DREAM

Design and development of REAlistic food Models with well-characterised micro- and macro-structure and composition

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Industry guide for Food Modelling

DRAFT

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1. Introduction

1.1. Objective of the guideline

The main objective of the guideline is to support the practical application of realistic food models, and to provide an overview on different food models and on modelling tools/softwares for the potential users. Hence, the guideline is intended to give a technical aid to the users but also to create awareness and encourage the use of modelling in the food industry.

The content of the guideline, including the descriptions of the models, is based mainly on the models that were developed within the **DREAM FP7** project (**D**esign and development of **REA**listic food **M**odels with well characterised micro- and macro-structure and composition) and moreover on some models outside the DREAM project that are actually available and frequently used in the food industry. Brief description of some general examples of successful practices and also hints for avoiding typical traps and failures are summarized in the guideline. This guideline can be used as a manual, in which people can find advice for the questions related to the use of specific models and also for general considerations on the application and design of food models.

1.2. Target audience of the guideline

Models can be used in many different activities in the food sector considering the complexity of the food and their different applications. As changes of the needs and requirements related to food products arise more and more quickly and frequently, therefore dissemination of the available and effective models to the food industry and also to all the sectors who deal with food is of high importance.

The target audience of this guideline includes several stakeholders of the food sector, particularly representatives of the food industry (including SMEs) and R&D teams, decision makers on food safety, quality and nutritional questions but it is also recommended for food safety and regulatory bodies, nutritionists and food scientists.

1.3. Applicability of the guideline and instructions on the use of the guideline

Although there is a wide range of models having different scope, the model development process is typically divided into five phases:

i) Defining the goal of the model: developing a statement of purpose

ii) Designing and developing the model

iii) Practical testing and verification

iv) Making the model available for the audience

v) Maintenance of the model

This guideline describes these five phases as a systematic procedure and provides a brief description of those steps that are essential to be considered during the model development.

In the subsequent chapter of the document, brief descriptions are given on some currently available specific models and modelling softwares. The most important facilities and requirements for application and operation of the models are discussed to help their use and to raise the interest of the potential users. The model descriptions are grouped by four major generic structure groups representing vegetable, dairy, meat and cereal products. Furthermore, there is an additional group for the general models in which the models are discussed according to their function, such as predictive microbial models and heat treatment models.

Models can be good tools for enhancing knowledge on process-structure-property relationships and facilitate the creation of a food matrix with functional and nutritional properties based on tailored microstructure from molecular to macroscopic level.

1.4. Objectives of the DREAM project

The goal of the DREAM (**D**esign and development of **REA**listic food **M**odels with well characterised micro- and macro-structure and composition) EU n°FP7-222 654 project is to harmonise and integrate research on food technology, safety and nutrition through commonly shared food models. DREAM aims at developing realistic, physical and mathematical food models for use as standards**.** These standards can be used across all major food categories to promote the development of common approaches to risk assessment and nutritional quality for food research and industry.

The concept of the DREAM project is to integrate experimental and mathematical approaches to develop ranges of food models that are realistic enough to be used by the industry and sufficiently versatile to be used as predictive tools of food behaviour for facilitating evaluation of the impact of changing microstructure, composition and / or processing conditions on nutrition and safety.

For four generic structure groups, such as filled cellular solids, proteinous cellular networks, combined gelled/dispersed/aerated systems and open solid foams, typical types of products were selected using criteria including structural characteristics, industrial and societal needs, ensuring the benefits/risks, associated with the product groups they represent, economic importance and sustainability were taken into consideration.

The objective of the mathematical approach is to realise a complete dynamic description of food processing using an innovative strategy by exploiting most recent advances in cognitive and complex system sciences to allow the generalised methodologies to be extended to other food products.

2. Overview of the models and of the modelling in general

2.1. Why we use modelling in the food industry – benefits of modelling

Food is a vital and basic element of our lives and it is complex both in composition and structure, so generic realistic models are required to mimic this complexity. A good model integrates experimental and also mathematical approaches.

One of the main advantages of the realistic food models is to mimic the behaviour of the real food products. Furthermore, models can predict the impact of the changes of the ingredients, compositions and process parameters. Thus they can reduce the number of necessary experiments in real conditions which is particularly important for the case of experiments in factory environments. The use of models can save time and can reduce the cost. Standardized physical modelling materials and calculations with mathematical models provide a more reproducible benchmark for the impact of different treatments on food properties than the experiments with real foods.

For the consumer it is more and more essential to access natural and fresh food and also to choose from a wide selection. Therefore, food producers would like to create more and more new products with improved quality and safety that meet all the requirements. Because of the rapidly changing conditions and demands of the market, it is required to have a safe but fast process for development. As the experiments at real conditions can be expensive and time-consuming, frequently there are significant limitations for carrying out a large number of experiments in real conditions. In these cases food models and model softwares can definitely be good tools to screen options at low costs and to enable to focus experiments with real foods in the most promising test parameters.

With using models, waste of the valuable real food product can be significantly reduced during the experiments.

Typical examples of the applications of the different models are the followings:

- optimizing process conditions (temperature/time profiles, product/water ratio, product size, etc.),
- standardising the system to assess external influences on properties and on quality,
- rapid assessment of product safety and stability,
- simulation of microbial growth or inactivation in different food materials,
- reinforcing the HACCP plan,
- evaluation and verification of shelf-life of foods,
- reducing costs in products development,

- optimisation of costs,
- meet sustainability requirements – eco-design of products and processes,
- high reproducibility, which enables reduction of the number of experiments necessary to prove specific differences, and enable to use the same process and the same final composition in different laboratories to compare experimental results.

It can be stated that using food models and model softwares provide quick and reliable results, which enable applying them as additional tools to complement the results of the real experiments. These models and modelling tools are getting more widespread and able to solve more and more problems in the food industry.

2.2. How reliable are the models – limitations of applications

As it is discussed in the previous chapter, food models and model softwares are very useful tools in many different areas in the food sector but beside their benefits some limitations can also be mentioned for which users should pay their attention.

One of the most important principles that have to be considered is that models do not replace the experiments with the real materials, the careful contemplation and the professional experience. Although the available models are mostly validated, of course they can't perfectly replace the measurements and experiments carried out on real foods. They can support decision making, but the verification of the outcomes at real conditions is unavoidable.

As food is a complex system, all cases of modelling are based on several necessary simplifications, assumptions and prioritization of a few selected factors. It is easier to work with a manageable number of variables and parameters.

A general list is provided on some typical limitations of food models, as follows:

- some models are limited to a few specific types of food products and/or parameters and/or conditions,
- some models are limited to specific processes,
- difficulties in availability of processing equipment facilities and conditions,
- limited availability of specific ingredients necessary for preparation of real food models,
- high cost and time-consuming application of models,

2.3. Different types of models

Before the discussion of the types of the models it is important to know what is the meaning of the term "model". The following definitions can clarify this issue:

Model:	Something that accurately represents something else (Onions C.T. and Little W., 1973). A simplified representation of a system or phenomenon, as in the sciences or economics, with any hypotheses required to describe the system or explain the phenomenon, often mathematically.…(Random House, Dictionary.com)
Simulation:	The representation of the behaviour or characteristics of one system through the use of another system, esp. a computer program designed for the purpose. (Random House, Dictionary.com)
Simulate:	Imitate or reproduce the appearance, character, or conditions of. (Soanes C., 2003)

Models can be categorized in many different ways and there is not any generally accepted conventional grouping for them. They can be categorised by their functions or by the targeted food type etc. In terms of functions some examples are listed below that are intended to solve different kinds of problems and issues:

- biochemical models,
- models for heat treatment processes,
- finite difference heat transfer models for foods heated inside containers,
- microbial growth/no growth models,
- decision making tools to evaluate the impact of process and storage on bacterial behaviour in food based on industrial data, food physical-chemical features, targeted spoilage or pathogenic contaminant,
- models based on polynomials derived from, graphical data on mould free shelf life of baked goods etc.

Another approach is applied by the DREAM project for categorisation:

- Generic Model Foods (GMFs) are realistic physical models in which several parameters can be varied, leading to a series of well-defined samples for each given type of foods;
- Basic Knowledge Models (BKMs) are elementary food models describing specific aspects of GMFs, through heuristic or mathematical approaches;
- Integrated Knowledge Models (IKMs) are dynamic networks - software systems - integrating the operating rules of BKMs, technical expert knowledge, food properties and food processing data from the GMFs.

2.4. What can the models be used for (practical applications)?

Models are used for a wide range of practical applications due to their specific functions and the range of the different parameters used by them. Models can be used at industrial, technical and also at scientific level in the food sector.

GMFs in general can be used to forecast the effect of addition of new components / ingredients, using different varieties and breeds to the product or applying new process conditions on

- shelf life,
- sensory properties,
- microbiological status and microbial growth, death
- physical properties (texture, viscosity, consistency, density, colour),
- heat and mass transfer,
- health benefits,
- nutritional properties,
- the amount of useful components in the final product,
- chemical composition, formation of beneficial or toxic compounds in food during different processes,
- yield,
- etc.

BKMs and IKMs are developed to simulate the construction of the food matrix. They are applied to predict all kind of parameters, such as predicting the behaviour of the food matrix under specified process conditions, to simulate process, food texture, nutrient availabilities and bacterial behaviour etc.

More specifically, one of the main applications of the models is product development. In product development models facilitate the evaluation of the impact of new ingredients, they help the evaluation of risks or improve the nutritional quality and also the safety. Models can be tools for describing the influence of ingredients on product properties and also on quality. The effects of the recipe and process changes on the quality of the final product and on the nutritional properties can be studied easier.

By using a heat treatment model (for example CTemp) “What-if” analysis can be carried out to simulate the worst case scenario of production conditions, for which the process parameters should be designed to meet the food safety requirements.

Predictive food microbiology models are developed to support the design of safe products/processes, the assessment of the effect of different combinations of critical controlling factors such as processing parameters and the intrinsic and extrinsic properties of the product (e.g. time, temperature, pH, salt content, water activity, nitrite content, modified atmosphere in the package, etc.) on the growth, survival and death of the different types of microbes. These predictive microbiology techniques can be applied as a part of the validation of a HACCP plan.

With a food model, which is designed to have a high reproducibility, the time for the process optimization (e.g. in case of a cheese model developed for the cheese-makers) can be reduced.

Models can help in understanding the impact of process parameters on final characteristics of the food, for example the impact of fat composition, interfacial composition or processing temperature on structure, texture, colour, lipid oxidation, sensory properties etc. Models can also be used for bio-accessibility studies (e.g. tomato/lycopene model, which is designed for qualifying the lycopene bio-accessibility in tomato puree).

