Review of the literature and guidance on food allergen cleaning: Report summary and discussion

This section of the report provides a summary and discussion of the findings presented in Section 6 (Results). For full details of the studies and literature it is recommended that Section 6 is read before this section to enable a contextual point of reference and better understanding.

7.1 Strengths and limitations of the literature review

This report provides a comprehensive review that takes into account a wide range of different literature types at an international level. The sources comprised literature from 18 geographical regions and also included some that were applicable to a global context. The review both consolidates the available published scientific literature and takes a detailed approach to extract the key principles from guidance documents. In addition, guidance and codes of practice, industry and professional body publications, website pages and other sources were captured to ensure viewpoints from industry bodies and professionals as well as governmental and non-governmental organisations were included. Although a single scientific literature database was used, FSTA was selected to complete an extensive search of the literature and to ensure that the results were from high-quality food-related peer-reviewed articles.

Sources were categorised based on the structure and format of the literature source but not ranked due to the fundamental differences (for example, audience, presentation etc.) between each category. The number of citations was provided for studies published in journal articles and theses, where possible, to give an indication as to the prominence of each article amongst the current studies included in literature published in scientific journals on the topic of allergen cleaning. For other types of literature, no relevant figures could be given to signify article prominence within the literature.

The report was limited to the topic of allergen cleaning methodologies, validation and verification of cleaning only, which provided a basis for the article exclusion criteria. Although frequently discussed in the articles selected, the capability of various allergen detection methods available to support validation and verification activities were not explored in great detail (for example, strengths and limitations).

The literature search was not limited to a single allergen and included those that are required to be mandatorily declared when intentionally present in food in the UK (retained Regulation (EU) No 1169/2011). Due to time constraints, the literature search was limited to literature published post-2012, but other relevant sources were captured where possible via citation tracking, a process that was conducted to source additional studies referenced in journal articles only. Although the results were predominantly English language sources, Campden BRI’s internal international expertise was used to capture relevant non-English language guidance documents and the relevant information was extracted where necessary. All sources underwent a thorough screening and extraction process by two individuals to ensure that only those articles specific to the requested review were included in the report.

It has been 15 years since the previous comprehensive study on the topic of allergen cleaning was published by Jackson et al. (2008). In the meantime, numerous guidance documents have been issued on cleaning to remove food allergens, as well as its validation and verification, and there are ongoing conversations internationally around the issues with allergen cross-contact and the need for harmonisation of PAL. The current report provides researchers, policymakers and industry with a detailed overview of international literature on the subject of cleaning for food allergen removal and provides a solid foundation on which to base future research study designs, develop guidance and subsequent industry practice.

7.2 Comparison between information from different literature sources

Detailed comparisons of cleaning methodologies between literature types were not possible due to wide range of variables included in published studies, as well as the lack of specific methodologies tested outside of published studies in journal articles. Nonetheless, it was clear that each literature type had a general focus, which are summarised below.

Each study detailed in journal articles selected for inclusion was based on a defined investigation of a specific situation. On the other hand, guidance documents described general principles and lacked specific details on the efficacy of methodologies. This finding was expected due to the general consensus found across most literature types that cleaning should take place on a case-by-case basis and is dependent on many factors such as the properties of the foodstuff produced, the food processing or food service environment and factors affecting the efficacy of the cleaning methodology.

The overarching principles extracted from guidance documents on allergen cleaning validation and verification (and the requirement to carry out such activities) were repeated across the majority of literature types. The basic principles of cleaning, however, were detailed in general guidance on cleaning, but were rarely mentioned in documents specific to food allergens. This lack of detail around cleaning to remove allergens in most sources is likely due to there being no one method for effective allergen removal.

Within industry and professional body publications, there was a focus on practical considerations, particularly the accessibility of equipment (including surface properties) alongside some additional considerations not always covered in guidance, such as the use of dry steam for cleaning. Website pages were presented in a variety of formats (guidance-like webpages, blog articles and government information webpages), some of which covered principles whilst others provided details on some cleaning methodologies, although this was limited to descriptive information about the cleaning protocol. As described in the report, those sources categorised as ‘other information’ were of a disparate nature and therefore could not be evaluated under a single description. Book chapters provided general overviews on the topic and referenced results demonstrating the efficacy of some cleaning methodologies but did not give information beyond that covered by the journal articles that were cited.

7.3 Cleaning to remove food allergens

7.3.1 Importance of cleaning to remove food allergens

One way that cross-contact can occur in food processing and food service environments is when allergenic foodstuffs are handled, prepared or processed on surfaces or equipment or using utensils that are not then cleaned appropriately before preparation of a food product that does not contain those allergenic ingredients, or even any allergenic ingredients. Cross-contact can also occur when allergenic foodstuffs spillage occurs in food handling, storage and transport

environments that is not cleaned up appropriately. Such contamination raises concerns around consumer safety for allergic individuals and FBOs alike. Therefore, cleaning is a critical step in preventing contamination or re-contamination of products; physical, chemical and biological cleanliness is a prerequisite for food safety (Schmitt and Moerman, 2016). It should be remembered that there is a legal responsibility placed on FBOs to produce safe food under the general food law retained Regulation (EC) No. 178/2002.

Cleaning to remove or reduce allergens to an acceptable level is therefore instrumental to the production of safe food. Cleaning is defined by Codex Alimentarius General Principles of Food Hygiene (2020b) as 'the removal of soil, food residues, dirt, grease or other objectionable matter' and it is stated that controls to prevent cross-contact from foods containing allergens to other foods should be implemented, for example by effective cleaning between foods with different allergen profiles. Codex Alimentarius Code of Practice on Food Allergen Management for Food Business Operators (2020a) includes recommendations on the management of food allergens by outlining a harmonised approach across the food chain based on general hygiene requirements. The document talks about the need in retail and food service for equipment, utensils, containers and preparation areas to be adequately cleaned (at a minimum visually clean) immediately after the preparation, storage, and dispensing of foods to prevent allergen cross-contact. Whilst in food manufacturing the advice is to develop cleaning procedures designed to remove food allergens to the extent possible. It is stated that such procedures should specify the equipment, utensil, or area of the establishment to be cleaned; the tools and cleaning materials to be used; the sequence of steps to be followed; any disassembly required; the monitoring activities; and any actions to be taken if the procedures have not been followed or if food residues have not been adequately removed.

