User Manual for the Food Safety by Design hazard identification tool

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Accessibility

The Food Safety by Design tool is accessible via the link below:

https://fsbd.wur.nl

For citation to the tool: https://doi.org/10.5281/zenodo.12699635

If you encounter any bugs in the tool, please contact the developers at **foodsafetybydesign@wur.nl**

Glossary

Digital services: the electronic transfer of information including data and content across numerous platforms and devices like web or mobile.

Decision Support System (DSS): an information system or computer program that supports business or organizational decision-making activities.

Food business operator (FBO): the natural or legal persons responsible for ensuring that the requirements of food law are met within the food business under their control.

Introduction

Microbiological and chemical contaminants can be major threats to the safety, stability and quality of food and beverages.

Under the General Food Law (GFL; Regulation EC 178/2002)[1], all food operators are responsible for ensuring that no unsaved food is placed on the market. In general, four groups of hazards that can cause unsafe food can be identified: (1) microbiological hazards, (2) chemical hazards, (3) physical hazards, and (4) allergens. Food businesses are legally required to implement a food safety management plan. The Hazard Analysis and Critical Control Point (HACCP) technique is the foremost tool for managing food safety and controlling hazards in food (Table 1). This qualitative process aims to identify hazards of concern in a food product.

Table 1. Seven principles and twelve steps of HACCP and their relation. Source: Van der Meulen and Van der Weerd (2014)[2].

Seven principles	Twelve steps
	The HACCP team & definition of the scope
	Product description
	Intended use
	Flow diagram
	Verification flow diagram
Hazard identification, analysis and control	Hazard identification, analysis and control
Determination of the CCPs	Determination of the CCPs
Establishing critical limits	Establishing critical limits
Monitoring CCPs	Monitoring CCPs
Corrective action plan	Corrective action plan
Verification of the HACCP system	Verification of the HACCP system
Record keeping	Record keeping

[1] http://data.europa.eu/eli/reg/2002/178/2024-07-01
[2] B. Van der Meulen, H. Van de Weerd, 1 - Food hygiene regulation in the European Union (EU), Technology and Nutrition, Hygiene in Food Processing (Second Edition), Woodhead Publishing, 2014, Pages 3-20, https://doi.org/10.1533/9780857098634.1.3.

To ensure the safety, ingredients and processes need continuous assessment of hazards and subsequent control strategies. The Food Safety by Design project[3] developed a web-based tool to support food producers in the first step of HACCP by identifying potential food safety hazards associated with their products and production processes.

The tool provides a data-driven decision support instrument for hazard identification. Its development involves integrating knowledge from research institutes, Wageningen Food Safety Research and Wageningen Food & Biobased Research, on safety hazards in food ingredients with additional scientific information and information from expert opinions, and outbreak reports. This comprehensive approach links hazards to 29 food ingredients and 10 plant-based side streams. Furthermore, the tool allows to qualitatively evaluate the effect of 17 processing steps and storage conditions on these potential hazards.

This web-based decision support tool is an instrument to help food business operators (FBOs) evaluate product safety through a data-driven approach, based on its ingredients, processing steps, and the intrinsic and extrinsic properties of the product during storage. Moreover, FBOs can utilise this output to design or redesign their production processes and incorporate it in the HACCP analysis.

This manual provides instructions on how to use the tool, along with background information on the data and knowledge rules behind this tool. For more detailed information on selection and knowledge rules applied, please refer to the following publications:

Van Asselt, E. D., et al. (submitted): "Reuse of plant-based side streams in food production: Overview of chemical food safety hazards".

Hayrapetyan, H. et al. (in preparation): "A data-driven decision support tool to evaluate microbiological safety of plant-based food products and derived side stream ingredients".

[3] https://www.wur.nl/en/project/food-safety-by-design-automated-hazard-identification-tool.htm

Expected users

The tool has been designed for a variety of stakeholders with some understanding of food safety hazards, including scientists, FBOs, and national and international governmental agencies. These users can leverage this web-based tool as input for their risk analyses. To effectively utilise this tool, users must understand the food safety risk analysis framework, as well as the interplay between risk assessment, risk management and risk communication (see Figure 1).

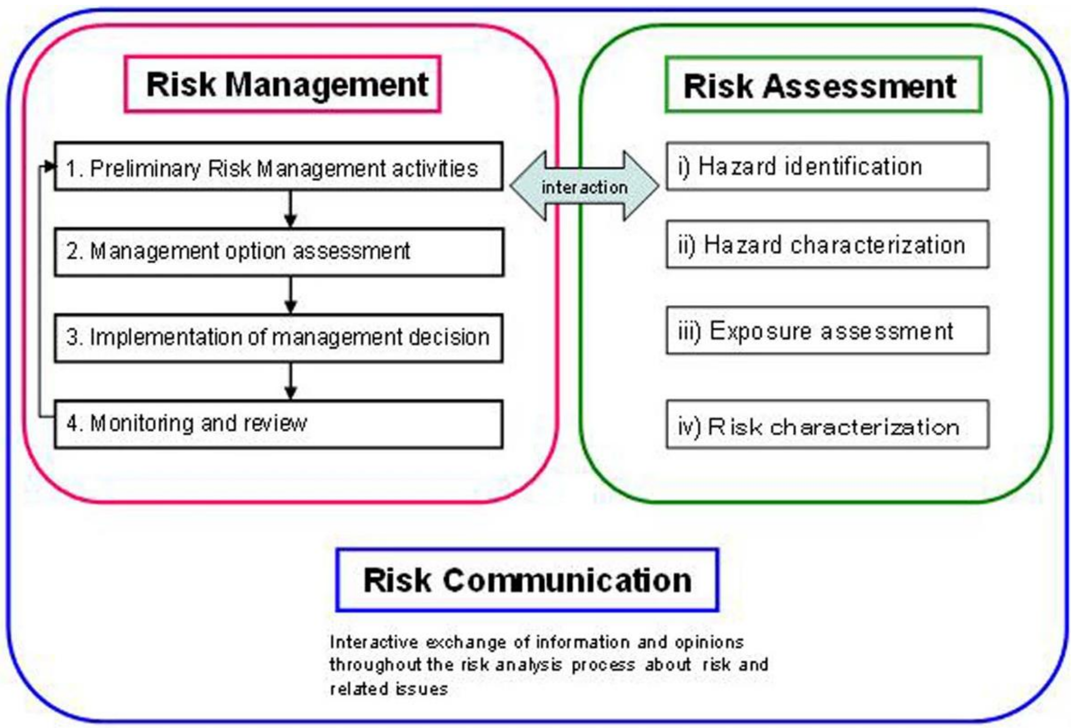

Figure 1. The food safety risk analysis framework. Source: Wu (2012) [4] .

Expected users can, for example, utilise the hazard list as scientific input into the risk assessment process, particularly during the hazard identification and hazard characterisation steps. In addition, the overview of ingredients and the effects of these processes on the resulting list of hazards can contribute to potential risk management activities and decision-making, as well as future monitoring and review efforts. Likewise, risk communication regarding the information provided by the tool, any identified knowledge gaps, and opinions on the types of risks will enhance the dialogue with stakeholders.

[4] Wu, Y. Translational toxicology and exposomics for food safety risk management. *J Transl Med* **10** (Suppl 2), A41 (2012). https://doi.org/10.1186/1479-5876-10-S2-A41

Tool instructions and functionalities

The tool is freely available. However, the first-time users will be asked to fill in a form to acknowledge the copyright and confirm their intended use. Once you have accomplished that, you start at the home page (Figure 2).