2.5. Identification of consumer's needs which have to be served with the application of food models

Due to the high competition on the food market effective and quick product and process development procedures should be applied by the food businesses. New product development can be the right solution either for improving quality or reducing cost. The product development process should be based on the up to date knowledge of the consumers' needs and expectations.

The aim of the consumer research is

- to collect information about the interest and the preferences of the consumers related to the product that the company intends to develop;
- to find out the opinion of the different groups (segments) of the potential consumers on the idea of the new product;
- to find out which properties do the different segments of consumers basically prefer and which aspects and to what extent influence their purchasing decisions. .

However, finding the satisfactory answers is a time consuming process. Models as time saving and cost effective tools provide fairly good support when a company decides to develop a new product: food models can help to reduce the time needed to provide an initial protocol for production process, and mathematical models can support the simulation of different processes and the changes of the parameters (see Figure 1).

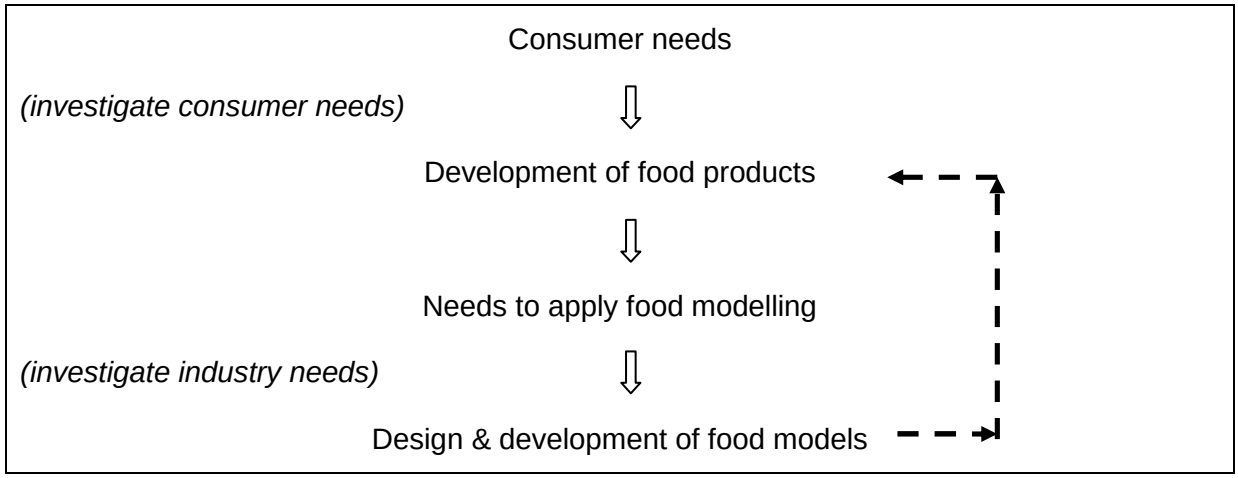


Figure 1: The scheme of the food modelling process driven by the consumer / industry needs

Consumer research methods provide tools to identify the consumer needs and expectations related to a food product. In addition to necessity of identification of consumer's needs at the start of the development of a model the needs and expectations of the users – e.g. the industry, particularly the SMEs, the food control authorities, the retailers and the researchers – should be identified. Consumer research methods can be used also for identification of the needs of practical users.

The use of existing modelling approaches as effective tools for assessing and optimising processes and their impact on product quality and safety and supporting decisions during the process and product development activities is currently relatively limited in the industry, especially at SMEs. This is caused by several reasons, including

- the lack of understanding of the potential capabilities and benefits of the available models;
- the real or falsely anticipated level of the sophisticated technical knowledge necessary for the use of the models;
- the lack of clear instructions for their use;
- the discrepancy between the results and their reliability delivered by the models and the information needed for problem solving at industry level;
- the limited information about successful examples of use of models, which can motivate other users to explore these methods.

In the case of a model development preliminary consumer research should be carried out first before the start of the development work. The aim of this consumer research is to collect and map the needs of the industry about using food models, to identify the problems for which the industry needs practical solutions, and to test the food modelling concept. It is advised to carry out an additional research in a later phase as work progresses.

One of the most frequently used qualitative market research methods for assessing the project viability is the focus group discussion (Shaw R. et al., 1996). By this method small groups of professionals from food business (8-12 participants) can be selected to obtain information about their view on the research objective (in our case reactions related to the necessity, functions and applications of the food models), and to uncover and understand the concept and to investigate various other aspects of respondents' perception and reactions. The focus group discussions should be managed and carried out by an experienced and properly trained interviewer / focus group moderator (Meilgaard M. et al., 1999). If necessary, it is advised to involve an external expert.

A discussion guide should be developed in advance for the focus groups, which is essential to ensure the efficient and effective implementation. It is advised to divide a discussion guide for model developing into 4 sections – introduction, understanding general knowledge regarding models including bottlenecks and success factors, discussion of the sector specific model concepts and its functions and summarizing the conclusions.

The focus group technique is applied, when the main aim is to understand product (in our case: model) attributes what professional users think about the importance of the models and their functions and applicability. It is also reasonable to apply this method for determining the bottlenecks and success factors of a model application. Focus groups can be useful in designing more valid questionnaire by helping to determine the most important questions and the appropriate wording in the questionnaire. The advantages of this technique are the followings:

- flexibility;
- provides opportunities for observation of real users in an interactive setting;
- involves fewer participants compared to quantitative methods;
- can be arranged on short notice and at lower cost;
- statistical analysis is unnecessary.

The disadvantages of the focus group method are:

- results are not quantitative;
- topics and direction of the discussion depends on the moderator;
- careful interpretation of data is crucial.

Professionals from the food industry can be easier interviewed individually in a one-to-one interview. The proper design of the interview questionnaire is essential, which can be used as a guide for carrying out face to face interviews. If the numbers of the professionals are high, the answers regarding food modelling can be analysed by quantitative approach.

To ensure the effectiveness of the modelling tools on the industry applications information can be collected on food modelling by the following typical questions of the consumer research methods (focus groups, as well as the interviews):

- In general, what are the most important expectations of the industry related to the food modelling?
- Which are the key fields and questions, in which the industry needs very quick information about the quality, safety and properties of the final products?
- At the initial stage of the model development for assessment of feasibility: what are the expectations of the industry and how the industry can use the models regarding to the available technology and raw materials and regarding to the economic aspects?
- What does a potential industry user mean on modelling?
- What are the most important attributes of a well applicable model?
- Which are the advantages / disadvantages of using the model?
- Which are the required functions of the model?
- For which specific purpose will the food modelling be applicable?
- Which are the input parameters of the model that can be provided by the industry?
- What are the expectations about the practical use of the results?
- What are the expectations about the availability of the model?
- Industry expectations about the resources (required staffing and skills, time for training, time for input (preparation process carried out by the industrial user), time for getting the results, pricing, special equipment & tools needed for use).

The subjects listed above can be varied according to the main aim. As the food model developing work progress, additional focus group discussions and/or face to face interviews can be organize to cover more specific topics for example concrete details, industry specific solutions and applicability of the model. The focus panels can be useful on this phase, when the interviewer (the moderator expert) utilizes the same group of industrial professionals / potential users.

3. Designing and developing models

During the model development some general considerations should be kept in mind all over the process by the model developers as follows:

- Using a model has to be simpler and faster than the production of the real food product.
- Changes in processing conditions must be reflected in the attribute studied in the same way as in the original food product, but the changes don't have to be identical.
- Model repeatability must be at least as good as the repeatability within the original product.

Model development is a multistep approach. The optimal multistep process consists of five typical steps:

1. Development of the "statement of purpose"
2. Designing and developing the model
3. Validation, practical testing and verification
4. Making the model available for the audience
5. Maintenance of the model

3.1. Defining the goal of the model: development and importance of the "statement of purpose"

The model designing and developing process should start with the development of a 'statement of purpose'. Definition of the 'statement of purpose' is necessary for each model. The statement of purpose should be provided by the model developer. This step, we can call it pre-step, is essential as the model should be developed for a specific purpose or specific application.

Many of the statement of purposes may be descriptive or narrative, but certain information should always be clear:

- Model type,
- Circumstances and ranges of use / what activities the model is intended to assist; the 'business need' being addressed (including boundaries, i.e. indications of the limits of applicability of the model);
- Foods and processes represented by the model (including boundaries);
- Delivery mechanism (how the model will be made available - publication, software, materials, bureau service etc.);

- Target users (who the model is intended to be used by - researchers or industry, regulatory authorities, standardisation authorities, product developers, risk assessors, production engineers etc.).

Those properties of the model which are representative of reality should be explicitly listed. Wherever possible those properties should be measurable and the appropriate units of measurement should be indicated. Often it is more important to model differences in a property than the absolute value of the property. Such cases should be made clear and the required accuracy of the differences described. Usually such differences should be listed as output properties as well as, or instead of, the absolute values. The accuracy of the required output variables (y) should also be indicated whether it differs between ranges of input variables. Often the 'real' values of output properties are highly variable or uncertain, so that the accuracy with which they can be modelled is fundamentally limited. It should be made clear when this is the case, and the extent of that 'real' variability or uncertainty indicated. Wherever possible that indication should be quantitative, perhaps as a standard deviation or a confidence interval. Usually models are used to assess the values of outputs under different circumstances; e.g. times, conditions, formulations – those circumstances are 'inputs'. The outputs are said to be dependent on the inputs which are independent variables. If the accuracy required of output variables differs between ranges of input variables, this should be indicated. Input variables (x) should be explicitly listed. If these variables are measurable then the appropriate units of measurement and also the valid ranges of input variables should be indicated.

Considering the facts above, assessment of practicality should be made against a “statement of purpose”. There are some examples that should be defined in such a document:

- detail the nature and intended use of the model:
  (discursive: model type, circumstances and ranges of use, foods and processes represented and the boundaries, delivery mechanism, target users)
- each model output with its required accuracy
  (Y variables)
- each model input with its valid range
  (X variables)
- constraints on the valid use of the model

Assessment of the model performance against its current statement of purpose should be continuous during the development.

3.2. Designing and developing of the models

This subsection uses the developing process of the DREAM project as a demonstration example. The main rationale of the DREAM project was to propose to the food industry and to the food research a wide range of models that can answer to different questions concerning food research (explanation of mechanisms) and development (modification of formulation or of processing variables, structures, consumer's acceptance, safety, nutritional value etc.).