Following adoption of the global principles laid down by Codex Alimentarius (2020a), the European Union has introduced Commission Regulation (EU) 2021/382, which amends the Annexes to the EU version of the general hygiene Regulation (EC) No 852/2004. The amendments introduce for all FBOs (including primary production) the legal requirement for good hygiene practices to prevent or limit the presence of substances causing allergies or intolerances in equipment, conveyances and/or containers used for the harvesting, processing, handling, transport or storage of foodstuffs. It is stated that such equipment 'should be cleaned and checked at least for the absence of any visible debris', if being used in the production of both allergenic and non-allergenic foods.

Other than in the EU, globally there is a lack of specific national or regional legislation relating to allergen management in general or cleaning in particular; guidance in some countries refers to Codex Alimentarius (2020a), for example Singapore, or the aforementioned EU legislation.

The importance of cleaning is also emphasised by commercial food management standards (for example, Global Food Safety Initiative (GFSI) recognised standards such as BRCGS and FSSC 22000), which state that applying an appropriate cleaning procedure is often necessary to reduce issues caused by cross-contact. The development of numerous guidance documents internationally that address cleaning also give weight to its importance.

In the context of cleaning to remove allergens, it is vital to understand that cleaning in this specific circumstance is about removing food soils. Unlike microorganisms, allergens are proteins (i.e. biochemicals), and therefore cannot be 'killed' or necessarily made non-allergenic by cleaning. What classifies as 'microbiologically clean' then does not strictly correlate to 'allergen clean'.

7.3.2 Food service and food processing environments

This study found that the majority of information on cleaning for allergen removal, particularly in guidance, is targeted at food processing rather than food service environments. Over half of the journal articles, however, involved food service scenarios and some information for caterers was

found on website pages. Advice and requirements were though skewed towards the use of cleaning methodologies and analysis for validation and verification, that whilst applicable in food processing environments would not be feasible for food service businesses.

With regard to the use of cleaning in food allergen management in different sizes of business, Jackson et al. (2008) referred to studies by US FDA (2006) and Taylor et al. (2006). It was reported that large food production facilities are more likely than small facilities to use cleaning protocols and production scheduling, with 76% using shared equipment (US FDA, 2006). In addition, it was found that 77% of manufacturers include cleaning and sanitation as part of their allergen control plan highlighting its implementation across the food processing industry (Taylor et al., 2006). Subsequently, FSAI (2012) found that food manufacturing businesses generally use scheduling when producing foods that contain allergens, either at the end of the day or before applying a thorough cleaning protocol. Of those that were audited, none used separate production lines and therefore relied heavily on cleaning procedures to control cross-contact. Interestingly, four out of 12 businesses did not carry out any allergen testing, although the majority tested either the equipment or the final product (one business tested both).

When forming policies, guidance, or even legislation, it is important to consider the practicability of the advice or requirements for different sizes of business and also the different sectors in which such businesses operate.

7.3.3 Basic principles of cleaning

Basic principles of cleaning were not defined in the literature that specifically relates to food allergens, however, as evidenced throughout this report, there was much discussion around the considerations concerning these principles. General guidance on cleaning does provide detailed descriptions of the basic principles including aspects such as hygienic design (of equipment, environment and cleaning equipment), components of the cleaning and disinfection programme (the four fundamental parameters of mechanical or kinetic energy, chemical energy, thermal energy or time), water quality and principal stages in the cleaning and disinfection programme.

It should be remembered that cleaning is not just about allergen removal, it is also used for purposes such as: to remove the majority of the microorganisms present; to remove materials that may conflict with labelling claims or consumer choice preferences, for example, vegetarian or vegan, Halal or Kosher; to remove materials that could lead to foreign body contamination; to extend the life of, and prevent damage to equipment and services; to provide a safe and clean environment for employees; and, to protect the reputation of a brand by providing a consistent and suitable production/food handling environment (Campden BRI, 2020b). Cleaning and disinfection are undertaken to remove microorganisms and materials conducive to microbial growth, which reduces the risk of contamination by pathogens and by reducing spoilage organisms, maintains the quality of the product and may extend its shelf-life (Campden BRI, 2020b).

Cleaning and disinfection must be designed using a risk-based approach and on a sound technological basis and should be regarded as part of the manufacturing/preparation process. The procedures must be validated by generating and documenting evidence that the cleaning is capable of achieving the desired risk management outcome. There should be written procedures, training provided to those involved and sufficient time allocated for the procedures to be carried out repeatedly and correctly.

7.3.4 Summary of findings from the published literature on cleaning to remove food allergens

The overall finding from the literature described in this study is that cleaning methodologies should be selected on a case-by-case basis depending on the context in which they are to be

applied. There are many factors to consider (including for example food matrix, surface, environment, equipment accessibility, cleaning chemical characteristics, concentration and temperature etc.) that make it difficult, and arguably impossible, to suggest one particular method that will effectively clean in all scenarios. As pointed out by Jackson et al. (2008) ‘no single wet-cleaning protocol is ideal for all situations’, this could be further expanded to ‘no single cleaning protocol is effective in all circumstances.’

Published studies within the literature on cleaning to remove food allergens are highly variable and context-dependent, and this is a reflection of the statements above on the many factors that need to be considered. Fryer and Asteriadou (2009) identify that data on the efficacy of cleaning is usually held by individual food manufacturers. As this wealth of information is not available in the public domain it is necessary to try and derive some general meaning from the information that is available. The following sections provide broad deductions on different factors affecting cleaning efficacy for allergen removal from the published literature.

7.3.4.1 Surfaces

The ‘cleanability’ of surfaces was presented in a hierarchy in multiple sources where it was agreed that stainless steel is generally the easiest surface to clean, whilst wood and cloth are the most difficult (for example, Littleton, Walker and Ward, 2021; RSSL, 2022). However, despite the surface material, equipment accessibility, hygienic design and hard-to-reach areas where product build-up can occur still need to be considered. It is also important to inspect equipment, as surfaces can erode and deteriorate over time leading to the potential for residues of allergenic foodstuffs to stick to previously cleanable areas.