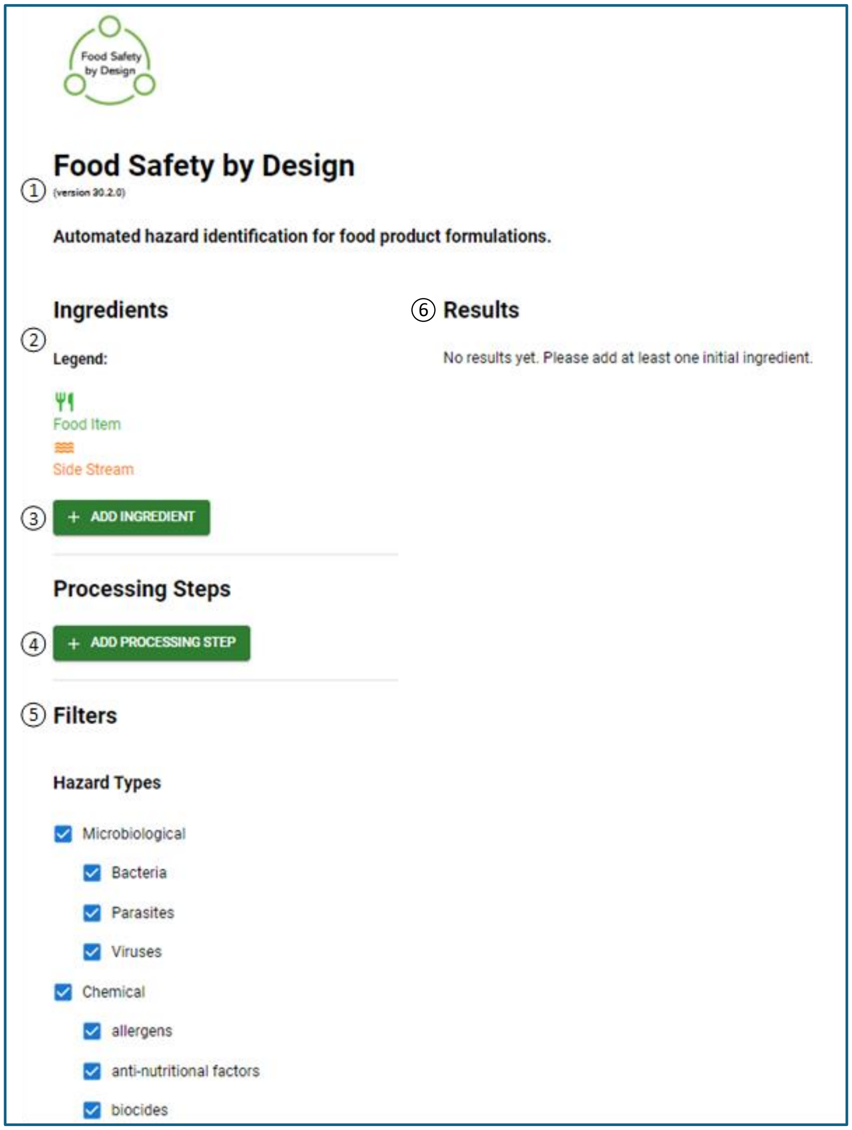

Figure 2. Home screen; upon opening the tool, you will see the screen where you can select your inputs.

Overview home/input screen

1. Title and version number.
2. **Ingredients**. Here, the ingredient categories will be displayed after selection (see step 3). It includes a legend for the type of ingredient: food item or side stream.
3. **Add ingredient**. An ingredient can be selected from a dropdown list.
4. **Add processing step**. A process can be selected from a dropdown list.
5. **Filters**. A hazard type can be selected, for which the tool will display results. By default, all hazard types are selected.
6. **Results**. Here, the resulting hazard list will be displayed.

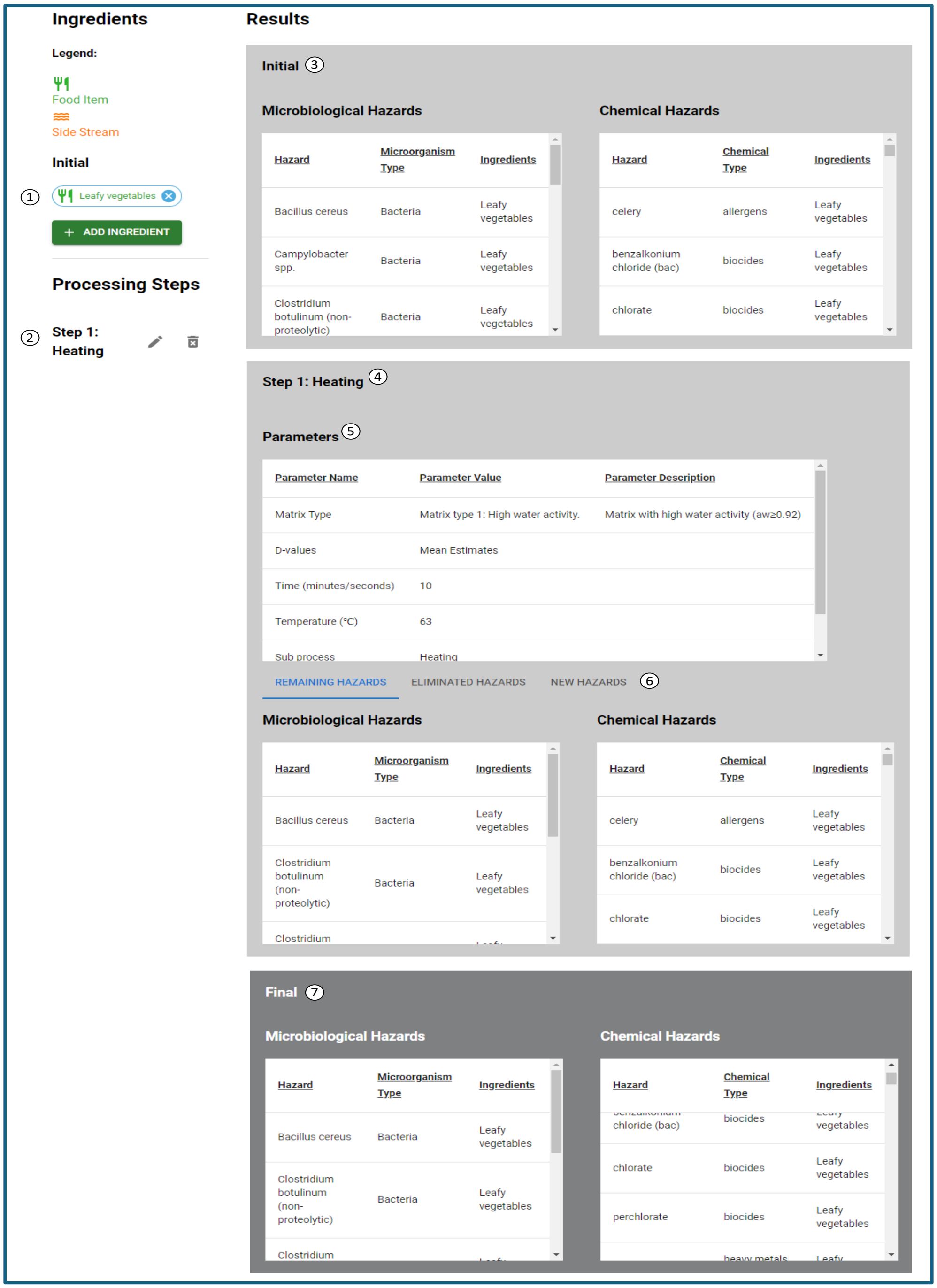

Figure 3. Overview example output for heating process on leafy vegetables.

Overview of Output screen (Figure 3)

1. The selected ingredients.
2. The selected processing steps.
3. Overview of the initial hazard list for microbiological and chemical hazards. The hazard name, hazard type and ingredient in which the hazard is present are shown in the tables. This result will appear after selecting at least one ingredient.
4. Overview of the processing step. This overview will appear after selecting a process step that contains a knowledge rule.
5. Overview of the input for variables of the processing step. The parameter name, selected value and description are shown in the table.
6. Tabs to see remaining hazards, eliminated hazards and new hazards after the process.
7. Final overview of remaining microbiological and chemical hazards.

Selecting ingredients and processes

Step 1: Select (an) ingredient(s)

Click the "+ ADD INGREDIENT" button (see Figure 2, number 3). A dropdown menu will appear with ingredients that can be selected. A distinction is made between food items and side streams. They are indicated with a different colour and icon (see Figure 2, number 2). The ingredient will appear under "Ingredients" (see Figure 3, number 1). Repeat this process for every ingredient to be selected.

After selecting ingredients, the resulting hazard list will appear under "Results" (see Figure 2, number 6).

Step 2: Select a process

Click the "+ ADD PROCESSING STEP" button (see Figure 2, number 4 and Figure 4). A pop-up screen will appear with a dropdown menu to select processes. Furthermore, a step number can be added. All processes require a step number, which determines where in the sequence of processes this specific process should take place (e.g. peeling occurs before cutting). By default, the last step number is selected.

After selecting a process and an option adjusting the step number, click the "+ ADD PROCESSING STEP" button.