Designing different types of models

At the design of the models three main requirements have to be met:

1. To integrate the mechanisms which determine the food composition and structure,
2. To be generic enough to allow a wide use,
3. To show a high reproducibility allowing to design low-cost experiments with a low number of repetition.

Since the integration, the generic character and the reproducibility not being always compatible, different kinds of models are developed.

Knowledge models

The classical concept of food science is that food processing is a Flow of Unit Operations (F.U.O.), i.e. a sequence of single technological operations (e.g. pasteurization, coagulation, freezing) from the raw material to the end product. According to this concept, the Unit Operations have to be the most independent, the most controlled and the most clearly understood that it is possible.

A single food process can be defined by a large number of successive operations. Specialised research teams are involved in each unit part of this complex process.

The first type of models which was developed in the DREAM project followed the design of modelling one or a few number of Unit Operations, using scientific knowledge, designing models which provide a large set of data, developing models that were consistent with food specificity.

The basic knowledge of the model on the net formation has to be integrated and applied on a numerical model. The results of the modelling have to be compared to real experimental results.

GMF models

With the development of better knowledge of basic mechanisms, it appeared very soon to industrial and research users, that solely the description of successive Unit Operations is not sufficient:

1. to reproduce real technology because unknown parameters must be estimated;

2. to integrate the knowledge of experts of food processing: this knowledge is not expressed in mathematical terms but is often formulated by qualitative assertions (links +/- or even ++, +-, -, – ; empirical tendencies etc.);
3. to integrate all the links between unit operations and technological control which can be more than one thousand and which vary along time, creating a dynamic complexity;
4. to organise realistic experiments, the results of which could be scaled up to industrial plants.

These are the 4 main reasons listed above which led the DREAM research team to build new models in different fields: cheese, meat, emulsions, foams, fruits and vegetables. In all the cases the development of the models is situated on a three dimension graph scale with three scales: realistic/less realistic; very reproducible/less reproducible; specific/generic. The GMF models are designed in function of the processing to-day's reality. In a wide range of Food Technology types, DREAM researchers developed models with very well-known characteristics (generic character, reproducibility, realistic/basic etc.) which can be presented to industrials for solving different types of problems.

3.3. Validation, practical testing and verification

Following the concept and the process of the DREAM project, all the three model types (GMF, BKM, IKM) were actualised in different forms, and it is those actualisations which must have been validated:

GMFs are written procedures and/or protocols for the selection and/or production of materials which are intended to have properties representative of the properties of food materials. The written procedures must be validated. **BKMs** are relationships between values, such that one or more 'dependent variables' are influenced by one or more 'independent variables'; the values and relationships may be quantitative or qualitative. The values and relationships are intended to be representative of those in foods and food processing. The relationships will always be written, but may also be presented in computer form – e.g. as spreadsheets. The relationships must be validated. **IKMs** are computer software systems intended to represent BKMs. The software systems must be validated.

DREAM project follows the definition of Hodges J.S. and Dewar J.A. (2011) in distinguishing between models which make testable predictions and those which do not. According to that it would reserve the term 'validation' for the former, using the word 'evaluation' for assessment of non-predictive models. Most authors reserve the term 'validation' for the conceptual model, using the term 'verification' for the actualization of the model, usually in a computer. For example, Balci O. (1997) says "*Model Verification* is substantiating that the model is transformed from one form into another, as intended, with sufficient accuracy"; this is consistent with other workers.

Verify:	make sure or demonstrate that (something) is true, accurate, or justified. (Soanes C., 2003)
Verification:	Model verification is often defined as "ensuring that the computer program of the computerized model and its implementation are correct" (Sargent R.G., 2005)

The term 'validation' is used quite generally, but following the workers cited above DREAM project partners recognize the differences and consider that:

- GMFs are non-predictive models which cannot be evaluated against observations. Instead, their fitness for purpose can be evaluated by comparing their behaviour with requirements.
- BKMs are predictive models, whose predictions can be compared with observations to assess their accuracy.
- IKMs are implementations of BKMs, whose fitness for purpose can be evaluated by checking both the accuracy of implementation ('verification'), and the agreement between behaviour and requirements (fitness for purpose).

Validation requires statement of purpose

Different principles underlie validation of the different types of model, but all will recognize that any model differs in some ways from that which it represents, so in some sense it must be wrong; "All models are wrong, some models are useful" (Box GEP, 1979).

The previous section mentioned fitness for purpose in passing, but purpose is central to validation; a model is valid if it is correct enough for its intended purpose.

Validity:	In science and statistics, validity has no single agreed definition but generally refers to the extent to which a concept, conclusion or measurement is well-founded and corresponds accurately to the real world.… In the area of scientific research design and experimentation, validity refers to whether a study is able to scientifically answer the questions it is intended to answer. (Wikipedia, the free encyclopedia, 2010)
Valid:	well-founded and applicable to the case or circumstances... (Onions C.T. and Little W., 1973)
Validation:	Model validation is usually defined to mean "substantiation that a computerised model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model" (Sargent R.G., 2005 citing Schlesinger et al. 1979)

A model can only be validated with respect to a stated purpose:

A model should be developed for a specific purpose (or application) and its validity determined with respect to that purpose. If the purpose of a model is to answer a variety of questions, the validity of the model needs to be determined with respect to each question (Sargent R.G., 2005). The appropriate form of quality assurance for a model depends fundamentally on how the model is used, so any attempt to define a single validation standard and procedure for all models in all uses will surely fail (Hodges J.S. and Dewar J.A., 1992).

The statement of purpose must indicate the range of conditions over which validity is required, and the required closeness of agreement.

A model may be valid for one set of experimental conditions and invalid in another. A model is considered valid for a set of experimental conditions if its accuracy is within its acceptable range, which is the amount of accuracy required for the model's intended purpose. This generally *requires* that the model's variables of interest (i.e., the model variables used in answering the questions that the model is being developed to answer) be identified and that their required amount of accuracy be specified. The amount of accuracy required should be specified prior to starting the development of the model or very early in the model development process (Sargent R.G., 2005).

GMF and BKM models

Verifications during the development

The main purpose of a model is to be as reproducible as possible. It is important to verify that it is true in practice. Therefore, the main parameter to be taken into account during the validation is the reproducibility of the state parameters and the outputs. For example, if the process temperature or the final texture is not reproducible, the model cannot be validated, and further trials have to be done to improve the reproducibility. In the case of un-reproducibility, several questions can be asked: Have one of the ingredients changed (batch, type, impact of the age of the ingredient, storage conditions…)? Are the production equipment (e.g. travelling oven), the analysis equipment (particle size analyser) and the protocol for the preparation of the samples for the analyses reproducible? If the model is reproduced at another place, the validation step can require to add or to modify a step in the process. For example, for the soft cheese model that was developed in the DREAM project, if all the equipment is not available (e.g. microfiltration equipment), the milk preparation can be simplified according to the equipment available.

All the analyses planned have to be performed at each trial, in order to have a maximum of information and characterise each trial as much as possible.

Application testing

Once the model is well characterised and reproducible, application tests can begin. Often, the purpose of a practical testing is to test the influence of one input on the outputs. For example, for the soft cheese model that was developed in the DREAM project, one application can be to study the impact of salt concentration in the brine on bacterial growth, or the impact of a specific strain on final texture.

It is preferable to focus on the outputs studied in the model. Otherwise, there is no guarantee that this output is stable and reproducible for this model. For example, the biscuit model developed in the DREAM project is designed to study dimensions, mass, colour, texture and moisture content. It is not recommended to use it for microbial studies. Otherwise, the whole trial and validation work should be done before testing the application.

IKM models

To test the accuracy of a software model, based on an IKM, it is necessary to validate the values with practical testing. These tests are different from the tests made during the development of the model.

Besides, for a user of the model (who did not develop it), practical tests are necessary to check if there are deviations from the software values. For example, the ERH Calc software was developed to simulate aw and shelf-life in cake products. However, it is necessary for the first trials, to measure the real values and detect eventual gaps between theoretical and real values. In the case of ERH Calc, these gaps can be due to good hygienic conditions (that will increase the shelf life compared to the software values) or to other phenomena not taken into account by the model (drying of the cake if the wrapping material is not totally impermeable).

3.4. How to make the model available for the potential users?

To make the model available for the potential users several conditions have to be fulfilled:

I. The practical dissemination of the model under various forms: scientific publications, technical articles, meetings, trainings,
II. The use of a language and medium (diagrams, graphs, images,) adapted to each targeted user (example: R&D departments, marketing departments, public researchers, members of food safety bodies etc.),
III. To describe the protocol of the model in a clearly understandable way with all the necessary details and to show the logical links of the technology clearly (the protocol must be presented as a chart-flow of clear unit operations),

IV. The reference results must be published that allow for everyone to compare his own results to the reference results must be published,

V. Practical experiences on the use of the model: advice for using the model and failures to be avoided i.e. the critical points of the protocol must be provided in a specific report,

VI. Training material must be published (how to use the models, possible problems and applications).

Publications are the first step of the dissemination strategy. The publication of the modelling procedure in scientific journals is an efficient tool to introduce them to the scientific community. Since it is often difficult to get papers dealing with technological methodology accepted for publication in such international journals, the applications of the model could be more easily published. The challenge is then to highlight the importance and significance of the model.

Short and concrete articles in technical magazines are more appropriate for the dissemination of the model to technical targeted users in the food industry. It is important to choose user friendly style and to give practical applications of the model.

The presentation of the models during meetings with professionals of the food industry is another way to disseminate the models. These meeting can be dedicated to the presentation of the models and a training session can be associated.

Specific training sessions must be organized for researchers and industrial users where the objectives of the models, examples of its applicabilities, practical demonstration, expectations of possible difficulties and reproducibility targets should be presented.

3.5. Maintenance of the models

Maintenance concerns all the work that should be done once the model is developed, functional and published. Examples of maintenance of the real models and software models are listed as follows:

GMF and BKM models

The accuracy and applicability of the models has to be revised regularly. With a set frequency (recommended frequencies at least once in every 3 years) the use of the models should be revalidated or recalculated.

- Revision of the method

When a new analysis method is published or developed at the user's company / laboratory, it can be preferable to use it instead of the initial method. This requires then to start again the validation work, and especially compare the results obtained by the old and the new method.

- Change of material and equipment

In the same way as the analysis methods can change, the material or equipment used for the model can also change and be updated. In this case, it is necessary to make adjustments and validations in order to get reproducible results. For example, in the case of the biscuit model that was developed within the DREAM project, using a different oven required to adjust the conditions to achieve a target colour. This adjustment is important because the heating conditions can be very variable according to the ovens used. The heating characteristics can be visualized by a heat flux profile.