7.3.4.2 Soil or matrix type

The physical form of the allergen to be removed (for example, solid, liquid, paste, particulate, or powder, aerosol) affects the efficacy of the clean. Although sticky paste residues are often recognised as more difficult to clean than dry residues, this can depend on the cleaning methodology applied and surface being cleaned. From the studies reported in section 6.1 it is not possible to state which allergen is most difficult to remove, as the form of the allergenic food has such an influence on cleanability. None of the selected studies investigated removal of soils of actual allergen protein as such, but this is not unexpected and would likely not yield results applicable to real-world scenarios.

Proteins have been described as typically the most difficult to remove of the constituents that make up food soils (the other food soil types being fat, carbohydrate and minerals) (EHEDG, 2021a; Jackson, 2018). Although allergens are proteins, it should be considered what the overall matrix containing the protein is when deciding how it should be cleaned, as food soils often contain the different constituents in differing quantities. It is also recognised that processing, in particular heat, can make food soils more difficult to remove (Fryer and Asteriadou (2009); with particular reference to proteins, this is due to their denaturation and consequent adherence to the surface. How long the soil has been in situ, effectively its age, can also affect how easy or difficult it is to remove; with older soils being more difficult to clean (Schmidt, 2018). In addition, build-up of soil and biofilm formation can affect its ease of cleanability (Schmidt, 2018). The nature of the soil should therefore be considered when selecting a cleaning methodology (Jackson et al., 2008).

7.3.4.3 Equipment and environment

The type of equipment being cleaned and the environment in which it is being used can dictate what cleaning methodology is applicable. For example, an automated CIP clean may be possible in some cases, such as piping systems, but not others (for example, a mixer). Equipment may not

always be accessible and push-through may therefore need to be considered, where feasible. Equipment being used in dry environments cannot be cleaned using water, as this may introduce the potential for microbial growth or affect the quality of the product.

In a food service kitchen, there may be some equipment that cannot be cleaned in an automatic dishwasher, due to its size or the presence of electrical components for example. Different equipment in different environments will determine what cleaning methodology is applicable and appropriate.

7.3.4.4 Cleaning methodology

As already stated, some cleaning methodologies are more suitable for particular purposes than others, but, as to be expected, all have their limitations beyond when and where they can be used. It is recommended throughout the literature that the method of cleaning is designed using a risk-based approach. This section outlines the findings of the review in relation to different cleaning methodologies.

Dry cleaning

Throughout this review it was found to be stated that dry cleaning has limited efficacy for allergen removal, even in cases where surfaces may appear to be visually clean. These findings emphasise the point that appropriate validation is required to understand the capability of cleaning methodologies for the intended purpose. Some guidance specifically states that filtered vacuum systems are preferred over scraping and brushing, but even vacuuming may not be sufficiently effective for allergen removal, hence the need for validation. Dry cleaning techniques may be complemented by the application of a detergent using a ‘controlled wet’ procedure (i.e. use of a commercial ‘wet wipe’, or a cloth, which may be ‘wetted’ with a specific cleaning chemical or antibacterial solution, to clean a surface in a controlled manner), which was found to be effective in some published studies (for example Jackson and Al-Taher, 2010 and Bedford et al., 2020).

There was general agreement throughout the literature that equipment that displaces allergen residues rather than removes them (for example, compressed air) should be avoided.

Push-through

As documented in this report, information on push-through is limited, again likely due to the highly context-dependent circumstances under which such procedures are undertaken. The production of chocolate was identified in multiple sources as an example where this type of cleaning method can be effective at allergen reduction. Evidence provided by journal articles notes the variable efficacy of the method and dependence on multiple factors including the food soil or matrix, the push-through material and the equipment; therefore, validation should be carried out for each individual scenario. Again, the use of dry cleaning could be complemented by other cleaning methodologies to increase the efficacy where feasible.

Wet cleaning

Wet cleaning is often referred to as the ‘best’ cleaning method for allergen removal in guidance and grey literature. This point is corroborated by the journal articles referenced in the report, which found a greater efficacy of wet cleaning methodologies (including controlled wet cleaning) compared to dry, although water alone was found to be insufficient. As with cleaning methodologies in general, the overriding finding was that wet cleaning should be selected on a case-by-case basis.

Wet cleaning involves application of a “solution of a chemical product in water at a certain temperature, for the required time necessary to dissolve or loosen soil deposits, and the mechanical action of the cleaning fluid aids in the removal these residues” (EHEDG, 2021a). Sinner’s circle was developed in 1960 (Sinner, 1960), which outlines the four factors that contribute to the efficacy of cleaning methodologies and includes: chemistry (detergent properties); heat application (temperature); mechanical force (impact or shear stress) and detergent contact time (and concentration). A similar expression of the factors is as the acronym, TACT; which stands for temperature, action, concentration and time. This acronym has been further extended to incorporate ‘coverage’ (TACCT) (Tamime, 2008). In the current review, some sources simply list factors affecting the efficacy of a cleaning methodology (particularly for wet cleaning), whilst others describe Sinner’s circle or use the ‘TACT’ acronym. It can be difficult to determine the weight (or relative significance) of each parameter for the particular cleaning context (EHEDG, 2021a). As stated, particularly in Section 6.1.2, it is challenging to interpret the results of disparate studies from peer-reviewed journal articles and use these to come up with guidance, due to the sheer number of variables involved in the different studies. Some comment can though be made on the efficacy of different cleaning formulation chemicals and other key components.

Widely recommended in most literature types in this review is the use of cleaning agents (for example, chemicals or detergents, with or without the presence of enzymes) as part of a wet cleaning procedure (or controlled wet in some cases). Information varies throughout the literature from simply stating the overall factors that impact the efficacy to specific advice on what chemical or detergent to use and under what conditions, although specific information is uncommon.

From the literature in this review general principles as to the most efficient chemicals for removal of different soils can be obtained and are summarised in basic terms in Table 12.

Table 12: Summary of the effectiveness of different cleaning materials for removal of different soil types

Soil type	Effective cleaning chemicals for removal of soil type
Carbohydrate	Alkaline, amylases and other carbohydrate-degrading enzymes
Protein	Alkaline or chlorinated alkaline, proteases
Fat	Alkaline with or without surfactants, lipases
Inorganic materials	Acid

Indeed, the most effective cleaning chemical for allergen removal, as evidenced by the selected studies in journal articles (Section 6.1.2.4), was chlorinated alkaline. Acid detergents were found to be variously effective, often depending on the temperature of the cleaning chemical.