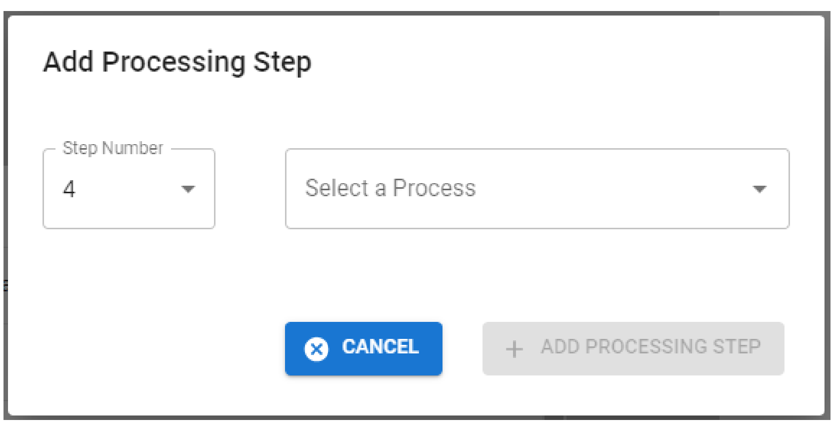

Figure 4. Add Processing Step pop-up screen.

After selecting a processing step, a pop-up screen will appear. Depending on the selected process step, a number of parameters must be entered (applicable to the processes described in steps 2a-2d). It is also possible to adjust the step number here.

Step 2a: Select a Heating process

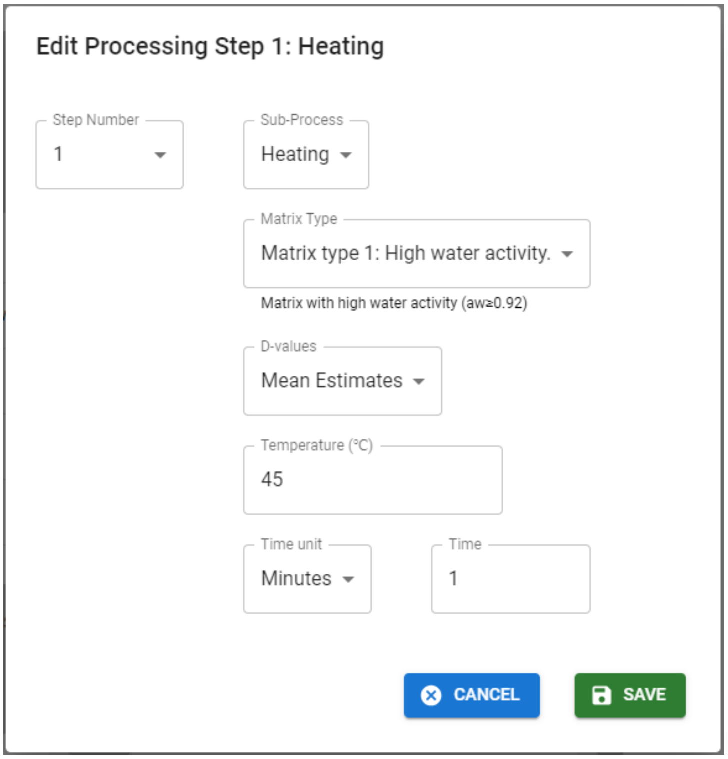

Figure 5. Heating pop-up screen.

After selecting the Heating step, a pop-up screen will appear, allowing to adjust a number of parameters (Figure 5). A specific heating process can be selected from the "Sub-Process" dropdown menu. Different Matrix types and D-values can be selected from a dropdown menu (see below under Processing steps, Heating). A numerical value for temperature in degrees Celsius can be entered. A numerical value for time can be entered. The time unit, either minutes or seconds, can be selected under "Time unit". Default values are shown in Figure 5. Once the parameters are set, click "SAVE" to add the process to the overview. To cancel all entries and remove the selected process, click "CANCEL"

Step 2b Select a Freezing process

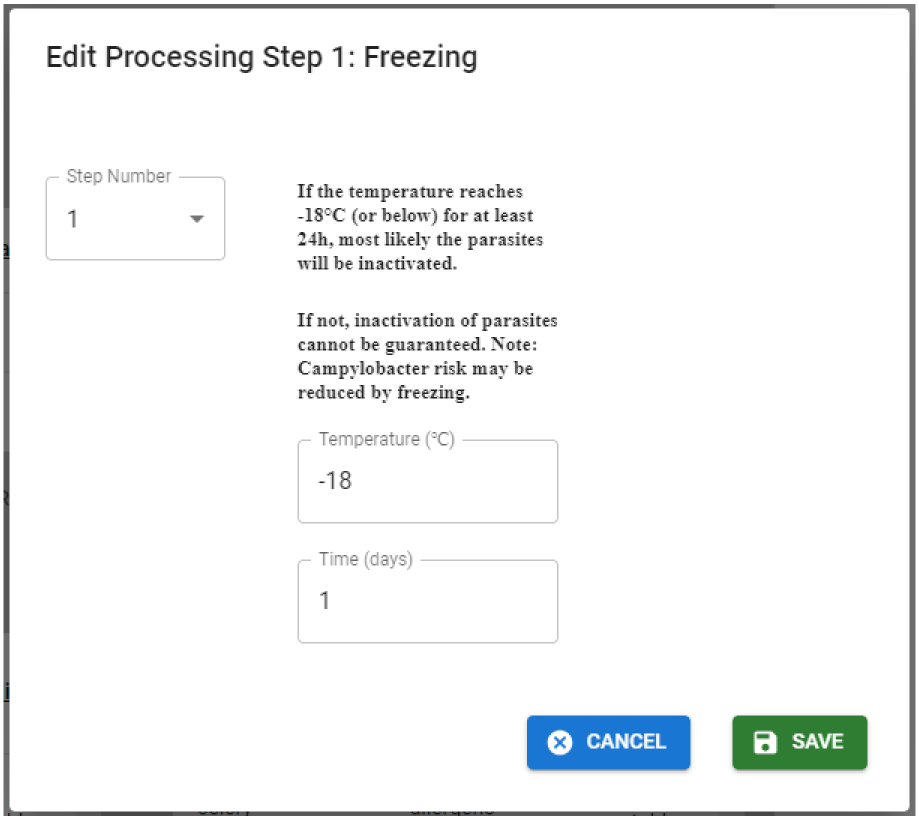

Figure 6. Freezing pop-up screen.

After selecting the Freezing step, a pop-up screen will appear, allowing to adjust a number of parameters. A numerical value for temperature in degrees Celsius and for time in days can be entered. Default values are shown in Figure 6. Once all parameters are set, click "SAVE" to add the process to the overview. To cancel all entries and remove the selected process, click "CANCEL".

Ensure the temperature is at least -18 °C and the time at least 1 day for the effect to take place. Temperatures above -17 °C will not affect the resulting hazard list, and decreasing the temperature further than -18 °C will lead to the same effect.