- Further improvements

With the experience gained by using the models regularly and by different users, improvement suggestions often appear. These improvements may need significant changes or minor modifications of the original design. Before approval of any changes their impact on the outputs and their accuracy, reproducibility and practical applicability has to be evaluated. Based on this evaluation a decision has to be made whether a full scale or partial revalidation is necessary or the planned changes will not have an impact on the outputs of the model and minor adjustments of the users instruction are satisfactory. Major changes can include modification of the process of modelling by adding a new step (such as a new disinfection step in the soft cheese model) or elimination, simplification of a whole step, extending the limits of applicability, or using another type of equipment (e.g. cheese-making equipment) to make the application easier. The results of this evaluation and the revalidation and adjustment activities have to be documented.

IKM models

- Feedbacks from the users

Model developers do not always have the experience and imagination to take into account all the circumstances of the use of their model. Therefore, feedbacks from users outside the developing team are precious, as they have a different point of view on the use of the model. They can for example detect bugs, or suggest improvements of functionalities or of the graphical interface.

- Improvement of functionalities

New needs can occur with the use of the model by other users. According to the importance of these needs, it can be an option to develop new functionalities, and therefore to start again all the development and validation process as appropriate.

- Improvement of graphical interface

As the number of users of the software increases, it is important to improve the graphical interface, make it user-friendly and intuitive. This will reduce the necessary training time, as well as the efforts and time spent by the users on solving a problem with the software.

- Update of the database

With time, and as the use of the software becomes wider, new data are collected and should be integrated in the database. For example, when microbial growth is studied on different matrixes and with different microorganisms, new data are obtained, regularly and are included in the model to enrich it. Further, if the software has been developed a long time ago, the data offered by the software can be obsolete. For example, in the case of ERH Calc model, the ingredient selection was made 40 years ago. Over this period, the baking products and the ingredients used have changed, so it is necessary to update them.

4. Description of the different models/modelling software

In this chapter a short description is given on each model that is intended to provide a clear summary of the main goals, parameters and conditions of the different models and on the use of them.

4.1. Vegetable models

PhytoVeg Brassica Thermal Treatment

PhytoVeg Brassica Thermal Treatment model is an Excel based macro that has been developed under the DREAM project. The **targeted users** of the model are mainly from the vegetable processing industry (canning, blanching, freezing), from the ready meals industry or researchers from the nutrition/epidemiological fields.

The **model is designed to** model the content of health promoting phytochemicals in vegetables during a thermal treatment as a consequence of cell lysis, leaching, and enzymatic and chemical reactions. The current version deals specifically with glucosinolates (GLS) as phytochemicals in Brassica vegetables. Specific glucosinolates (GLS's) are of interest due to their anti-carcinogenic activity after their conversion and absorption in the human gut. Metabolites from GLS's are known to induce certain detoxification systems in the human body that are linked to a reduction in the risk of certain cancers. It is therefore interesting to market vegetable products with higher levels of these specific GLS's.

One of the **main benefits** is that PhytoVeg can simulate various processing scenarios and a prediction can be obtained on the retention by this process. The processing conditions can be optimized with respect to the level of health promoting phytochemicals in the final product. In the current version this is the level of glucosinolates in Brassica vegetables (Red cabbage, White cabbage, Kale, Brussels sprouts and Broccoli). The following process conditions can be optimised:

- temperature/time profile,
- vegetable/water ratio,
- product size.

Users will get a better understanding of how processing conditions affect the retention of phytochemicals in Brassica vegetable products.

The model has also some **limitations** that are intended to be improved later. The macro is limited to vegetables and to phytochemicals yet whose model parameters are known or can be estimated based on vegetables characteristics. It is limited to processes involving

temperatures between 50 and 130 °C and times between 0 and 5 hours. The macro has not included the fermentation processes and the storage yet. Specifics of the process like equipment or packaging geometries are not taken into account. Their influence on the simulation is assumed to be only through the product temperature profile that is an input of the model. Analytical testing of the GLS content is not industry-friendly as it is a pretty expensive measurement, but a list on the accredited laboratories who provide GLS-testing service will be provided by the model developer.

As this model is based on an Excel macro only a PC with the proper software (Beta version of Excel macro of PhytoVeg) is necessary for the simulation. Before using the model some kind of training or workshop is recommended for the user to be trained on the proper usage of the model. A workshop on the simulation model is advised as well because some practical advises can be given.

For calculation, the model expects the following **input** parameters:

- Temperature (profile) (°C, 50-130, accuracy 1°C)
- Time (minutes, 0-120, accuracy 0.5 min)
- Weight vegetables (gram, accuracy 1%)
- Weight water + solutes (gram, accuracy 1%)

The simulation usually starts with raw vegetables. A sequence of thermal processes can be simulated as well by using the output of one step as the input levels for the next step of the sequence.

Then the following **outputs** can be obtained by the model after calculation:

- Relative content of individual glucosinolates in the final product (± 20%)
- Relative content of individual glucosinolates in the water (± 20%)
- Relative myrosinase activity in the final product (± 20%)
- Relative myrosinase activity in the water (± 20%)
- Fraction of cell lysis in the final product (± 20%)

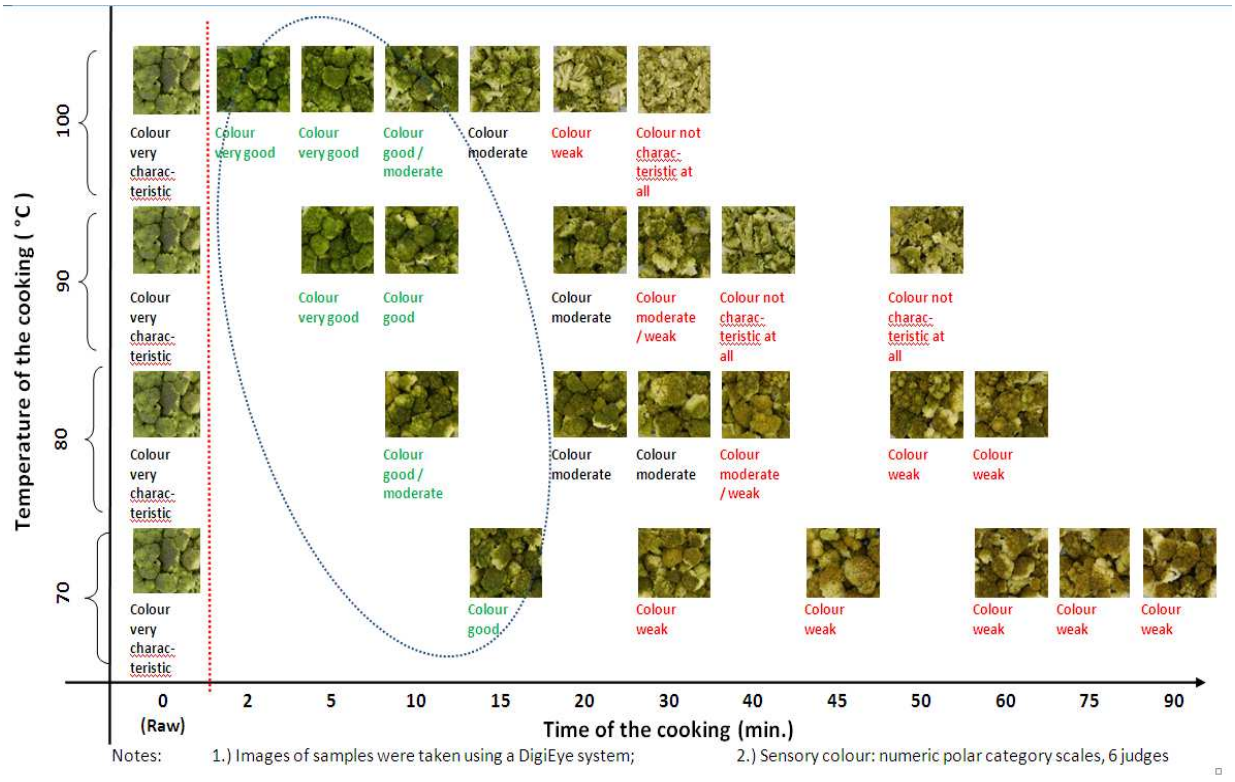
More specific estimates of the accuracies of individual outputs will become available as the DREAM project proceeds with new experimental results and validation.

The model predicts the level of the glucosinolates having significance from the nutritional point of view, myrosinase activity and cellular integrity in the Brassica vegetables as a function of processing conditions. Currently the level of the major occurring individual glucosinolates in the five types of Brassica's can be predicted. If the model users (e.g. from the industry) would like to compare the GLS content of their product with the GLS content estimated by the model,

it is advised to prepare samples and send them into an accredited laboratory (in that case please ask a protocol for the sample preparation from the model developer directly, see more information at the end of this section).

The user should particularly pay attention to the simulation of the processing conditions that are beyond the limits of the model and to the extrapolation to other phytochemicals which are carried our without any estimates of their parameters. These two cases have to be handled carefully and **should be avoided**, otherwise the simulation provides false outputs.

The model allows determining the optimal time-temperature combinations for the marketable Brassica products regarding sensory properties and GLS content. Image scales made by DigiEye system can represent the visible sensory differences between the raw and the different heat-treated samples. The following colour chart is given as an example that presents the properties of broccoli samples characterised by verbal descriptions. These pictures are intended to provide some supplementary information for the potential users of the model.



As a conclusion, optimisation of time/temperature profiles and water/vegetable ratios of blanching, sterilising and cooking operations can be successfully carried out with PhytoVeg model at the present time. In addition to that, improvements will be continuously in progress regarding to the model (e.g. future extension of the model can include dynamic temperature profiles, microbial inactivation, texture changes, colour changes and sensory aspects).

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Tomato/lycopene model

The Tomato/lycopene model is a filled cellular solid model that is intended to analyse the availability of carotenoids from tomato purees. The model is designed within the DREAM project by INRA Avignon by which **the industries and nutritionists** can carry out process optimisation and preconception complementing to food composition databases.

The model would provide a simple and efficient mean to rank tomato purees according to the availability of their carotenoid content. This constitutes additional information to calculate the nutritional value of purees, in addition to the overall carotenoid content, as this step (diffusion of carotenoids from tomato to oil phase of the digestion bolus) is the first step of the digestion of carotenoids. The model will be continuously under improvement to be valid for any fruit purees. The model has already been tested on carrots, apricots except for green fruits, because the separation of carotenoids from chlorophylls when both are dissolved in oil has not been solved yet.