Jackson (2018) comments that the use of alkaline plus oxidiser (for example sodium hydroxide in combination with sodium hypochlorite or peroxide) is excellent at removing protein soils, as these chemicals can partially hydrolyse and solubilise proteins. If more general literature around cleaning in food processing and handling is consulted it is found for example that a ‘rule of thumb’ is provided by Schmidt (2018); i.e. that alkaline cleaners dissolve acid soils and food wastes, whilst acid cleaners dissolve alkaline soils (minerals). In fact, acid cleaners are known to precipitate protein, which can make such soils more difficult to remove. Schmidt (2018) goes on to say that removal of many soils and biofilms require ‘more sophisticated’ chemicals containing oxidising agents (such as chlorinated detergents).

It is interesting to note that whilst Galan-Malo et al. (2019) found that use of a detergent with proteases resulted in a significantly reduced occurrence of allergenic residues, Jackson (2018) states that the length of time needed for enzymes to be effective limits their use, as the contact time required may take from a few minutes to several hours. There is scant mention of the use of enzymes in cleaning throughout the selected literature. EHEDG (2021a) states that “as enzymes are proteins, they can themselves induce allergic reactions when inhaled and thus may pose a risk for operators, therefore a suitable risk assessment should be carried out before their use”. Campden BRI (2020b) points out that cleaning products containing enzymes are especially susceptible to heat degradation.

It is clear that some chemicals are generally not effective in food allergen removal; disinfectants and sanitisers may be used in cleaning operations to reduce the level of microorganisms, however, they alone are not effective at removing allergenic food soils (Jackson, 2018).

In addition, some chemicals are not suitable for certain surfaces or circumstances, for example acid and highly alkaline cleaners can damage aluminium surfaces, rendering them ‘non-cleanable’ (Schmidt, 2018). Chlorinated alkaline is not recommended for use in CIP as the "in use temperature" will cause the chlorine to be vented, which is itself corrosive to stainless steel (N Blitz 2023, personal communication, 13 March).

Again, the choice of cleaning chemical will depend on the soil to be removed and it should be remembered that although allergens are proteins, consideration should be given to the matrix containing the protein when deciding how it should be cleaned.

The use of commercial dishwashers in food service scenarios was included in studies investigating the efficacy of cleaning in school canteen kitchens (Galan-Malo et al., 2019 and Ortiz et al., 2018) where cleaning was found not to be effective for all utensils. Information on allergic reactions occurring during the study described by Ortiz et al. (2018) were also reported (Ortiz-Menéndez et al., 2019); there was a significant relationship between episodes of food reaction (not requiring epinephrine) and positive egg LFD results, suggesting that the presence of egg traces in the school kitchens may have contributed to the appearance of these reactions. A case study conducted by Arrowsmith, Ng, Clarke and Brown (2009, Campden BRI Research Summary Sheet (2009-42) Cleaning validation for removal of allergens: comparison of ELISA or dipstick tests, not published in the public domain) demonstrated plates on which fried eggs had been served in a food service establishment, were still found to have a residue of egg white protein after dishwashing when tested using an ELISA, but were negative using an LFD for egg.

In addition, washing by hand in food service environments was included in few studies (for example, Galan-Malo et al. (2019); Schembri (2017); Ortiz et al. (2018)) and was found to be variously effective. A case study conducted by Arrowsmith, Ng, Pettit and Brown (Campden BRI Research Summary Sheet (2009-50) Efficacy of cleaning and management controls for allergens in catering establishments, not published in the public domain) showed that a sponge used to clean a pan that had contained poached eggs tested positive for egg using an ELISA test for egg. When the same sponge was used to clean a tray that had been used to cook bacon, swabs of the tray were positive for egg. The sponge tested positive for egg after it had been used for manual cleaning throughout an eight-hour shift.

More work is needed, therefore, to elucidate the efficacy of cleaning to remove allergens, in different forms and matrices, from a variety of surfaces by commercial dishwashers and washing by hand.

7.3.4.5 Laundry and hands

Clothing and hands are potential sources of cross-contact in food processing and food service environments and yet few literature sources described the need for appropriate handwashing and

laundering techniques to reduce cross-contact, nor did much of the published literature measure the efficacy of such techniques. Where it is discussed, findings show that water alone is not sufficient for allergen removal.

Two of the journal articles reported on in this review (Schreder et al., 2013 and Aleksi? et al., 2020) respectively found that cleaning work surfaces, tools or hands and gloves with detergent or soap is sufficient to prevent cross-contact and that cleaning of hands in combination with replacement of protective clothing and the most stringent cleaning regime was also effective. Whilst Perry et al. (2004) found that peanut butter applied to the hands of volunteers was effectively removed by liquid soap and bar soap.

Arrowsmith and Brown (2006, Campden BRI Research Summary Sheet (No. 2006-69) Laundering to remove allergens from protective clothing worn in food factories, not published in the public domain) conducted a case-study to determine whether laundering is effective at removing allergens from protective clothing, and to examine whether protective clothing could become contaminated with allergens in the laundry. Results demonstrated that protective clothing worn in two food manufacturing environments, one dealing with nuts, the other with prawns, has the potential to be contaminated with allergens to a significant level. However, laundering removed allergens from the overalls in the study described. In the specific scenarios studied, the laundry was not a source of cross-contact of protective clothing; however, it was advised that testing of protective clothing for allergen residues following laundering should be considered as part of the validation of allergen control measures in food handling environments.

The studies described demonstrate that the influence of protective clothing, its laundering and washing of hands must not be excluded from future studies into cleaning efficacy where relevant.

7.3.4.6 Cleaning equipment

It is pointed out that the use of equipment (such as brushes, scrapers, brooms and vacuums) can support effective cleaning, particularly in dry environments where water cannot be used, but such equipment can itself be a potential source of allergen cross-contact (Littleton, Walker and Ward, 2021). Where possible, the use of dedicated cleaning equipment is encouraged to minimise cross-contact and the benefits of having different coloured equipment for certain allergens are explained (Teng, 2013; Smith, 2019; FDE 2022). In addition, it is recommended that hygienic design of cleaning equipment is important but is not always considered (Smith, 2015; Smith, 2016; Smith, 2019).