Step 2c Select a High Hydrostatic Pressure process

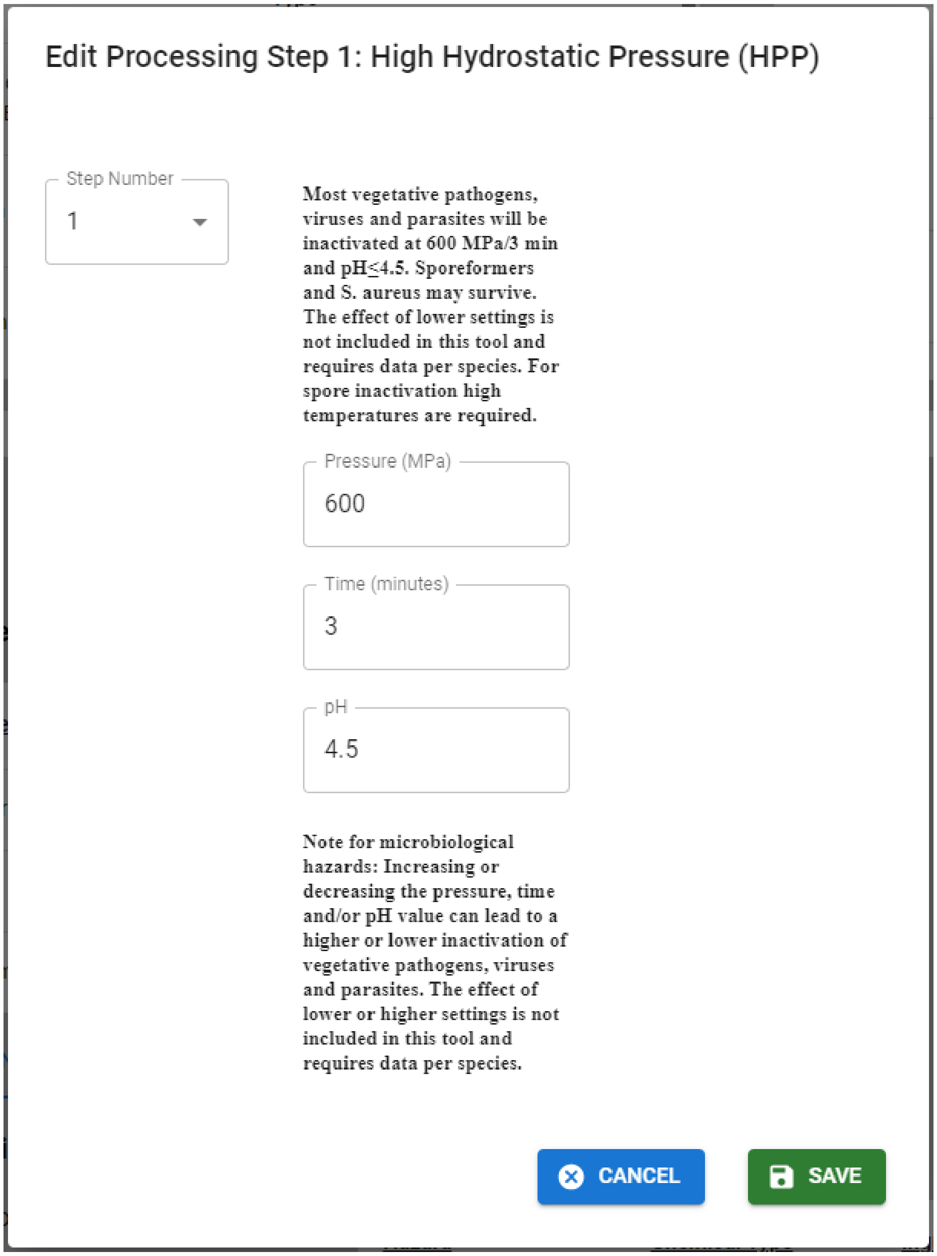

Figure 7. HPP pop-up screen.

After selecting the High Hydrostatic Pressure (HPP) step, a pop-up screen will appear, allowing to adjust a number of parameters. A numerical value for pressure in MPa, for time in days and pH can be entered. Default values are shown in Figure 7. Once all parameters are set, click “SAVE” to add the process to the overview. To cancel all entries and remove the selected process, click “CANCEL”.

Please note that for microbiological hazards, increasing or decreasing the pressure, time or pH value can lead to a higher or lower inactivation of vegetative pathogens, viruses and parasites. The effects of lower or higher settings are not included in this tool and require species-specific data.

Step 2d Select a Storage process

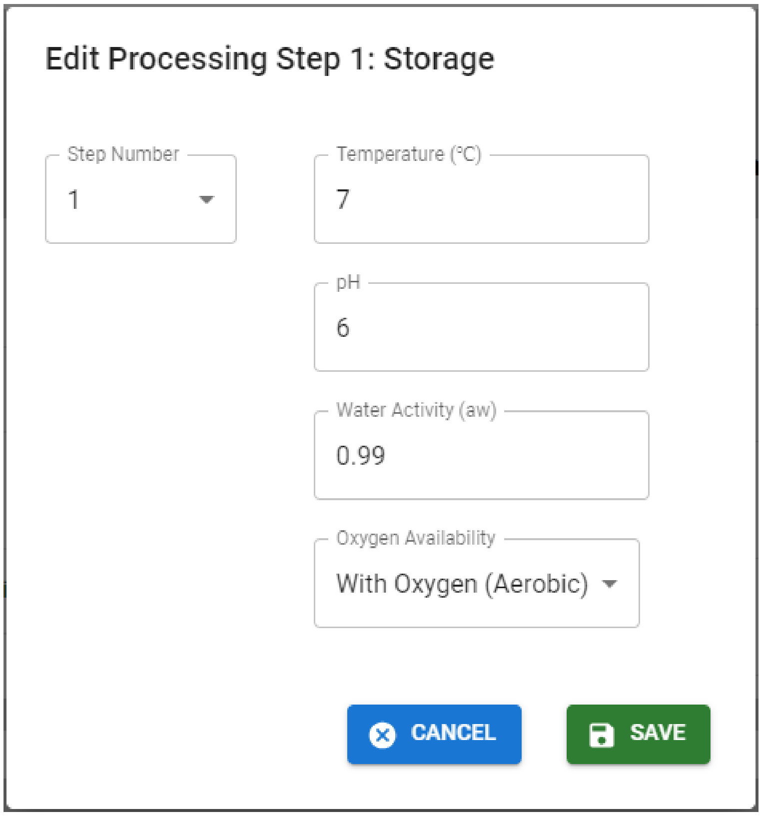

Figure 8. Storage pop-up screen.

After selecting the Storage step, a pop-up screen will appear, allowing to adjust a number of parameters. A numerical value for temperature in degrees, pH and water activity can be entered. In addition, for 'Oxygen availability', the options 'With Oxygen (Aerobic)', 'Little Oxygen (Micoaerobic)' and 'No Oxygen (Anaerobic)' can be selected from a dropdown menu. Default values are shown in Figure 8. Once the parameters are set, click "SAVE" to add the process to the overview. To cancel all entries and remove the selected process, click "CANCEL".

Step 3 Apply filters

Under 'Filters' (see Figure 2, number 5), hazard types of interest can be selected. When selected, only the results for those selected hazard type(s) will be shown (e.g. If only "Bacteria" is selected, only bacterial hazards will be shown in the result). It is also possible to select either for microbiological or chemical hazards, in which case all hazard types within the chosen group will be shown in the results. By default, all hazard types are selected.

Explanation of Results

Overview of Ingredients

After selecting ingredients, they are added to the list under 'Ingredients' (see Figure 3, number 1). It is indicated when an ingredient was added (either initially or after a specific processing step). To remove the selected ingredient, click the corresponding 'x' next to it.

Overview of Processes

After selecting processes, they are added to the list under 'Processing steps' (see Figure 3, number 2). They can be edited using the pencil icon and removed with the bin icon.

Overview of Resulting hazard lists

The complete hazard list for present microbiological and chemical hazards will be shown for the initial step, intermediate steps, and the final step (after all processes) (see Figure 3, numbers 3, 4 and 7). These tables show each hazard, its type and which ingredient(s) introduced them.

Overview of Processing step

The result for the processing step includes an overview of the entered parameters, when parameters were required (see Figure 3, number 5). If no parameters are required, a warning will appear. The overview of resulting hazards is organised into three tabs: remaining hazards after the process, eliminated hazards after the process, and newly introduced hazards after the process.

Other Functionalities

To export the results as pdf, click the 'EXPORT' button. The pdf will be downloaded.

Ingredients

The web-based tool includes **39 food ingredient categories**, of which 29 are main ingredients, and 10 are side stream ingredients. A list of the food categories, along with examples, is shown in Table 2.

The **29 main ingredient categories** are based on the European Food Safety Authority (EFSA) FoodEx2 classification standardisation system, a system used to classify and describe food[5], with some slight modifications. For example, we incorporated plant-based drinks and drink ingredients and subdivided certain dairy products (e.g., by raw, processed, powder). Raw and mildly processed products are included in the tool. Highly processed products, such as canned foods and ingredients for beverages (water, hot drinks, alcoholic beverages, etc.), as well as meat and fish are excluded.

The **10 side-stream ingredient categories** represent different foods that are currently used in animal feed and have potential to be upscaled for food production or used as novel ingredients in food production. Due to legal limitations on applications of animal by-products, the side stream categories focus only on plant-based ingredients.

Table 2. Food ingredient categories with examples.