The novelty of the model is that till this time a lack of a quantitative relationships between concentrations in foods and metabolites in plasma has not been established, so that on one hand, one of the **benefits** of the model is that nutritional qualities of processed F&V can be evaluated by the model, moreover the model can be utilized for process development for F&V.

On the other hand, besides the benefits there are some **limitations** of the model yet, such as carotenoid content can't be quantified in oil in presence of chlorophyll that means that the model has not been adapted to green F&V. Furthermore the model needs a qualification of the starting plant material, a qualification of the carotenoid content and composition with for example HPLC. Transferability between species is only very partially addressed. In addition to that, the model is not applicable yet in industrial environment, as the microwave cooking is not reproducible at that level. The cooking protocol was adapted within the DREAM project at pilot scale (Stephan blender) which solution provided a wide range of colour / viscosity but did not provide a quick enough heating-up. The model could be applicable with a tubular heat exchanger, but these processes are still under practicability testing and under validation.

For proper utilization of the model a **list of equipment and some tools** are determined especially for the production and also for the analyses. For the production a fruit puree production unit is needed, including efficient heating units. For the analyses HPLC for quantification of original plant material (eventually can be avoided using classical solvent/spectrometric quantification), a spectrophotometry and some small lab equipment like water bath, stirring, centrifuges are required.

The users have to provide some **input** that are expected before getting any expected outputs. The following parameters are required as inputs:

- dry mater content of purees,
- carotenoids content and composition per weight unit of dry mater,
- heating temperature.

Then data on the content of available carotenoids (i.e. carotenoids available for diffusion) are provided by the model as an **output**.

There is a detailed **production protocol** developed by the model developers that describes the use of the model precisely.

A. Percentage of available lycopene can be evaluated through the proportion of initial lycopene that diffuse to oil, when tomato puree and oil are mixed:

1. The total carotenoid content in tomato has to be determined by HPLC using a standard solvent extraction method.
2. 10 g of puree has to be mixed with 90 g of peanut oil. The mix is stirred with a propeller (diameter: 3 cm) in the beaker at 6000 rpm. Aliquots (2ml) is sampled after 1, 5, 15, 30, 45 and 60 min into a 2ml-microtube, centrifuged 5 min at 5000g, and the lycopene content of oil has to be measured by spectrophotometrie, blanked with pure oil, and calibrated with standard solutions of growing concentration of lycopene in oil.
3. Partition factors of oil (i.e., the percentage of available lycopene) is determined as follows: PF=(Lycopene in oil (2)/Total Lycopene in Puree)x100

B. Production of tomato purees contrasted for their lycopene bioaccessibility can be achieved by taking care of achieving a very quick heating step to 95°C (enzyme inhibition) before or immediately after the first grinding step of the process. Such purees liberate from 30 to 50%.

Besides the production protocol, some **practical advises** are given below for better understanding and for the best application of the model.

<u>Diffusion model</u>:

- Diffusion should be achieved at stabilized temperature (at 37°C (waterbath))
- Efficient stirring (with propeller) is needed, especially with viscous products (i.e. tomato paste)
- Disperse or dispersible product particle size matter! Do not grind more than chewing would.

Contrasted tomato purees:

A crucial point to succeed in the production of tomato puree with enhanced level of available lycopene is to heat the matrix to 95°C as quickly as possible before or immediately after the first grinding of fruits.

Typical **failures** that should be avoided include the followings. The heating system requires a greater attention, because this system can lead to progressive and inefficient heating (like convection system without efficient product stirring; like Stephan system or convection systems without circulation of the product). Furthermore, if the heating process is operated below 90°C it would result in a low efficiency of enzyme inhibition and result generally in non-contrasted purees regarding their lycopene availability. As low temperature heating transfer is heterogeneous, accordingly, these purees generally exhibit low contrast of viscosity.

The models has been successfully used at pilot scale production of purees (around one ton) using tubular heating system and with continuous flow. This operation resulted in a very efficient and quick heating of tomatoes just after their chopping and it resulted in a tomato puree liberating 48% of the lycopene to oil. While the puree prepared from the same tomatoes but included a 30 min maceration step between chopping and heating was risen to 90°C, it is liberated only 22% of its lycopene to oil.

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Tannins from fruit to juice

Tannins from fruit to juice model (outside from DREAM) is produced by C. Le Bourvellec and JM Le Quéré, INRA-URC Rennes and SQPOV, Avignon. This biochemical model is designed to predict the content of tannins in a juice starting from the fruit composition and pressing temperature, and allows to modulate it by simple means such as changing temperature or mixing apple varieties. By the application of the model it can be understood why the juice composition changed along a pressing season. Changes in the juice characteristics can be analysed by heating or cooling the pressing room (model works from 5°C to 25°C) or by mixing low and high phenolics fruits can be analysed at pressing.

The **targeted users** of the model are producers of juices from pip fruits because the fresh produce model allows the juice producers to realize that there are simple ways, compatible with existing pressing processes, to change juice bitterness and astringency.

A **limitation** is that the model can only be used for fruits high in condensed tannins. Furthermore it has not been tested in conjunction with enzyme treatment of pulp.

There are some equipments and tools that are necessary for the production and more that are needed for the analyses. List of the equipment / tools that are necessary for the production:

- grinder and press
- temperature-controlled room (measure the temperature to calculate, change the temperature to modulate)

List of the equipment / tools that are necessary for the analyses:

- Phenolics: *Ideally HPLC, but for apple, pear and quince can be degraded literature data and to a total phenol content (Folin-Ciocalteu) i.e. colorimeter/spectrophotometer, centrifuge and minimal labware (tubes, pipettes, reagent).*
- Cell wall content: *grinder, filters, balance*
- Physico-chemical characteristics (should already be available in a fruit juice industry): *Densitometer (or oven for dry matter determination), refractive index, total acidity (burette and phenolphtaleine plus reagent).*

The model calculates with some **input** provided by the user, by which the procyanidin concentration in juice can be calculated as an **output**. The following inputs are required for the simulation:

- apple dry matter content;
- apple cell wall content *(which can be approximated as 20 g / kg);*
- juice density OR dry matter content *(it estimates the juice dry matter from the density);*
- juice acidity and pH *(used to calculate juice ionic strength, assuming al acid to be malate neutralized by K);*
- temperature at pressing;
- condensed tannins *(procyanidin)* content of the apples *(either on dry or fresh weight)* and degree of polymerization. (*can be degraded to total phenols and litt data for DP)*

The model is implemented in an excel file that calculates the transfer of procyanidins from apple to juice, using the constants determined in Le Bourvellec et al. (2007). In this model, the basic hypothesis is that procyanidins are retained in the pomace through non covalent bonds with the cell walls of the fruit (Renard et al., 2001 2011, Le Bourvellec et al., 2004, 2005, 2007; Le Bourvellec & Renard, 2005).

The variable that can be manipulated is the temperature at pressing. All other parameters are determined by the apple composition: they can be varied by changing the variety but are mostly imposed.

The equation is:

$$[PP_f] = \frac{(K_L \cdot ([Tot] - [CWM] \cdot N_{max}) - 1) + \sqrt{(K_L \cdot ([Tot] - [CWM] \cdot N_{max}) - 1)^2 + 4 \cdot K_L \cdot [Tot]}}{2 \cdot K_L}$$

Where:

- [PPf] is the concentration in the juice;
- [Tot] is the concentration in the juice as present in the apple;
- [CWM] is the cell wall content of the apple;
- Kl and Nmax are parameters of the binding isotherms obtain don purified cell walls and procyanidins.

Kl and Nmax themselves vary with procyanidin degree of polymerization, temperature and ionic strength.

$$K_L = [C \cdot T \cdot IS^* + D \cdot IS^* + E \cdot T + F] \cdot \frac{\overline{DPn} - 1}{Bk + (\overline{DPn} - 1)}$$

$$N_{max} = Am \cdot Exp(Cm \cdot \overline{DPn}) + Bm$$

With:

- T temperature in °C,
- IS ionic strength,
- DPn: number average degree of molymerization of the procyanidins,
- C, D, E , F, Bk, Am, Bm & Cm: constants calculated in Le Bourvellec et al. (2007).

Some **practical advices** can make the application of the model easier. The excel file uses named columns and cells. The file is provided with examples from work of URC between 2001 and 2006, including the validation data (actual observed concentrations in the juices). The first line named “pseudo” is an average apple. It contains the values that may be used if the experimenter failed to measure them. To use the file, copy down the whole lines and fill the column highlighted in yellow. You may fill in the apple procyanidin concentration either reported on the dry matter or on the fresh weight of the apples. By default, “Pseudo” used the procyanidin concentration relative to the dry matter. Similarly the file uses juice density to calculate apple juice dry matter. There is a “masked” column where this could be filled in instead of calculated. Acidities are expressed here in mMol H+ per L, not in malic or sulfuric acids.

Besides the practical advices there are some typical **failures** as well, that should the user avoid during the application. The model assumes a classical and rather rapid pressing (1/2h-2h), and does not take into account the eventual action of pectolytic enzymes that may be used as a processing aid (they may modify the cell wall content in apples). It neglects

oxidation, which is less of a problem when dealing with industrial pressing of apples than with lab scale, as the surface for oxygen penetration is more limited. Very small volumes demand oxygen elimination, so it does not work well at lab scale unless the process is inserted. The model developers are aware that this underestimates the juice concentrations in particular for low degrees of polymerization, accurate prediction would require using a DP distribution, not just the average. In addition, not all the cell wall is accessible for binding during pressing.

The model has been tested by Institut Français des Productions Cidricoles and used in the French cider industry to modulate bitterness and astringency.

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4.2. Dairy product models

Dairy dessert model

Dairy dessert model is designed within the DREAM project to be representative of an actual dairy dessert product at neutral pH. It is a reproducible low-fat and low-protein system, a neutral cream textured by hydrocolloids (starch and carrageenans). It is intended to assist research on food, especially to understand interaction mechanisms in dairy products such as dessert creams. The model can help understanding the impact of process parameters on final characteristics of the model: for example the impact of fat composition, interfacial composition or processing temperature on structure, texture, colour, lipid oxidation, sensory properties etc. It was developed to be used for bioaccessibility studies of protein and lipids in gastric digestion systems, or microbiological studies. This model is meant to be used by researchers (in public and private bodies) and by R&D teams in dairy industries.

