirenti, Andrea Licciardello, Fabio
Evaluación de la vida útil primaria y secundaria de paté de salmón y algas (Primary and secondary shelf-life evaluation of salmon and seaweed pâté)	Daroz Díaz, María José Fuentes López, Ana Fernández Segovia, Isabel
Modeling moisture change of packaged dry tablet dosage forms under consumer use condition	An, Duck Soon Lee, Dong Sun
Modeling of Greek coffee aroma loss during storage at different temperatures and water activities	Makri, Emmanouela Tsimogiannis, Dimitris Dermesonluoglu, Efimia K Taoukisa, Petros S
Secondary shelf life assessment of UHT milk and its potential for food waste reduction	Nicosia, Carola Fava, Patrizia Pulvirenti, Andrea Licciardello, Fabio
Effect of pulsed electric fields on the shelf stability and sensory acceptability of osmotically dehydrated spinach: A mathematical modeling approach	Dimopoulos, George Katsimichas, Alexandros Balachtsis, Konstantinos Dermesonlouoglou, Efimia Taoukis, Petros
Modeling the secondary shelf life of ground roasted coffee	Anese, Monica Manzocco, Lara Nicoli, Maria Cristina
Modeling the effect of the oxidation status of the ingredient oil on stability and shelf life of low-moisture bakery products: The case study of crackers	Manzocco, Lara Romano, Giulia Calligaris, Sonia Nicoli, Maria Cristina

Desarrollo y aplicación de un procedimiento de vida útil secundaria en quesos (Development and implementation of a secondary shelf-life evaluation procedure for cheese)	Fernández Isasi, Leonor
Effects of a Biobased Antioxidant Gel on Meat Shelf-Life: Oxidative Stability and Color as Quality Parameters	Pitirollo, Olimpia Messinese, Edmondo Grimaldi, Maria Barbanti, Davide Cavazza, Antonella
Study on the influence of visible molds on primary and secondary shelf life of pasteurized gnocchi	Lacivita, Valentina Lordi, Adriana Conte, Amalia Del Nobile, Matteo Alessandro
Primary and secondary shelf-life of bread as a function of formulation and MAP conditions: Focus on physical-chemical and sensory markers	Bianchi, Alessandro Venturi, Francesca Palermo, Carmelo Taglieri, Isabella Angelini, Luciana Gabriella Tavarini, Silvia Sanmartin, Chiara
Theoretical analysis of secondary shelf life: Interactive relationship with package opening time and food quality degradation rate shift	Lee, Dong Sun
Stability of powdered infant formula during secondary shelf-life and domestic practices	Condurso, Concetta Cincotta, Fabrizio Merlino, Maria Stanton, Catherine Verzera, Antonella
Regression models for description of roasted ground coffee powder color change during secondary shelf-life as related to storage conditions and packaging material	Benković, Maja Tušek, Ana Jurinjak
Survival analysis and CATA questions methodologies to predict croissants' secondary shelf-life	Puleo, S Volpe, S Di Monaco, R Torrieri, E
Impact of different packaging and capping systems on the secondary shelf-life of white wine	Bianchi, Alessandro Taglieri, Isabella Sanmartín, Chiara Macaluso, Monica Venturi, Francesca Zinnai, Angela

Changes of the volatile compounds and odors in one-stage and three-stage infant formulas during their secondary shelf-life	Li, Yilin Li, Ruotong Hu, Xinyu Liu, Jiani Liu, Guirong Gao, Lipeng Zhang, Yongjiu Wang, Houyin Zhu, Baoqing
Kinetics of colour change in roasted ground coffee during secondary shelf-life	Tušek, A.J. Benković, M. Bauman, I.
Exploring the Impact of Different Packaging Types and Repeated Package Opening on Volatile Compound Changes in Ground Roasted Coffee	Trenzová, Kristina Gross, Michal Vítová, Eva Pořízka, Jromír Diviš, Pavel
Secondary Shelf Life: an Underestimated Issue	Nicoli, Maria Cristina Calligaris, Sonia
Greek Coffee Quality Loss During Home Storage: Modeling the Effect of Temperature and Water Activity	Orfanou, Foteini Dermesonlouoglou, Efimia K. Taoukis, Petros S.
Combined stochastic modelling of pathogenic and spoilage microorganisms	Maciejewska, Nikola; Stefanou, Constantine-Richard; Stathas, Leonardos; Koutsoumanis, Konstantinos