Number	Category	Examples
1	Cereal	Barley, buckwheat, bulgur, fonio, kaniwa, maize (corn) dry, millet, oat, quinoa, rice, rye, sorghum, triticale, wheat.
2	Leafy vegetables	Leafy vegetables (including cabbages and fresh herbs), flowering brassica.
3	Sprouts	Sprouted seeds: alfalfa, broccoli sprouts, chickpea sprouts, coriander sprouts, fennel sprouts, fenugreek sprouts, garlic sprouts, leek sprouts, lentil sprouts, mung bean sprouts, onion sprouts, pea sprouts, radish sprouts, shiso sprouts, sunflower sprouts, wheat sprouts.
4	Fruiting vegetables	Tomatoes, fresh peppers and aubergines, corn fresh (e.g., corn on the cob, frozen corn kernels), gourds and squashes including butternut squash, button squash, courgette, cucumber, green spaghetti squash, Hubbard squash, ivy gourd, abocha, pepita squash, pumpkin, tinda, olives.
5	Mushrooms	Edible mushrooms.
6	Legumes (fresh)	Pulses/legumes and fresh pods: azuki bean, black-eyed pea, chickpea, common bean, dolichos bean, drumstick, fava bean, green bean, horse gram, Indian pea, kidney bean, lentil, lima bean, moth bean, mung bean, okra, pea, pigeon pea, rice bean, snap pea, snow pea, soybean, tepary bean, urad bean, velvet bean, winged bean, yardlong bean.
7	Legumes (seeds)	Pulses/legumes, dry seeds, dried legume products.
8	Seeds (edible and oil)	Seeds for consumption: amaranth, cannabis seed/hemp seed, chia seed, flax seed/linseed, ginkgo seed, marrow seed, poppy seed, pumpkin seed/pepitas, safflower seed, sesame seed, sunflower seed. Including oilseeds.

[5] https://www.efsa.europa.eu/en/data/data-standardisationhttps://efsa.onlinelibrary.wiley.com/doi/epdf/10.2903/sp.efsa.2015.EN-804

9 Fruits	Fresh fruits, minimally processed fruit products (fresh-cut, frozen, dried), mixtures of fresh fruit. Fruit examples: apple, apricot, avocado, banana, berries, cantaloupe, cherry, coconut, currant, grape, honeydew, kiwi, lemon, lychee, mandarin, mango, melon, nectarine, orange, papaya, pear, persimmon, plum, pomegranate, quince.
10 Nuts	Almond, Brazil nut, cashew, chestnut, coconut, hazelnut, macadamia, peanut, pecan, pine nut, pistachio, walnut.
11 Potatoes	Potatoes, potato powder, starchy roots, minimally processed potatoes such as peeled, cut fresh or frozen.
12 Root and stem vegetables	Roots (e.g., carrots), stems, bulbs, sugar plants. Excludes potatoes (starchy roots).
13 Dried herbs and spices	Spices and dry herbs: basil, black pepper, celery, chilli, chive, cilantro, cinnamon, clove, coriander, cumin, curcuma (turmeric), curry, dill, garlic powder, ginger, laurel, marjoram, mint, nutmeg, onion powder, oregano, paprika, parsley, peppermint, rosemary, sage, thyme, turmeric, white pepper, including spice mixes and dried herb mixtures.
14 Milk (raw)	Raw milk.
15 Milk (processed)	Processed fluid milk (pasteurised or UHT treated) and other fluid dairy products such as whey. Processed dairy products, such as butter, concentrates, cream, etc.
16 Milk (powders)	Milk powder, milk protein powder, whey powder.
17 Cheese (hard)[6]	Cheese with a low moisture content. Moisture on a fat-free basis (MFFB) < 56%. Examples are matured Parmesan, Cheddar, Manchego, Gruyere.
18 Cheese (soft)	Cheese with a higher moisture content. MFFB > 67%. For example, fresh cheese, unripened cheese such as mozzarella, mascarpone.
19 Eggs (whole)	Whole eggs.
20 Eggs (products)	Liquid & powdered eggs.
21 Confectionary, including chocolate	Confectionery: cacao, candy, caramel, chocolate, cocoa, fondant, halva, marshmallow, marzipan, nougat, wine gum.
22 Oils and fats	Oils, fats & margarine (plant origin), spreads.
23 Sugars and syrups	Sugars (cane, beet, palm), syrups.
24 Honey	Honey.
25 Plant-based drinks	Processed fluid plant-based drinks (pasteurised or UHT treated): almond drink, cashew drink, coconut drink, flax drink, hemp drink, macadamia drink, oat drink, pea beverages, quinoa beverages, rice drink, soy drink.
26 Mycoprotein	Mycoprotein.
27 Food additives: Dry supplements	Dietary supplements (dry), food additives (dry), artificial sweeteners, other chemical ingredients, dry ingredients not included in other categories (e.g., baking powder, colorants, preservatives), food flavours, food colours.
28 Food additives: Miscellaneous	Gelatine and other protein powders not included in the other food categories, yeast powder and enzyme preparations, starches.
29 Food additives: Yeast	Liquid yeast, dried yeast
30 Apple side stream	Peels, pomace or pulp thereof.

[6] https://www.fil-idf.org/wp-content/uploads/2021/02/Cheese-and-varieties-Part-2_-Cheese-styles-.pdf

31 Beetroot side stream	Peels, pomace or pulp thereof. Excludes sugar-beet.
32 Carrot side stream	Peels, pomace or pulp thereof.
33 Citrus side stream	Peels, pomace or pulp thereof.
34 Potato side stream	Peels, pomace or pulp thereof.
35 Sugar beet side stream	Peels, pomace or pulp thereof. Excludes beetroot.
36 Tomato side stream	Peels, pomace or pulp thereof.
37 Brewer’s spent grain (BSG) side stream	
38 Corn germ fibre and corn gluten meal side streams	
39 Wheat bran side stream	

Processing steps

A funnel approach was applied to select the processing types for the tool, as depicted in Figure 9. Only processes that impact the microbiological and/or chemical hazards were considered. Additionally, process parameters were defined only for the selected processes. The final list of processing steps and parameters included in the tool is presented in Table 3.

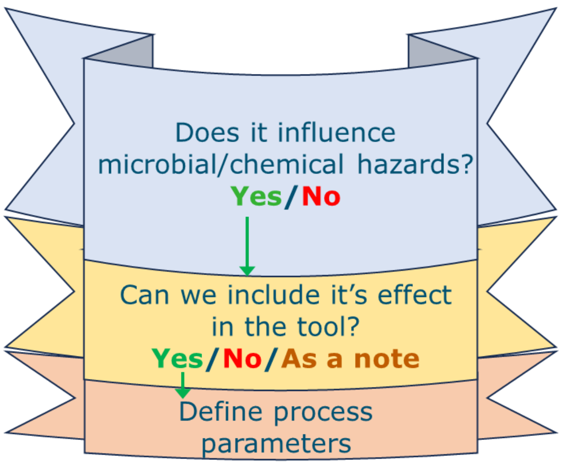

Figure 9. Selection of relevant processing steps.

Table 3. Final list of Processing steps.

Processing step	Notifications (notes)	Remarks
Cooling	For microbiological hazards: Can inhibit the growth of microorganisms, but will not eliminate them. However, if cooled slowly microorganisms could grow.	
Crystallisation	For microbiological hazards: Can decrease the water activity and, therefore, slow down the growth of microorganisms (Roos, 2020)[7].	
Cutting	For microbiological hazards: Can result in redistribution of microorganisms. Tissue damage can promote growth.	
Drying	For microbiological hazards: Can inhibit the growth, but will not eliminate microorganisms. (Beuchat et al., 2013[8]; Roos, 2020[9]). For the effect of water activity on growth, select "Storage". For chemical hazards: Can increase the concentration of chemical hazards due to water evaporation.	

[7] Roos, Y. H. (2020). Water Activity and Glass Transition. In Water Activity in Foods (pp. 27-43).
[8] Beuchat, L. R. et al. (2013). Low-Water Activity Foods: Increased Concern as Vehicles of Foodborne Pathogens. Journal of Food Protection, 76(1), 150-172. doi:https://doi.org/10.4315/0362-028X.JFP-12-211
[9] Roos, Y. H. (2020). Water Activity and Glass Transition. In Water Activity in Foods (pp. 27-43).