Dairy dessert model has many **benefits** but also some **limitations** that give the possibility for further improvements in the future. First of all, the time required for the production of this model is only 2 hours for the production and 1 hour the previous day for powder dispersion. The ingredients are quite easy to obtain and the equipment necessary is usually found in laboratories (lab-scale model) or pilot plants (pilot-scale model). However, there is no sanitation step, so contamination is easy, and shelf-life is quite short. As the model is a low fat system (3% fat) textured by hydrocolloids, the impact of fat and its interface is not as important as in a dispersed model. It is therefore mostly representative of pudding custards.

For the production at pilot scale, the following equipment is required:

- Low pressure homogenizer
- Rotor stator homogenizer or mixer
- Stephan blender

For the analyses, the following equipment is used:

- Particle size analyzer (e.g Saturn DigiSizer TM 5200, Malvern MasterSizer)
- Rheometer (e.g AR2000, Haake Mars)
- Confocal Laser Scanning Microscope, optical microscope
- Color meter or chromameter (Konika Minolta, Tokyo, Japan)

It is required to **input** the ingredient recipe (composition in caseins, carrageenans, fat etc.), heating and cooling temperatures, as well as homogenizer pressure to receive the **outputs** of the model that are:

- fat globule size distribution,
- rheological measurements: firmness, flow, viscosity,
- interface structure and composition (starch granules, fat globules, proteins etc. by confocal microscopy),
- oxidation: Secondary metabolites (hydroperoxides, aldehydes formed upon PUFA oxidation), oxygen use,
- colour.

The following flowchart of the process gives the conditions and parameters used for the production (Figure 2).

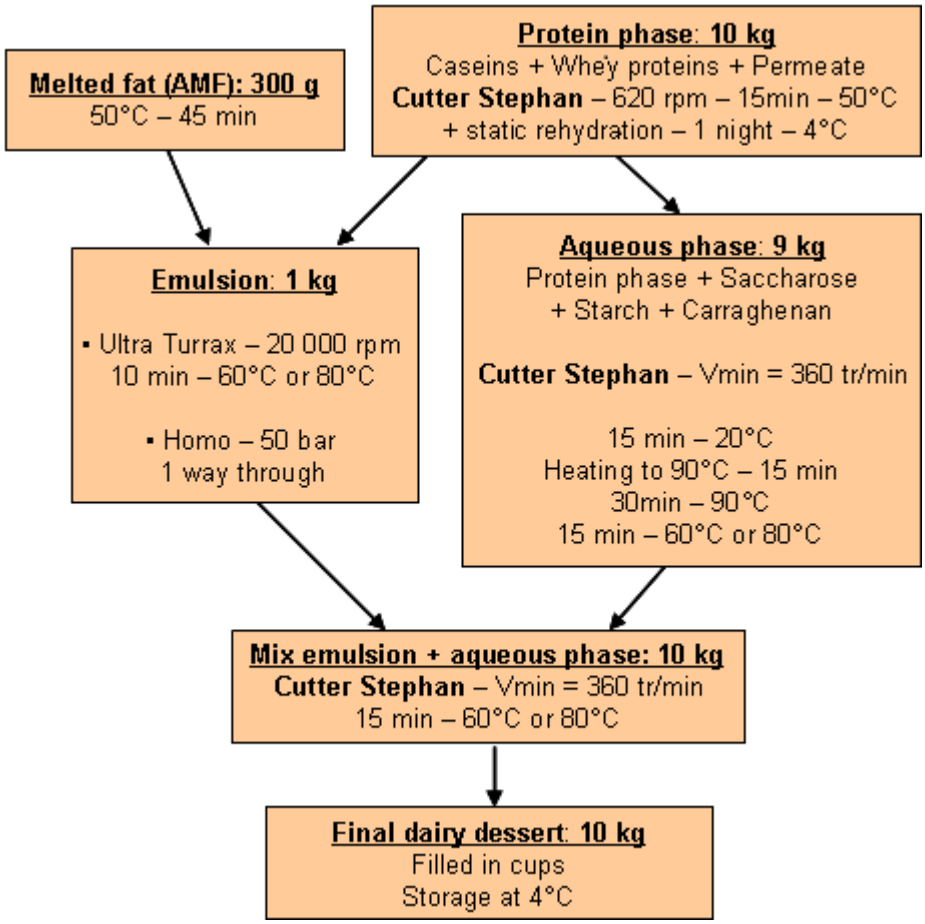

Figure 2: Flowchart of the process of the Dairy dessert model

For practical application some experiences are collected for the users. The following advice should be considered. The anhydrous milk fat should be melted before use. Besides, if the emulsion is not mixed immediately with the aqueous phase, it should be placed at 60°C (or 80°C, according to the protocol) before use, to prevent the fat from solidifying. When using a pilot low-pressure homogenizer, there are significant losses of product. This should be anticipated by preparing more emulsion than necessary (for example, prepare 2 kg to use only 1 kg after homogenization). In addition, for maximum reproducibility, the dairy dessert should

be stored at 4°C immediately after the production, and the packaging (size and shape) should always be the same. Furthermore, if the product is supposed to be tasted, great care should be taken regarding sanitary rules during the production. As there is no sanitation step, it is recommended to taste the product in the next few days after the production.

The scale-up of this model, using a Stephan blender, and producing 10 kg of product instead of 200 g at lab-scale, was successful. The analyses performed were: particle size analysis, confocal laser scanning microscopy and rheology.

Limitations of the model and failures that should be avoided: One of the objectives of this model was originally to study the lipid oxidation. However, it has been shown that there is no fatty acid oxidation in this model, whether the heat treatment is 60°C or 80°C. This model is therefore not appropriate for oxidation studies, but it has the advantage that the fatty acids remain stable in these conditions. Protein oxidation at 60°C was studied at lab-scale, and it appeared to be very limited in this model. The size and shape of the packaging may have an influence on the formation of the structure at 4°C, though no studies have been made on this subject. For our productions, different packaging was used each time (small plastic pots, larger plastic trays, and 10 litre-buckets). This may have had an influence on the structure, given the differences of surface of the packaging in contact with the product. To avoid possible differences, the same type of packaging should always be used. Finally, aerobic growth boost was observed in incubated samples (37°C) after 4 days and was associated with *Bacillus* and related genera of aerobic spore contamination encountered in dehydrated ingredients (milk and permeate powders for example). This model is therefore not stable regarding spore contamination in the given manufacture conditions, the model is not appropriate for microbiological studies at 60°C, but could be with a higher heat treatment. Furthermore, no impact of temperature (60 and 80°C) was detected on structure and texture.

Nevertheless, potential users can use this model to study the impact of ingredient composition on structure/texture and for bioaccessibility studies of protein and lipids in gastric digestion systems even if they were not tested in the DREAM project.

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Soft cheese model

The pilot scale Soft cheese model has been developed and characterized in order to provide a realistic and reproducible model to anyone that wish to perform cheese trials: cheese pilot-

plant managers or technicians, technologists in cheese industry, dairy scientists. The objective of the model is to reach a high level of reproducibility in order to reduce the number of pilot tests that are expensive. This model is representative of a real soft cheese. This model is useful for various **applications:** technological studies (e.g. influence of rennet type on yield, flavour and functionalities), nutritional topics (e.g. reduction in salt content, use of probiotic strains, and enrichment in poly-unsaturated fatty acids), food safety experiments (e.g. survival rate of pathogenic microorganisms, contamination with chemicals). This model is a white mould surface ripened cheese made using a modern brie style technology of cheese making. In particular, the process involves a strong heat treatment of milk and the enrichment of milk with casein in order to increase the actual cheese yield. The enrichment in caseins (that implicate high Ca/protein in cheese) and fat (high fat cheese) together with the use of moderate acidifying starters (i.e. specific culture of *Streptococcus thermophilus*) allow the early production of a mild flavour, soft and homogeneous texture in cheese.

One of the basic **benefits** of the model is that the soft cheese model is a standardised system with high level of reproducibility and realistic composition. However, its use relies on the availability of pilot scale production facilities for cheese milk preparation, cheese making and cheese ripening.

Target users of the soft cheese model are everyone that wishes to perform cheese trials: cheese pilot-plant managers or technicians, technologists in cheese industry, dairy scientists.

Some **equipment and tools** are essential for using the model. For the cheese milk preparation the following conditions must be ensured:

- Microfiltration pilot equipped with 1.4 µm ceramic membrane
- Pasteurizer
- Triblender or mixer
- Skimming centrifuge

And for cheese making some further conditions should be complied with:

- Cheese vats
- Cutting blades or wires
- Cheese molds
- Thermostated cheese making room

For cheese ripening wire grids and a ripening room (hygrometry and temperature regulated) is required.

For the production a list of ingredients have to be ready as **inputs** of the model. The following ingredients are required for the production:

- good quality raw milk,
- microfiltration retentate powder,
- lactic starters,
- ripening starters,
- glucono-delta-lactone (acidulant),
- recombinant chymosine,
- salt for cheese,
- wrapping material.

Around hundred state- and control-variables are recorded during the preparation of the model including the composition of milk, the parameters of milk preparation, the parameters of the cheese manufacture and ripening, the kinetics of drainage and acidification, yields and matter balance, the composition and biochemistry of the ripened cheeses.

The **production protocol** is very important and contains the basic instructions of the model. The protocol contains the detailed instructions of the process that should be carried out: The soft cheese model involves highly standardized cheese milk (target composition: Casein 36 g/Kg, Denatured whey proteins: 2g/kg, Fat 75g/L, Lactose 45 g/kg). The raw milk is pasteurized at 88°C for 60 sec in order to denature whey proteins and inactivate vegetative bacterial cells, cooled at 50°C and skimmed on a pilot centrifugation device. The cream fat content is adjusted to 400 g/kg by adding skim milk and the standardized cream is then heat treated at 120°C for 1 min. in order to inactivate thermoresistant bacteria. A casein concentrate was prepared by dispersing microfiltration retentate powder (85% Proteins) and milk permeate powder in warm water (10/5/85). After 90 min rehydration at 50°C, the skim milk is enriched with the casein concentrate and microfiltered on 1,4 µm membranes. Finally, heat-treated cream and microfiltered casein enriched skim milk are blended and stored at 2-4°C until use. Figure 3 shows the flowchart of the cheese milk for the standardisation.