7.3.4.7 Costs

Cost considerations were rarely discussed in the literature reviewed, despite the recognition that cleaning and change-over procedures are recognised as a key factor for allergen management, with an annual cost estimate per company of $1M to $2.5M, based on small companies (those with earnings of ?$500 million annually) and large companies (those with earnings of >$500 million annually) (Gupta et al., 2017). Factors that affect the cost include those relating to the cleaning methodology, such as labour and supervision, chemicals, water heating and cleaning equipment. It was described that 60% of the cost is for appropriate labour and supervision (U? urcan, 2022), whilst detergents and cleaning solutions have a low contribution to cost (5%) but have a large impact on efficacy (Holah, 2014).

Colour coding of equipment to more easily prevent and manage cross-contact was described as a low cost initiative (Teng, 2013).

Based on the information extracted throughout the report, the below bullet points summarise some of the factors that may affect the cost of the cleaning methodology selected:

- Wet cleaning: the need for appropriate cleaning agents; chemical expertise; water; energy; training to ensure equipment is used effectively and procedures are carried out appropriately.
- CIP: purchase and operation of specialised equipment as well as the same considerations as for wet cleaning; although reduced labour and supervision required.
- Dry cleaning: physical equipment (considering any additional premium for colour-coded equipment); equipment maintenance; potential additional labour costs compared to other methodologies; potential risks due to issues with cross-contact.
- Push-through: flushing material and the quantity required; costs (and reduced productivity/increased downtime) to carry out validation studies.

7.3.4.8 Inconsistent terminology

Throughout the literature, terminology is not always used consistently. For example, sometimes push-through is included under the definition of dry cleaning. Controlled wet cleaning is not always highlighted as a separate cleaning methodology and is sometimes also grouped with dry cleaning due to carefully controlled application of water or a cleaning agent before wiping. Some sources refer to the operational modes of cleaning i.e. mechanical, foam or gel, automated (CIP) which have also been categorised as either dry cleaning, deep cleaning, inter-product 'changeover' cleans or automated cleaning. Others group on the basis of the cleaning energy required i.e. mechanical, thermal or chemical, or even on the basis of physical (for example, scrapers), chemical (for example, cleaning with hot water or detergent) or biological (for example, ultraviolet light).

In addition, there are nuances between use of the terms 'cross-contact' and 'cross-contamination'. The term 'cross-contact' is used internationally and is defined by Codex Alimentarius (2020a) as occurring "when an allergenic food, or ingredient, is unintentionally incorporated into another food that is not intended to contain that allergenic food". WHO (2006) explain that 'cross-contamination' refers to "the introduction of microorganisms or disease agents from raw food into ready-to-eat food making it unsafe". In some places the terms are used interchangeably, or 'cross-contamination' is qualified by stating 'allergen cross-contamination' (for example, Government of Canada, 2019). A consensus on use of the terms would aid harmonisation of understanding.

The terms 'validation' and 'verification' are also not widely understood and therefore need definition, see Section 7.4 for further information.

7.4 Validation and verification of cleaning for allergen removal

Effective cleaning is widely accepted, as part of a wider allergen control plan, as one of the best strategies for preventing or minimising allergen cross-contact in food processing and food service environments, particularly where lines, equipment, utensils or areas are used to prepare foods with different recipes, without allergens or containing different allergens. This use of cleaning as a control measure, defined as 'any action and activity that can be used to prevent or eliminate a food safety hazard or reduce it to an acceptable level' (Codex Alimentarius, 2020b), is therefore well established.

Legislation (retained Regulation (EC) No 852/2004 on food hygiene) lays down various principles relating to food hygiene, including that primary responsibility for food safety is borne by the FBO. In addition, the legislation underpins the requirement that FBOs shall put in place, implement and maintain a permanent procedure or procedures based on the HACCP principles. Codex Alimementarius General Principles of Food Hygiene (Codex Alimentarius, 2020b) lays down the HACCP principles by international consensus; of relevance is principle 3 'the requirement to

establish validated critical limits.’ Principle 3 then goes on to state that, “criteria often used include minimum and/or maximum values for critical parameters associated with the control measure such as measurements of temperature, time, moisture level, pH, aw, available chlorine, contact time, conveyor belt speed, viscosity, conductance, flow rate, or, where appropriate, parameters that can be observed, such as a pump setting.” Many of these variables have been documented specifically previously in this text.

This then also relates to principle 6 ‘validate the HACCP plan and then establish procedures for verification to confirm that the HACCP system is working as intended.’ This includes CCPs, critical limits and control measures. It could be considered that while allergen management may not typically be a CCP to an FBO, it could certainly be a control measure, thus requiring validation.

Validation and verification are, therefore, inherent principles of HACCP. These activities are explained further in Codex Alimentarius Guidelines for the Validation of Food Safety Control Measures (2008) and are incorporated into GFSI-benchmarked standards including for example BRCGS.

However, it is rarely the case that the hazards associated with allergens can be controlled at a particular step in the manufacturing process. Control of such ‘generic’ or site-wide hazards, i.e. those that may impact many steps of the process and are not specific to a particular process step, is therefore achieved by good manufacturing practices. Allergens must therefore be considered as part of the FSMS (European Commission, 2022).

It is important to consider the definitions of validation and verification to truly understand the activities involved in each, as there is sometimes misinterpretation of the terminology; the following definitions are from Codex Alimentarius (2020b):

- Validation of control measures: Obtaining evidence that a control measure or combination of control measures, if properly implemented, is capable of controlling the hazard to a specified outcome.
- Verification: The application of methods, procedures, tests and other evaluations, in addition to monitoring, to determine whether a control measure is or has been operating as intended.

Another term that is often used, but misconstrued is also defined (Codex Alimentarius, 2020b):

- Monitoring: The act of conducting a planned sequence of observations or measurements of control parameters to assess whether a control measure is under control.

With specific reference to food allergens, the Codex Alimentarius Code of Practice on Food Allergen Management for Food Business Operators (2020a) states that “the validation process should be specific to the allergen, process and product matrix combination. Cleaning processes should be verified through visual observation (checking that equipment is visibly clean) and, where feasible and appropriate, through an analytical testing program.” It is pointed out by Schmitt and Moerman (2016), however, that cleaning validation is not necessarily required for potentially non-critical cleaning of floors, walls and the outside of equipment, unless required by hazard evaluation.