Extrusion (via Heating)	For microbiological hazards: Please select "Heating" as a processing step. Use the temperatures and times that extruded material is exposed to in the extruder.	
Fermentation	For microbiological hazards: During uncontrolled fermentation undesirable microorganisms may grow and produce toxins, such as mycotoxins and bacterial toxins. Furthermore, in protein rich substrates toxic by-products such as biogenic amines can be produced. In alcoholic fermentations ethyl carbamate can be formed. Appropriate fermentation can improve the safety and shelf life of the food.	
Filtration	For microbiological hazards: Filter pore size <0.22 µm will eliminate the majority of the microorganisms (Hahn, 2004[10]; Hasegawa et al., 2003[11]).	
Freezing	If the temperature reaches -18°C (or lower) for at least 24 h, it is highly likely that the parasites will be inactivated. If this temperature cannot be reached, inactivation of parasites cannot be guaranteed. Note: *Campylobacter* risk may be reduced by freezing.	Freezing temperature and time need to be provided.
Heating		See text for more information. Includes all forms of thermal processing.
High hydrostatic pressure	Most vegetative pathogens, viruses and parasites will be inactivated at 600 MPa/3 min and pH≤4.5. Spore formers and *S. aureus* may survive. The effect of lower settings is not included in this tool and requires species-specific data. For spore inactivation, high temperatures are required. For microbiological hazards: Increasing or decreasing the pressure, time and/or pH value can lead to a higher or lower inactivation of vegetative pathogens, viruses and parasites. The effects of lower or higher settings are not accounted for this tool, and require species-specific data.	HPP. Pressure (in MPa) and time (in minutes) of the treatment need to be provided as well as the pH of the product.
Pulsed electric field	For microbiological hazards: High intensity PEF can inactivate vegetative cells via electroporation, but not spores. PEF typically applied for the preservation of liquids is more effective in high-acid products than in low-acid ones. The effect of PEF depends on many different parameters and is, therefore, not included[12].	PEF

[10] Hahn, M. W. (2004). Broad diversity of viable bacteria in 'sterile' (0.2 µm) filtered water. Research in Microbiology, 155(8), 688-691. doi:https://doi.org/10.1016/j.resmic.2004.05.003
[11] Hasegawa, H., Naganuma, K., Nakagawa, Y., & Matsuyama, T. (2003). Membrane filter (pore size, 0.22–0.45 µm; thickness, 150 µm) passing-through activity of *Pseudomonas aeruginosa* and other bacterial species with indigenous infiltration ability. FEMS Microbiology Letters, 223(1), 41-46. doi:10.1016/s0378-1097(03)00327-6
[12] Timmermans et al. (2019). Moderate intensity Pulsed Electric Fields (PEF) as alternative mild preservation technology for fruit juice, International Journal of Food Microbiology,
Volume 298, Pages 63-73, https://doi.org/10.1016/j.ijfoodmicro.2019.02.015

Peeling	For microbiological hazards: Can eliminate microorganisms on the peel. However, recontamination can occur if pre-washing is not applied (Rocculi et al., 2009[13]). Some microbes can also be present inside the crops and will not be removed by peeling. For chemical hazards: Can reduce some chemical hazards, such as pesticides, plant toxins, heavy metals and mycotoxins. However, they will not be completely eliminated, especially if they are systemically present.	
Soaking / rehydration	For microbiological hazards: Can promote the growth of microorganisms (Roos, 2020[14]). For the effect of water activity on growth, see "Storage".	
Soil removal and brushing	For chemical hazards: Can reduce some chemical hazards, such as heavy metals. However, they will not be completely eliminated.	
Storage	For microbiological hazards: Will provide information if a microbiological hazard is able to grow during storage. See text for more information.	Temperature (in °C), pH, water activity and atmosphere need to be provided. Atmosphere can be: -with oxygen (aerobic) -little oxygen (microaerophilic) -no oxygen (anaerobic) If the product is frozen, choose "Freezing" as processing step.
Supercritical CO_2	For microbiological hazards: Can inactivate vegetative cells such as *Salmonella*, *E. coli* and *Listeria* on foods and liquid media (Furukawa et al., 2009[15]; Zambon et al., 2021[16]; Zambon et al., 2022[17]). Spores are more resistant. Important process parameters include: time, temperature, pressure, matrix, but also CO_2 ratio and mixing (Buszewski et al., 2021)[18].	
Washing	For microbiological hazards: Can reduce the microorganisms by 1 Log CFU/g, but it can also introduce cross-contamination. This effect is not included within this. For chemical hazards: Pesticide residues can be reduced by washing. The reduction in fruits and vegetables depends on factors like the type of	

[13] Rocculi, P., Romani, S., Gomez, F., & Rosa, M. D. (2009). Effect of minimal processing on physiology and quality of fresh-cut potatoes, a review.
[14] Roos, Y. H. (2020). Water Activity and Glass Transition. In Water Activity in Foods (pp. 27-43).
[15] Furukawa, S., Watanabe, T., Koyama, T., Hirata, J., Narisawa, N., Ogihara, H., & Yamasaki, M. (2009). Inactivation of food poisoning bacteria and *Geobacillus stearothermophilus* spores by high pressure carbon dioxide treatment. Food Control, 20(1), 53-58. doi:https://doi.org/10.1016/j.foodcont.2008.02.002
[16] Zambon, A. et al. (2021). Supercritical CO_2 for the drying and microbial inactivation of apple's slices. Drying Technology, 39(2), 259-267. doi:10.1080/07373937.2019.1676774
[17] Zambon, A., Facco, P., Morbiato, G., Toffoletto, M., Poloniato, G., Sut, S., . . . Spilimbergo, S. (2022). Promoting the preservation of strawberry by supercritical CO_2 drying. Food Chemistry, 397, 133789. doi:https://doi.org/10.1016/j.foodchem.2022.133789
[18] Buszewski, B., Wrona, O., Mayya, R. P., Zakharenko, A. M., Kalenik, T. K., Golokhvast, K. S., . . . Rafińska, K. (2021). The potential application of supercritical CO_2 in microbial inactivation of food raw materials and products. Critical Reviews in Food Science and Nutrition, 62(24), 6535-6548. doi:10.1080/10408398.2021.1902939

	pesticides, washing method, product type. Reusing the wash water may result in the accumulation of chemical hazards.	

Heating

When Heating is included as processing step, the following information must be provided/chosen:

- Sub-process (choose one):
    - Heating
    - Grilling, roasting, frying, baking (in oven) > relevant for chemical hazards
    - Baking in oil or deep-frying > also relevant for chemical hazards
- Matrix type (choose one):
    - Matrix type 1: High water activity (water activity (aw) ≥0.92). If information is desired on heat resistant *Bacillus cereus* strains, choose matrix type 4 (see below).
    - Matrix type 2: Salty products (>10% NaCl) > relevant for microbiological hazards. Only information for *Listeria monocytogenes* is available for this matrix type.
    - Matrix type 3: Low water activity (aw<0.92) > relevant for microbiological hazards. Only information for *Cronobacter*, *L. monocytogenes* and *Salmonella* spp. is available for this matrix type.
    - Matrix type 4: Low water activity and high fat (aw<0.92, fat≥18%) > relevant for microbiological hazards. Only information for *Salmonella* spp. (in peanut butter and chocolate) and *B. cereus* heat resistant strains is available for this matrix type.
- D-values (choose one):
    - Mean estimates.
    - Upper 95% prediction interval (PI) D-values.
- Temperature in degrees Celsius. This should represent the temperature of the coldest spot (usually the core of the food product) during the heating process.
- Time and time unit. This should specify the time applied at the coldest spot (see above regarding Temperature). The unit can be in minutes or seconds.

Storage

The minimal required growth conditions of bacterial pathogens used for storage are based on cardinal paramaters from scientific literature (EFSA, 2012)[19],(ICMSF, 1996)[20] (Nicoletti, 1990)[21] (Beuchat et al., 2013)[22] (Portaels & Pattyn, 1982)[23]. The cardinal parameters are: temperature, pH, aw and atmosphere (oxygen availability).

[19] EFSA. (2012). Scientific Opinion on Public health risks represented by certain composite products containing food of animal origin. *EFSA Journal, 10*(5), 2662. doi:https://doi.org/10.2903/j.efsa.2012.2662
[20] ICMSF. (1996). *Microorganisms in Foods 5 - Characteristics of Microbial Pathogens* (1 ed.). New York: Springer New York
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[23] Portaels, F., & Pattyn, S. R. (1982). Growth of mycobacteria in relation to the pH of the medium. *Annales de microbiologie, 133*(2), 213-221. Retrieved from http://europepmc.org/abstract/MED/7149523

Microbiological hazards

A list of 22 microorganisms has been compiled based on the most common foodborne pathogens relevant to the included food categories (Table 4 and

Table 5). All pathogenic *Escherichia coli*, including Shiga-toxin producing *E. coli* (STEC), are included under the generic name: "Pathogenic *E. coli*". This list was developed assuming that production occurs in regions with adequate hygiene standards. Opportunistic pathogens such as *Aeromonas* spp., *Enterococcus*, *Proteus*, *Entamoeba histolytica*, *Sarcocystis* were excluded from the list, as their behaviour is assumed to be similar to pathogenic *E. coli* and *Salmonella* spp. If desired by the user, these opportunistic pathogens can be considered as relevant if either *E. coli* or *Salmonella* spp. are identified as a relevant hazard for the selected ingredients.