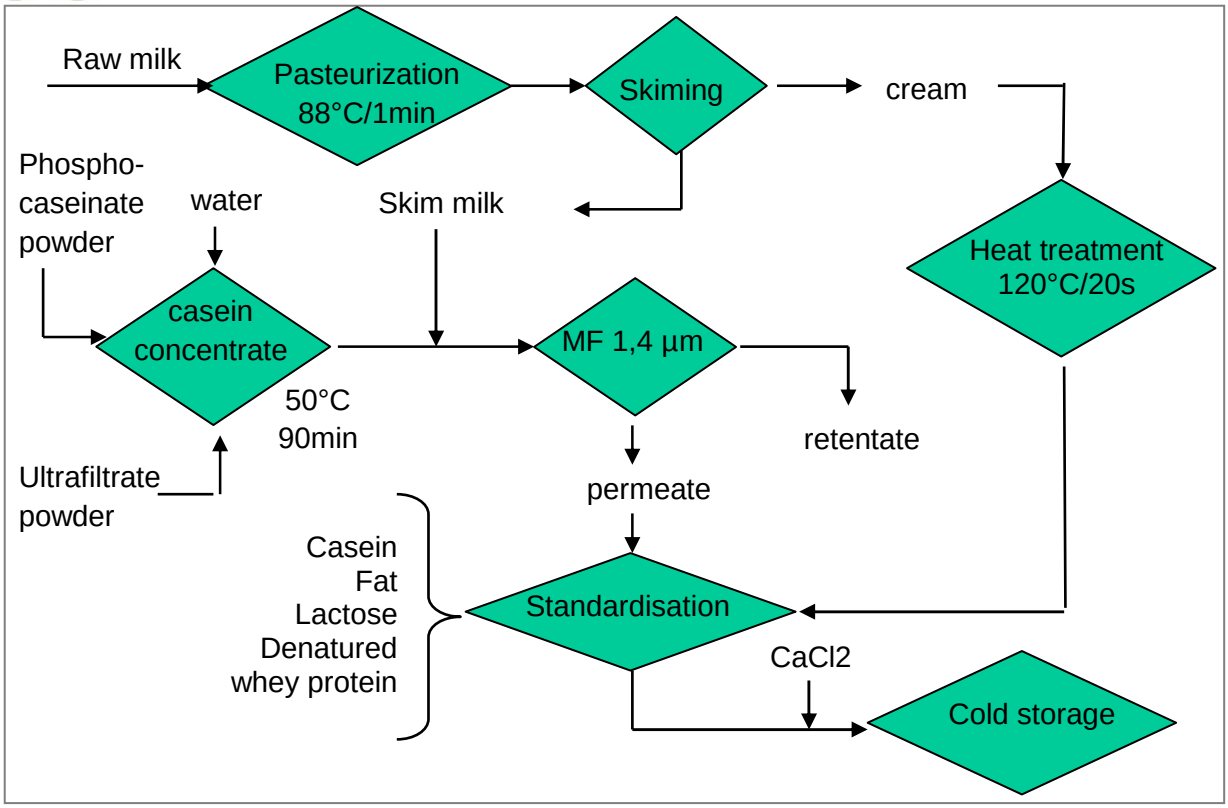

Figure 3: Flowchart for the standardisation of the cheese milk

The cheese manufacture is performed with a pilot plant in a temperature and hygrometry controlled room. The cheese milk is warmed at 39°C and inoculated with lactic starters (freeze dried culture TA054, Danisco, 30 DCU/100L cheese milk) and ripening starters (freeze dried cultures: PCVS, Danisco, 8 doses/1000 L cheese milk; Geo17, Danisco, 2 doses/1000L cheese milk). Calcium chloride (0,15g/kg) and the acidulant glucono-delta-lactone (GDL, 0.9 g/kg cheese milk) are also added and the cheese milk is ripened for 30 min. When pH reached 6.30, the milk is coagulated with recombinant chymosin (Chymax Plus, Chr Hansen, 22 mL/100L cheese milk).The setting time is around 8 min and the gel is allowed to firm during 10 additional min. The coagulum is cut up with vertical knives and a knife grid into 1.5 x 1.5 x 1.7 cm cubes. The curd is allowed to drain in vat for 30 min, a gentle stirring with a single paddle being performed each 5 min. After having taken a part of the whey off (around 30%), the moulding was carried out manually (with a bucket or a beaker) by pouring the curd into mould: 6 moulds (diameter 20 cm) for 25kg cheese milk. The curd is allowed to drain in moulds for around 3 hours (room temperature: 33°C) until the pH reaches 5,40. During this period, the cheese are turned 3 times (0.5, 1.5 and 3 hours after hooping) and then allowed to acidify overnight in a 18°C room. At day one, six cheeses (≈1kg each) with the following composition are obtained: Moisture-in-Non-Fat-Substance (MNFS) 73%, Fat-in-Dry-Matter (FDM) 61%,pH 5.2, Calcium/Solid-Non-Fat (Ca/SNF) 2,4%.

The cheeses are cooled at 12°C and immersed in a NaCl-saturated brine (NaCl 26g/100g brine, pH 5) for 55 min. After a short drying off, the cheeses are ripened on cheese grids at 12°C and 96% Relative Humidity for 12 days. During ripening, a suspension of mould spores (rehydrated overnight on 4°C in an isotonic solution made with 9g/L salt and 1g/L glucose) is sprayed onto the cheeses. The cheeses are then wrapped in the usual paraffin wax coating paper and stored in cardboard boxes. Typical composition of the ripened cheeses (35 days) is: 71% MNFS, 62% FDM, 3.5% Salt-in-Moisture an 2,4% Ca/SNF. Figure 4 shows the flowchart for the preparation of the Soft cheese model.

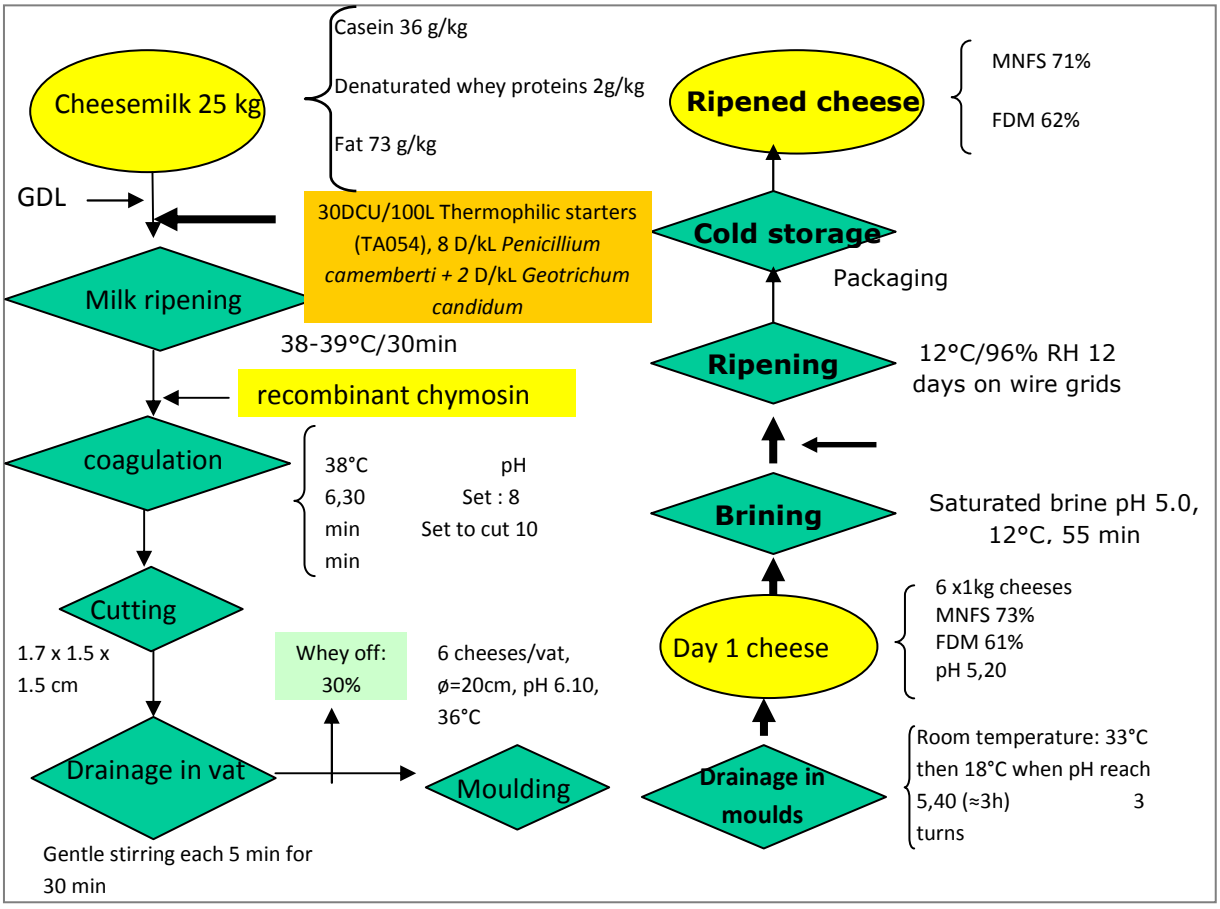

Figure 4: Flowchart for the preparation of the Soft cheese

Advices and **failures** from the practical point of view are important to interpret to the users. The disinfection of the material used for the cheese milk preparation and the cheese making is absolutely required. Before the first using the model, we recommend to check the reproducibility for each variable during some preliminary trials. The characterization of the data distribution and the adjustment to the Normal law (or Student law depending on the number of replicates) are useful to validate the model or to highlight critical points in its application. The

comparison of the results obtained with the reference data published by Actilait can also be useful for the development of the in-house model. The control of the pasteurization temperature is very important since it determines the rate of denaturation of the whey proteins. Indeed, the amount of denatured whey proteins in cheese milk strongly influences the syneresis of curd and the composition and structure of cheese. Moreover the protein recovery in cheese and the cheese yield depend on the rate of whey protein denaturation. Another critical point of the cheese milk preparation is the rehydration of the retentate powder during the preparation of the proteins concentrate. A bad rehydration leads to a strong retention of undissolved proteins particles in the retentate of microfiltration. This phenomenon induces a decrease of the protein content of the microfiltrate and of the cheese milk, which in turns reduces the curd syneresis and increases the Fat-In-Dry-Matter. The conditions of the rehydration of the concentrate (i.e. temperature, time, agitation, concentration) must be strongly controlled. Moreover, the Best Before Date must be respected since the rehydration ability of the powder decreases during storage. The critical points of the cheese manufacture are i) inadequate temperature (poor acidification and drainage, inadequate salt intake), ii) poor acidification (inhibitors in milk, failure of starters), iii) low hygrometry during cheese manufacture (cooling of cheese due to the vaporization of water on the surface) and during ripening (drying of cheeses).