7.4.1 Summary of findings from the published literature on validation and verification of cleaning for allergen removal

Other than Jackson (2008), peer-reviewed journal articles did not detail principles for validation and verification of cleaning to remove food allergens. Most information in this area was provided in guidance documents, where 61% of the selected sources stated that validation of allergen

control measures is required. Of those, 33% referred to the majority of principles of validation as established from the selected sources. Verification was discussed in all but one of the documents that detailed cleaning validation. Industry and professional body publications mentioned validation and verification with reference to cleaning for allergen removal, but unsurprisingly based on the length and detail of the articles only topline information was available on the whole. Websites and other information sources (such as white papers and presentation slides on the internet) either didn't mention validation and verification, mentioned it briefly or were focussed on it as the main topic of the source. Similarly, book chapters and webinars either provided limited information beyond the requirement for validation and verification or were specifically focussed on this area.

There did not seem to be discernible differences between guidance from different areas of the world.

7.4.1.1 Principles of validation and verification of cleaning to remove allergens

Jackson et al. (2008) remarked on a lack of consensus on the principles of validation and verification of cleaning to remove food allergens at that time. Subsequently, and not specifically relating to allergens, the food industry has seen international consensus on the validation of food safety control measures in guidance from Codex Alimentarius (2008), peer-reviewed literature (for example Schmitt and Moerman, 2016) and guidance, such as 'Cleaning Validation, Monitoring and Verification' (EHEDG, 2021b), which is based on the recommendations of guidance from the pharmaceutical industry. The general principles of validation and verification then are well established.

Specifically relating to food allergens, this review found various sources of information and general agreement between them in terms of the principles of validation and verification of cleaning to remove food allergens that were mentioned; however, only two of the guidance documents detailed all the principles established in this review. It remains then that consistency of the extent of advice on the principles in relation to validation and verification of food allergen cleaning is lacking.

The food industry would benefit from consensus and consistency in guidance relating to both validation and verification of cleaning for allergen removal.

7.4.1.2 Visual inspection

One area among the literature where there was divergence was around the use of visual inspection in validation and verification of cleaning to remove food allergens. Some references only mentioned checking for visually clean for verification, not validation. Generally though there was agreement that where visual inspection is used it should be in combination with appropriate analytical testing.

It is clear that visually soiled surfaces following a clean suggest a failure to adequately remove the food soil, meaning that the likelihood allergenic proteins are present increases. But it was reported in some of the journal articles that, even when surfaces seem to be visually clean, analytical tests can still detect the presence of allergenic food soils. Visually clean then should be the first objective in any cleaning regime, but there is also a need for analysis of environmental samples (such as swabs of surfaces, rinse waters, flush-through material, where relevant) and product samples to fully understand the capability and on-going efficacy of the cleaning regime where appropriate and feasible.

7.4.1.3 Analytical detection of food allergens in cleaning validation and verification

The lack of the use of allergen analysis, particularly by SMEs is evidenced in a report for the FSA (FSA, 2022). It was found that overall, allergen testing by SMEs as part of risk analysis process was minimal. There was some testing of pathogens and particularly cleaning validation for microorganisms for manufacturers. There were two examples of an allergen being tested to validate a free from claim in the study. There were no examples of allergen cross-contact being tested to support the use of PAL, either as cleaning validation or a product test.

In addition, Jackson et al. (2008) reported on a survey that had been undertaken by the US FDA in 2001 (link no longer available). The survey was carried out on businesses that had had previous issues with allergen cross-contact and found that only 4% utilised analytical testing to verify cleaning, highlighting an association with the use of allergen detection methods and reduced contamination. The percentage compared to overall industry figures was reported to be vastly different, as a report from the Institute of Food Technologists (IFT) (also reported by Jackson et al. (2008)) found that than 85% of companies validated cleaning programs and 71% conducted analytical testing to verify that the cleaning programs were effective. Of concern considering the findings of this current literature review is the result that at the time visual inspection was the most common verification method for the majority of companies (100% of small companies, 90% medium, 93% large) despite a lack of evidence supporting it's effectiveness. The second most popular method was ELISA testing, although this was carried out by a much smaller number of companies (15% of small companies, 38% medium, 52% large). A more recent survey of Canadian food processors by Dominguez et al. (2022) found that 81% confirmed cleaning procedures using allergen-specific swabs, followed by 75% using ATP and/or general protein swabs, and 75% using visually clean inspections. Results suggest that there has been a shift away from visual inspection as the main method of detection to more allergen-specific techniques, although geographical differences and regulatory contexts may also contribute to the perceived difference.

When discussing analytical methods for detection of food allergens many sources provided general information on how the methods work. Some made comment on the use of particular methods in specific circumstances, for example Jackson and Al-Taher (2010) talked about the importance of using visual inspection in combination with either ELISA or total protein swabs for detecting the presence of allergenic food residues after dry cleaning equipment surfaces. From the journal articles lack of agreement between results from different methods was evidenced. The findings show that it is important to select test methods carefully, to consider their inherent benefits and limitations, and what is most applicable to the specific situation. Use of a combination of tests is encouraged (for example, Chen et al. (2022)) and frequently imparted is the advice to validate tests for their intended purpose, especially for the specific samples collected.

This need to validate tests relates not only to those that specifically detect food allergens (for example, ELISAs or LFDs), as it is know that different factors (such as the food matrix and the processing the sample as undergone) can affect their efficacy, but also and perhaps more so, the tests that are indirect measures of cleaning efficacy. In particular, tests for the detection of ATP have variously been found to be comparable, but more frequently, non-interchangeable with specific food allergen tests.

Of most relevance to cleaning validation and verification for allergen removal are tests specific for food allergens, not only because these have been found to be more sensitive than other tests (with plate ELISAs being more sensitive than LFDs, and both generally being more sensitive than total protein tests, for example), but also because they are the most clinically relevant (due to them detecting protein from allergenic foods, which is the constituent to which allergic people react). Such tests, however, are not always available, or they may not be appropriate, for example due to ease of use, cost, possible interference or cross-reactivity due to the matrix being tested or the processing that the samples have undergone. In which case the general advice is to test using the most specific, relevant, sensitive tests for validation and alongside the non-specific

tests that will be used for verification, to check for agreement or at least to understand the limits of those methods.