To determine which microbiological hazards are relevant to each food category, the approach described below and depicted in Figure 10. Criteria for microbiological hazard identification for each food ingredient category.Figure 10 has been applied. All available data were compiled into an Excel document, generating a long list of potential hazards for each main ingredient and each side stream ingredient. All criteria listed above were scored as either 0 or 1. Microbiological hazards were linked a food category when either the sum of scores ≥ 3 or when the expert opinion =1.

The main criteria and information sources used to link pathogens to food categories were:

(1) Detection of the pathogen on the product as reported in scientific literature, outbreaks reported in scientific literature and/or public databases on outbreaks (mainly CDC from USA), and an expert opinion.
(2) Relevant information from the scientific literature has been collected, using the Scopus search database with tailored search-strings for each food category. For some of the ingredient categories, previously executed hazard identification studies were available, either published [e.g. dairy chain (Van Bokhorst-van de Veen, Minor, Zwietering, & Nierop Groot, 2015)[24,25], egg chain (Bolder et al., 2018)[26], potato chain (Hayrapetyan, Van Bokhorst-van de Veen, Zwietering, Janssens, & Nierop Groot, 2018)[27]] or unpublished (seven plant-based commodity chains, such as fruiting vegetables or leafy greens, conducted by WFBR), which were utilised to obtain relevant information.
(3) For ingredient categories with limited information available in scientific literature, specific searches in Google Scholar were performed. In addition, the ICMSF book on Microbial Ecology of Food Commodities (2005)[28] and relevant EFSA/WHO reports were consulted for information on the microbiological hazards. A conservative approach was used: if at least one scientific article or a report was found on a foodborne hazard for a specific food category, a score "1" was assigned. For example, one report on detection of the microorganism or one report about an outbreak was sufficient to classify the pathogen as a potential hazard (score 1 in the corresponding column).

For all ingredient categories and hazard combinations, the combined consensus opinion of three microbiologists and/or food safety and quality experts from Wageningen University & Research (WUR) and the project partners was formed (Figure 10). The expert opinion was based on the aspects such as previous experience, knowledge obtained from the literature search, own interpretation of relevance, consideration of the possibility of recontamination during the production of the ingredients. The expert opinion was based on the assumption that the product would be used as an ingredient rather than an end food product. For example, *Clostridium botulinum* is not likely to grow out in a yoghurt with low pH, however, if a yoghurt

[24] Van Bokhorst-van de Veen, H., Minor, M., Zwietering, M. H., & Nierop Groot, M.N. (2015). *Microbial hazards in the dairy chain* (1553). Retrieved from Wageningen: https://edepot.wur.nl/451235

[25] Van Asselt, E.D., Van der Fels-Klerx, H.J., Marvin, H.J.P., Van Bokhorst-van de Veen, H. and Nierop Groot, M.N. (2017), Overview of Food Safety Hazards in the European Dairy Supply Chain. Comprehensive reviews in food science and food safety, 16: 59-75. https://doi.org/10.1111/1541-4337.12245

[26] Bolder, et al. (2018). Microbiologische risicobeoordeling eierketens: Achtergrondstudie ten behoeve van een integrale risicobeoordeling van de eierketens door de NVWA (2015-0122). Retrieved from Bilthoven: https://www.rivm.nl/publicaties/microbiologische-risicobeoordeling-eierketens-achtergrondstudie-ten-behoeve-van#abstract_en

[27] Hayrapetyan, H., Van Bokhorst-van de Veen, H., Zwietering, M. H., Janssens, B., & Nierop Groot, M. N. (2018). Microbiologische gevaren gerelateerd aan consumptie van aardappelproducten (1758). Retrieved from Wageningen: https://edepot.wur.nl/545778

[28] ICMSF. (2005). *Microorganisms in foods 6 Second edition - Microbial ecology of food commodities*. New York: Kluwer Academic/Plenum Publishers.

potentially containing the spores is included as an ingredient in an end product where *C. botulinum* spores can grow out, it becomes a relevant hazard for the yogurt as an ingredient.

Table 4. List of microbiological hazards included in the tool

Microorganism Type	**Microorganism species**
Bacteria	*Bacillus cereus*
Bacteria	*Brucella* spp.
Bacteria	*Campylobacter* spp.
Bacteria	*Clostridium botulinum* (non-proteolytic)
Bacteria	*Clostridium botulinum* (proteolytic)
Bacteria	*Clostridium perfringens*
Bacteria	*Cronobacter* spp.
Bacteria	*Escherichia coli*, pathogenic (STEC, EPEC, ETEC, etc)
Bacteria	*Listeria monocytogenes*
Bacteria	*Mycobacterium* bovis
Bacteria	*Salmonella* (non-typhoidal)
Bacteria	*Shigella* spp. / EIEC
Bacteria	*Staphylococcus aureus*
Bacteria	*Vibrio* spp. (non-cholerae)
Bacteria	*Yersinia* spp.
Parasites	*Cryptosporidium* spp.
Parasites	*Cyclospora cayetanensis*
Parasites	*Giardia duodenalis*
Parasites	*Toxoplasma gondii*
Viruses	Hepatitis A virus
Viruses	Hepatitis E virus
Viruses	Norovirus (+ astro, entero, rota)

Table 5. Types of foodborne microbial hazards considered (adapted from EFSA 2012).

Type number	Hazard types	Microorganisms
1	Bacterial hazards not needing growth to cause illness	*Salmonella, Shigella, Campylobacter,* pathogenic *Escherichia coli, Yersinia*
2	Bacterial hazards that usually require growth to cause illness	*Listeria monocytogenes, Vibrio, Clostridium perfringens, Bacillus cereus* (diarrhoeic)
3	Bacterial hazards that require growth and toxin production to cause illness	*Staphylococcus aureus, B. cereus* (emetic), *Clostridium botulinum*
4	Spore formers	*B. cereus, C. perfringens, C. botulinum*
5	Parasites (do not proliferate outside the host)	*Cryptosporidium* spp. *Cyclospora cayetanensis* *Giardia duodenalis* *Toxoplasma gondii*
6	Viruses (do not proliferate outside the host)	Hepatitis A, hepatitis E, norovirus
7	Hazards relevant for infants or immunocompromised consumers (e.g. transplant patients)	*Cronobacter* spp., *C. botulinum,* (*L. monocytogenes*)
8	Minor opportunistic pathogens only relevant for immuno-compromised consumers (minor pathogens)	*Enterobacteriaceae* (opportunistic pathogens, *Citrobacter, Enterobacter, Escherichia, Moellerella, Proteus, Serratia*)

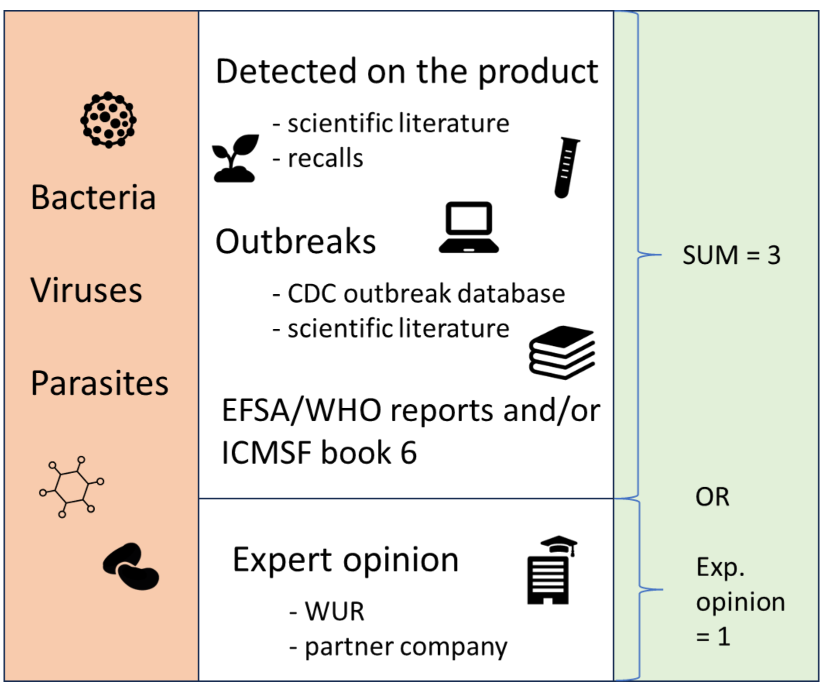

Figure 10. Criteria for microbiological hazard identification for each food ingredient category.