In terms of acceptable levels, consensus is on the whole that for cleaning validation, the lower limit of quantification (LLOQ) should be considered. As stated in this report, much work is being undertaken at the time of writing regarding the use of ‘thresholds’ or ‘action levels’ for PAL and information; however, these should not be regarded as ‘acceptable limits to work to’, but rather as an approach to harmonised data gathering and methodologies for food allergen risk assessment (ILSI Europe, 2022). Mention was made in one guidance document (AFREA, 2014) of HACCP critical limits. Codex Alimentarius (2020b) states that a deviation from the critical limit indicates that it is likely that unsafe food has been produced. In addition, critical limits for control measures should be specified and scientifically validated to obtain evidence that they are capable of controlling hazards to an acceptable level if properly implemented. Critical limits could be based on existing literature, legislation or guidance from competent authorities, or studies carried out by a third party, for example, studies conducted by an equipment manufacturer. Validation of control measures are further described more fully by Codex Alimentarius (2008).

ATP tests were mentioned throughout the literature in relation to allergen cleaning validation and verification on the whole with a note of caution. As summarised by Courtney (2016) “ATP testing is not ideal for allergen detection as it does not specifically detect allergen proteins and various factors can influence the [..] readings which complicate the determination of a limit value”.

One source not included in the book chapters results section of this report, as it is not focussed on cleaning, validation or verification per se, so was not picked up during the initial searches relates to sampling for food allergens (Brown and Arrowsmith, 2015). It is pointed out that sampling is a critical part of analytical testing for food allergens, and its significance can not be overemphasised. Information is provided on approaches to sampling (representative sampling, selective sampling, random sampling and composite sampling), sample types (food samples, rinse water, wash water and flushing materials, settle plates to sample allergens deposited from the air, environmental swabbing) and ensuring the quality of samples. This information is therefore relevant to cleaning validation and verification where samples are collected and should be considered.

In summary then, there is no one straight answer as to what is the best test to use, as this will depend on factors such as the situation, the question/s being asked, the sample type, the sample matrix, whether tests are to be conducted on-site in the production facility or by an analytical laboratory and any time limitations for example. As the choice of detection methods for food allergens can be complicated, it is best to seek the advice of experts (for example, test kit suppliers or an accredited testing laboratory) to determine the most appropriate tests, whilst designing the cleaning validation, i.e. before sampling commences. In addition, understanding the results can be complex, it is recommended (Codex Alimentarius, 2020a) that, if necessary, the FBO should obtain expert advice on interpretation of results (again from the test kit supplier or an accredited testing laboratory).

7.4.1.4 Interference of cleaning chemicals in allergen detection tests

There was limited evidence in the peer-reviewed journal articles of the potential for interference of cleaning chemicals with allergen detection methods. Such chemicals may be present in samples such as rinse waters from cleaning operations or equipment, such as tray washers, or even in swab solutions from surfaces from which disinfectants have not been rinsed.

In a thesis by Courtney (2016) removal of milk soils from various food processing surfaces was investigated by commercial milk-specific LFDs and general protein tests. It was found that the caustic solutions gave false negative results with LFDs, while the sanitiser caused false positive results with a general protein kit.

In a study by Arrowsmith and Brown (2006, Campden BRI Research Summary Sheet (No. 2006-67) Effect of cleaning fluids on detection of allergens, not published in the public domain), when cleaning fluids alone were tested directly at their recommended working concentration, a number of false positive results were obtained in different brands of allergen ELISA test kits and a general protein test. However, false positive results were found to depend on the particular combination of a specific cleaning fluid with an individual test; no one fluid gave false positive results in all the tests and no one test had false positive results for all concentrations of cleaning fluids. When testing a known concentration of allergen in the presence of cleaning fluids at the working concentration, some false negative results, and interferences in terms of higher and lower than expected results, were observed.

Sanitisers are a detergent plus disinfectant blend and must therefore be rinsed from surfaces due to the detergent component. Disinfectants with a defined maximum residue level (MRL), set under biocides or pesticides legislation, are not required to be rinsed from surfaces if the user can prove that they do not exceed the MRL after the recommended contact time. Those that do not meet the relevant MRL must be rinsed off, as is the case for quaternary ammonium chloride compounds (quats), for example (N Blitz 2023, personal communication, 22 March). Some disinfectants may therefore remain on surfaces following cleaning.

In the study reported above, Arrowsmith and Brown (2006, Campden BRI Research Summary Sheet (No. 2006-67) Effect of cleaning fluids on detection of allergens, not published in the public domain) found that when alcohol was used as part of the terminal clean of filler nozzles after packing pasteurised soya milk, the alcohol showed no effect in a soya residue ELISA, but gave a false positive in a general protein test. In this case the ELISA was suitable for validation work, but the general protein assay was not.

These studies show that when samples that may contain cleaning fluids (for example wash waters, rinse waters, swabs from surfaces with terminal disinfectants) are analysed for the presence of allergens, the cleaning fluid should be tested both alone and in the presence of the allergen to confirm there is no interference with the test being used. This is important to avoid arriving at the wrong conclusion about the presence or absence of food allergens.

7.5 Evidence gaps in the published literature

This review found that only six allergens (milk, soy, peanut, egg, hazelnut (as just one of the eight nuts), gluten (as a marker for cereals containing gluten)) were included in studies in peer-reviewed journal articles, meaning that for eight of the allergenic foods requiring mandatory labelling declaration in the UK (celery, crustaceans, fish, lupin, molluscs, mustard, sesame, sulphites) plus the remaining nuts (almonds, walnuts, cashews, pecan nuts, Brazil nuts, pistachio nuts, macadamia or Queensland nuts) there was no published literature investigating the efficacy of cleaning found during the review period of ten years (2012-2022). Of the matrices or soils studied few were heat treated, or for those that were the soils were unrepresentative substances like slurries containing peanut flour, skim milk powder, whole egg powder, soy flour, soy milk and soy infant formula powder, rather than foodstuffs typically present in food service kitchens, such as scrambled or fried egg for example.

It was also found that there was more published literature covering wet cleaning methodologies compared to dry, push-through or controlled-wet methods. Only one study was carried out using CIP (albeit in a simulated environment). Where automatic dishwashers were mentioned it was generally as part of much larger studies, so it was not always possible to deduce results specific to this cleaning methodology. Studies on these cleaning methods did not specifically investigate the reuse of cleaning fluids in CIP or recirculation of water in automatic dishwashers for example; one study, however, did implicate partial recirculation of water in a dishwasher for higher levels of allergen contamination of utensils washed using this method (Galan-Malo et al., 2019).

COP was not referred to specifically; although several studies utilised this methodology it was difficult to form conclusions on its efficacy due to the confounding factors between the different studies, or the lack of specific information on the effectiveness of this cleaning methodology. OPC, however, which involves for example conveyor belt removal and cleaning ‘in situ’, was not studied.

Although some journal articles investigated food service scenarios, most literature types focussed on food processing environments suggesting that there is a gap for general principles and guidance for cleaning methodologies suitable for food service and any additional considerations that need to be taken into account for cleaning validation and verification in that context.

It is also clear, with respect to food service, that further evidence on the efficacy of handwashing, laundry and dishwashing appliances is needed.

In terms of detection of food allergens, it is widely reported that even when surfaces seem to be visually clean, analytical tests may still detect the presence of allergenic food soils. It is unclear how the detection of residues on visibly clean surfaces relates to contamination within foodstuffs. It is pointed out by FDE (2022) that in risk assessment terms, the important consideration is the extent to which any residue transfers to the product.

Further outlined in the report is the lack of information on cost considerations for different cleaning methodologies in the context of cleaning to remove food allergens.

The lack of information about the efficacy of cleaning for allergen removal in the public domain could be improved if more could be done to investigate current industry practices and examine data held by FBOs, cleaning chemical manufacturers, cleaning services providers to the food sector and other organisations to understand the variety of methodologies applied and their efficacy in specific contexts. It remains, however, that it is difficult to directly extrapolate from cleaning practices in food processing to food service, where the time, resources and expertise are generally not available, especially in micro, small and even medium businesses.

7.6 Emerging cleaning methodologies for allergen removal

The literature review detailed throughout this report was primarily focussed on existing cleaning practices for allergen removal, as not only was this area where most information was found, but arguably these methods are most relevant to the intent of this review, i.e. as a starting point in co-developing allergen cleaning guidance with industry. It was found, however, that in various publications mention was made of emerging cleaning methodologies, which are being developed in part to fulfil the need of FBOs looking to improve the efficiency of their processes and reduce energy and water usage. But, as these methods are generally still at the development stage (some of the published studies describe this development) and are not in routine use, they have not been included in the preceding sections of the report. This section discusses some examples of emerging cleaning techniques and provides illustrations of where their efficacy has been studied in regard to allergen removal.

Ultrasound (sonic waves above human-hearing threshold) has been used for a wide range of food processing operations both in research laboratories and commercially; including for example for cutting, food preservation, defoaming, degassing and sealing packages (McHugh, 2016). Ultrasound can be used for surface cleaning of a wide range of materials (Otto et al, 2011), such as conveyor belt materials, and is generally applied at laboratory scale using sonication baths or ultrasonic probes. Axelsson et al. (2013) used an ultrasonic probe mounted on a rig above petri dishes containing pieces of conveyor belt materials (polyurethane and polyvinyl chloride) that had been soiled with dried suspensions of wheat flour or skimmed milk, to demonstrate that allergen residues were removed more efficiently by ultrasound procedure than by rinsing with water only, as determined by allergen-specific ELISA testing.

Wet steam (water vapour at the boiling point of water, containing water droplets) has long been used for cleaning, and whilst although the use of dry steam (water vapour at the boiling point of water but without water droplets) as a cleaning tool has become much more common in recent years, the technology is still very much confined to certain niche segments within the cleaning industry (Stücken, 2017). Yan et al. (2013) investigated the use of a dry steam vacuum-cleaning device to remove peanut butter, soy protein and egg white soils dried onto the surface of two conveyor belts (vinyl fabric-reinforced and polyurethane solid-homogenous-plastic). LFDs were used to test for allergen residues remaining on the conveyor belts following cleaning until the surface was visibly clean. It was found that peanut butter was more difficult to remove than soy and egg white from the vinyl fabric reinforced belt, but all of the three soils were effectively removed from the polyurethane solid-homogenous-plastic belt. The use of superheated steam (water vapour at a temperature higher than the boiling point of water that does not contain water droplets) in cleaning is being investigated for the inactivation of microorganisms (for example, Labs, 2023). Rana et al. (2022) applied peanut butter and non-fat dry milk to aluminium foil coupons, which were then treated with superheated steam. It was found that as the duration of superheated steam treatment increased, the ease of visual removal of peanut butter from surfaces increased, however, the ease of non-fat dry milk removal decreased. Allergen residues were though detected on surfaces using allergen-specific LFDs, regardless of the duration of superheated steam treatment. Changes to the microstructure (by scanning electron microscopy) of the non-fat dried milk soil were attributed to the high lactose content. In addition, severe colour changes of the non-fat dried milk were recorded after superheated steam treatment; such modifications may be due to the soil becoming ‘baked’ onto the surface by the high temperature.

Enzymes are proteins that catalyze chemical reactions (Timmerman, Mogensen and Graßhoff, 2016). Enzyme-based cleaning is not yet commonly used throughout the food industry (Delhalle et al., 2020), however, processes for enzymatic cleaning of equipment and plants in the egg and meat processing industry, ice cream manufacturing and dairies have been established (Timmerman, Mogensen and Graßhoff, 2016). Fuciños et al. (2019) studied the effectiveness of proteolytic enzymes to remove gluten residues and the feasibility of incorporating them into cleaning products for industrial purposes. Preliminary validation of the effectiveness the enzymatic cleaning formulation developed to hydrolyse gluten was performed in a ready-to-eat/frozen food company. It was found that after application of the enzymatic formulation, with a contact time of five or 15 minutes, followed by rinsing with water, the gluten content decreased to values lower than 0.125 ?g/100 cm2 (i.e. lower than the detection limit of the R5 gluten ELISA used).

Other emerging techniques that are being investigated for their potential to be used for cleaning, and that may be of use for allergen removal, are cold plasma and surface texturising (D Bayliss 2023, personal communication, 18 May). Cold plasma is otherwise referred to as the 4th state of matter, created when enough energy is applied to a gas to achieve a plasma discharge. Surface texturising involves the use of super hydrophobic surfaces to support easy rinse down and reduced bacterial adhesion. The application of these techniques to cleaning is currently in the early phases of development, future research will be required to assess efficacy and applicability to the food industry.