Heat inactivation

The microbial reduction of a thermal treatment is semi-quantitative in the tool. In the background, the log inactivation of the microbiological hazards is calculated based on the user-specified temperature and time combination. When the required minimum inactivation level is reached [e.g. Performance Objective (PO) of 5 log], the hazard is considered inactivated. Information on heat inactivation parameters (D- and z-values) was collected from scientific literature and used to calculate the inactivation for indicated time/temperature combinations.

Logarithm of D-values were plotted versus temperature, from which the z-values have been derived (Equations 1, 2 and 3). Both the average line and the upper 95% prediction interval (PI) for the worst-case scenario were plotted.

Equation 1	$log\,D = logDref - (T - Tref)/z$
Equation 2	$log\,Dref = intercept(logD, T) - Tref/z$
Equation 3	$z = 1/slope(logD, T)$

Log D is the logarithm of the D-value (log min, the amount of heating time needed to obtain a 1-log reduction);

z is the temperature increase needed to reduce the D-value with a factor of 10 (°C);

T_{ref} is the reference temperature (°C);

Log D_{ref} is the logarithm of the D-value at T_{ref};

Assumptions

The following factors were excluded when assessing which microbiological hazards to include in the web-based tool:

- Recontamination is not considered in the hazard identification as these are factory-specific events that cannot me generalised.
- The inactivation rates used for matrix types 2 to 4 depend on availability of data from literature and are not applicable to all hazards.
- The storage step is only considered as the final step for the end product, not for intermediate steps in the process. Intermediate storage steps do not affect the presence or absence of hazards; they may, however, affect the levels of these hazards.

Chemical hazards

Approach

The following approach was used to identify chemical hazards for the main ingredients:

A. **Internal reports from Wageningen University & Research**. The potential presence of chemical hazards in the raw agricultural commodities was obtained from research previously conducted by Wageningen Food Safety Research. Only those hazards were included that were either frequently found in the ingredient, found above legal limits or reported as relevant ingredient contributing to human health effects (the so-called short list included in the reports) (Nijkamp, Van Asselt et al. 2017[29], Banach, Hoffmans et al. 2019[30], Nijkamp, Hoek-van den Hil et al. 2019[31], Hobe, Hoffmans et al. 2020[32], Hoffmans, Hoek-van Den Hil et al. 2020[33], Klüche, Hoek-van den Hil et al. 2020[34]). Identified knowledge gaps in this previous research were also considered when identifying relevant chemical hazards.

B. **Scientific literature screening of chemical hazards**. For ingredients not previously researched, a literature review was performed to retrieve papers on chemical hazards from two bibliographic databases (Scopus and Web of Science). Furthermore, a literature review was performed.

C. **The Rapid Alert System for Food and Feed (RASFF).** RASFF notifications were obtained from the RASFF portal covering a 10-year period (mid-July 2012 up to mid-July 2022).

D. **SecureFeed.** Information on a risk classification performed by SecureFeed, a Dutch branch organisation on animal feed, was used as one of the input variables[35]. A risk classification from 2022 was used, and hazards were included that were classified as having a basic, low, medium or high probability of presence.

E. **Riskplaza**. The Riskplaza tool[36], which includes raw materials that FBOs can consider when controlling food safety hazards, was consulted. A risk classification from 2022 was used.

F. **Expert elicitation**. Interviews served as input, e.g., to fill in knowledge gaps on upcoming chemical hazards including those that may form during the processing of side streams.

The list of chemical hazards in the ten side streams was obtained, using the results for the main ingredients as starting point, complemented with a literature review for each of the side streams using two sets of search strings (Van Asselt et al., 2024 submitted)[37]. Furthermore, RASFF and SecureFeed were used as indicated above (Factors C and D respectively). Additionally, academic and/or industrial experts were consulted to provide their opinions on the obtained hazards. Given data uncertainties from the literature on chemical food safety hazards of concern, e.g. for the side stream ingredients, several experts were elicited for their opinions on the effects of processing on chemical food safety hazards of side stream ingredients**.** Finally, the solubility, the mode of action (systemic or non-systemic) and processing factors were used to assess whether pesticides are likely present in the side streams.

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[29] Nijkamp, M.M., et al. (2017). Chemische en fysische gevaren in de Nederlandse aardappelketen, RIKILT Wageningen University & Research: 96 p.
[30] Banach, J.L., et al. (2019). Chemical hazards in leafy vegetables on the Dutch market. Wageningen, WFSR.
[31] Nijkamp, M.M., et al. (2019). Overview of chemical hazards in the Dutch fruit chain. Wageningen, the Netherlands, RIKILT: 68 p.
[32] Hobe, R.G., et al. (2020). Chemical hazards in the fruiting vegetable supply chain in the Netherlands. Wageningen, WFSR,: 64 p.
[33] Hoffmans, Y., et al. (2020). Literature study on the chemical hazards in bulbs, tubers, stem and root vegetables. Wageningen, WFSR,: 76 p.
[34] Klüche, M., et al. (2020). Overview of chemical hazards in cereals, seeds and nuts. Wageningen, WFSR: 112 p.
[35] https://securefeed.eu/producten/risicoclassificatie-diervoeders
[36] https://riskplaza.com/nl/
[37] Van Asselt, E. D., et al. (submitted): "Reuse of plant-based side streams in food production: Overview of chemical food safety hazards".

Compilation and priorisation of chemical data

All available data were compiled into an Excel document, generating a long list of potential hazards for each main ingredient and each side stream ingredient. All criteria were scored as either 0 or 1.

For the **main ingredients** (approach A-F), the initial list of chemical hazards was prioritised as follows:

- Hazards were included in the prioritised list when identified as relevant based on the available literature (A and B) *or*
- Hazards were included when they contributed ≥2% of the RASFF notification for the side stream (C); a threshold that was previously used to rank hazards in seaweed (Banach, Hoek-van den Hil et al. 2020[38]) *or*
- When the relevance of more than one of the additional data source was considered (Factors D-F).

The formula used to prioritise hazards was: IF(OR(Factor A=1,Factor B=1, Factor C>=0.02,SUM(Factor D:F)>1),1,0). All chemical hazards resulting in a final score of 1 were included in the tool.

Chemical hazards identified as relevant for the main ingredients were only included as relevant for the **side streams** when their presence was either confirmed by the literature review or by RASFF notifications (using the same 2% threshold). Furthermore, hazards were included when identified as relevant for the side stream by academic experts, or multiple industrial experts, or when input from industrial experts was confirmed by the Securefeed database. For plant protection products, additional information such as the solubility and mode of action were also used as inclusion criteria. Details about the steps taken and the final prioritisation are described in a scientific publication[39].

Assumptions

The following factors were excluded when assessing which chemical hazards to include in the web-based tool:

- Allergens are included but only for known food ingredients, not for potential recontamination as this is not addressed within the framework (e.g. gluten contamination in potato products).
- Fraud is not included, therefore no unauthorised substances are considered unless RASFF notifications indicate that>2% of these substances are present in ingredients.
- Packaging is not included, therefore, no hazards leaking from packaging into products are included. Only food ingredients are included as starting material.
- For mycoprotein, we evaluated the safety (mycotoxins to be expected) based on the strain *Fusarium flavolapis*. Using other strains may lead to other mycotoxins.
- We assume ingredients are produced using Good Agricultural Practices, Good Hygiene Practices and Good Manufacturing Practices.
- We assume crops are not grown in contaminated sites (e.g., per- and polyfluoroalkyl substances, heavy metals).

[38] Banach, J.L. et al. (2020). Food safety hazards in the European seaweed chain. Comprehensive Reviews in Food Science and Food Safety 19(2): 332-264.
[39] Van Asselt, E.D., et al (submitted). Reuse of plant-based side streams in food production: Overview of chemical food safety hazards.

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