The **results of the model can be used** for several ways. Two examples of the application of the model outside from the DREAM project are given here in this guideline. Studies of recipe and process effects on final product quality and nutritional effects were carried out: the reduction of the level of sodium in soft cheese has been studied by reducing the brining time. Its influence on the biochemistry of the cheese ripening and the sensory properties was recorded. Additionally, evaluation of new ingredients was successfully performed: the influence of new ripening cultures on the sensory characteristics of cheese has been tested with the soft cheese model.

For better understanding, an **example on successful practice** is given here: The influence of the salt in moisture on the growth and survival of Bifidobacteria has been tested using the soft cheese model. Three vats were inoculated with 1.107 CFU/mL of the Bifidibacterium lactis BB-12 strain (CHR Hansen). One control vat was made without inoculation of Bifidobacterium. The green cheeses from each control- or trial-vat were separated into two aliquots and brined for 18 min (reduced salt content) or 35 min (regular salt content) respectively. As expected, the Bifidobacteria were concentrated into the curd without a significant growth during cheese manufacture. Indeed, the four-fold increase of the Bifidobacteria count during cheese making corresponds to cheese yield (around 24 kg cheese per 100kg cheese milk). The Bifidobacteria count did not evolve during ripening despite the carbohydrate and lactate exhaustion. The salt-in-moisture did not influence the survival of Bifidobacteria.

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4.3. Meat models

Protocol for standardized pork meat samples

Protocol for standardized pork meat samples is a model developed by the Institut de Recera y Technologia Agroalimentáries in Spain within the DREAM project. The model description is developed for preparing standardized fresh pork samples in the industry to study the effect of product composition and process parameters. The **targeted users**, for whom the model has been designed, are meat scientists and partners from the meat industry.

The model is intended to assist providing homogenous raw materials for testing in general or studying the effect of composition and process parameters. Determination of protein changes in meat can be analysed due to heating and their impact on protein digestibility can also be evaluated by the model.

An instruction protocol was written for the users using loin as an example to obtain proper homogeneous fresh pork samples for testing in industrial conditions. The characteristics of interest are specified, and steps are provided to obtain samples which meet the inclusion criteria. Equipment and procedures needed for sample evaluation and verification are indicated.

The selection criteria are the **inputs** of the model. The following criteria have to be considered: carcass weight, lean percentage, pH, electrical conductivity, colour score, marbling score, firmness score, drip loss, instrumental colour, and composition. Table 1 shows a range and optimum score for pork quality parameters as a reference for the sample selection process.

Table 1: Measurements, range and optimum score of meat quality (van Heugten E., 2001).

Measurement	Range	Optimum Score	Comments
Minolta L*	38-55	< 5 for Japanese market	Higher score is lighter
Color Score	1-6	3, 4, or 5 for Japanese market	1: lightest, 6: darkest
Initial pH	5.6-6.8	6.7-6.3 approx.	<5.8 may result in PSE
Ultimate pH	5.2-6.4	6.1-5.7 approx.	>6.1 indicates DFD; <5.5 indicates PSE
Firmness Score	1-5	3-4	1: softest, 5: firmest
Marbling Score	1-5	2 (depends on the final use of the product)	1: devoid of fat; 5: abundant marbling
Drip Loss	3-6%	Less loss is more desirable	Affected by pH and chill

Measurement	Range	Optimum Score	Comments
			rate

The **outputs** of the model are the homogenous fresh pork samples for testing. The selected samples will have to be ≤ 10 % of coefficient of variance.

A detailed **instruction protocol** is provided by the model developers which contain all the details including exact measurements that have to be performed. This should be followed step by step to obtain the expected standard meat samples. The instruction protocol as follows:

1. Identify and select 1 large farmer that produces animals that represent as close as possible the raw material for the type of product that you intent to use for the test. (*Production and slaughter conditions must be controlled: farmer, management, diet, transport conditions, animal handling, day of slaughter.)*
2. Select one animal breed. (p*ure or well-defined cross)*
3. Select one animal sex. *(entire or castrated male or female)*
4. At approximately 1 h post-mortem, select carcasses according to: carcass weight, lean percentage (FOM or AutoFOM), and initial pH.
5. At 24 h post-mortem, select carcasses according to: pH and electrical conductivity.
6. After carcass fabrication and deboning, select cuts or muscles (e.g. loin) from the selected carcasses according to: colour score, marbling score, firmness score.
7. Cut selected muscles according to specifications for further analyses.
8. Perform analyses and select muscles according to: drip loss, instrumental colour, composition.
9. Data analysis.

Before data analyses the following **measurements** have to be carried out on each of the samples specifying all the equipment and necessary tools:

Lean percentage: determined using the Fat-O-Meat'er probe. Fat and muscle depth are recorded for each carcass within 1 h post-mortem, and carcass lean percentage is predicted using an official equation (Gispert M. and Diestre A., 1994).
pH: determined using a Crison portable meter equipped with a xerolyt electrode, at the last rib level of the loin at 45 min. (initial) and 24 h (ultimate) post-mortem.
Electrical conductivity: determined using a Pork Quality Meater at the last rib level of the loin 24 h post-mortem.

Color score: determined using the Japanese Colour Scale (1: very pale to 6: very dark) by two trained technicians and the final score averaged across technicians.

Marbling score: determined using the NPPC standards (1: devoid of fat to 6: abundant marbling) by two trained technicians and the final score averaged across technicians.

Firmness score: determined using the NPPC standards (1: softest to 5: firmest) by two trained technicians and the final score averaged across technicians.

Cutting specifications:

A 15 cm approx. section is cut beginning between the 3rd and 4th ribs counting from the last one, and then cut into slices with different thickness according to the required analyses.

Instrumental color: L*(lightness), a*(redness), and b*(yellowness) are measured on the exposed cut surface of the loin muscle using a Minolta Chromameter in the CIELAB space with illuminant C and 2º viewing angle after 15 min. of bloom time.

Drip loss: determined according to Honikel K.O. (1997). Two slices (2 cm each) are weighted and placed inside a net and kept in an acrylic container individually at 2±2°C for 24 h. Samples are weighed again at 24 h, and the percentage of drip loss calculated using the following formula:

Composition (protein, moisture, fat, and collagen): determined using NIT (Food ScanTM Lab). One pork slice (2.5 cm) is ground and approximately 100 g of sample are placed on a plate for reading.

Data analysis: the mean values for each pork quality parameter will be registered in an Excel table, and the standard deviation and the coefficient of variance (CV) calculated. Samples that are > 10 % of CV will be eliminated.

For the right application the required **equipment or standard** needed are summarized in Table 2 for determination of pork quality including a supplier or reference.

Table 2: Equipment or standard needed for determination of pork quality including a supplier or reference.

Measurement	Equipment/Standard	Supplier/Reference
Lean percentage	Fat-O-Meat'er probe	SFK Technology, Denmark. (Gispert M. and Diestre A., 1994)
pH	pH portable meter	Crison, Barcelona, Spain
Electrical conductivity	Pork Quality Meater	PQM-I, INTEK Aichach, Germany
Color Score	JCS (Japanese Color Scale) standard	Nakai, Saito, Ikeda, Ando, & Komatsu, 1975 (Nakai H. et al, 1975)

Measurement	Equipment/Standard	Supplier/Reference
Marbling Score	NPPC (National Pork Producers Council) standard	NPPC. 1999. Pork Quality Standards. Natl. Pork Prod. Counc., Des Moines, IA.
Firmness Score	NPPC standard	NPPC. 1999. Pork Quality Standards. Natl. Pork Prod. Counc., Des Moines, IA.
Drip loss	Scale	300g maximum, 0.001g resolution
Instrumental Color	Minolta Chromameter	CR-400, Minolta Inc., Osaka, Japan
Composition	FoodScanTM analyzer	Type 78800, FOSS, Hilleroed, Denmark

It can be mentioned as a **limitation** of the model that the instruction protocol is developed for fresh pork using the loin as an example, and may need modifications for direct application to other cuts or muscles, or to meat from other species. Another limitation of the model is that there is no European distributor for the JCS (Japanese Colour Scale) standard and for the NPPC (National Pork Producers Council) standard. It may cause difficulties as regards of the availability of these standards.

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Cooking yield model

The model cooking yield of beef meat' has been developed within the European **PROSAFEBEEF** project. As a limited extension, the method and the mathematical structure of the beef model was applied in the European DREAM project to test the practicability of the approach on pork meat. For this purpose a pork meat law have been determined from laboratory experiments on small samples; this is a first order reaction model which accounts for both the change in proteins-water de-binding with temperature and water migration. The weight loss predictions have been successfully tested against experimental measurements on large parallelepiped shapes (70mm x 70mm x 30mm).

The simulation tool can be used to optimize the cooking processes. The model has been built and validated on beef and pork meat. It cannot be distributed, but simulation calculations can be provided.

When industrial conditions are characterised through a few temperature measurements in industrial plants (e.g. using the 'thermal plastic mimics' developed by Campden BRI), the cooking boundary conditions can be assessed. From this information and the above model it is then possible to answer to a lot questions on what is the effect of a change of process conditions or of a change in meat shape and size on cooking losses.

The **aim** of the extension of the model on pork meat is to predict the cooking losses (cooking yield) for pork meat in function of time-temperature course within meat pieces. The **target users** of the model are the R&D staff from the meat industry.

For beef or pork meats any shape can be considered, but complex shapes need many descriptors. For other species and for surface drying other model refinements are needed.

The **input** parameters asked from the industry are:
(1) Parameters of the raw meat:

- initial water content (dry matter): the mean value and standard deviation from 10 samples of 5g whole meat previously grinded, measured by oven drying 24h ± 6h in a ventilated dry oven at 105°C temperature; the dried samples cooled at room temperature in a desiccators (full of silica gel).
- shape and size
- an ultimate pH, more than 24h post mortem for pork, more than 48h post mortem for beef

(2) A few temperature records (e.g. with the 'thermal plastic mimics in place) of the products in the industrial plant.

The Simulation Tool is a 3D mathematical model based on differential equations, which combines the simulation of temperature inside the meat and the meat law to predict local water content and overall juice loss during cooking. As **outputs**, the simulation calculations provide tables and/or abaci:

- evolution of the temperature field within the product during the whole process time
- mean weight loss kinetics

With these outputs it is possible to identify what part of the process is significant for weight loss and to evaluate the impact of new industrial cooking & cooling procedures (duration, temperature of the heating, the product size).

From the input information provided by industry, the experts of INRA-Clermont laboratory can perform the simulation calculations. This needs to use complex numerical software and trained staff (INRA). A commercial agreement should be established for each specific study.

Figure 5 shows graphs to a small sample (3 min for the whole cooking/cooling process).

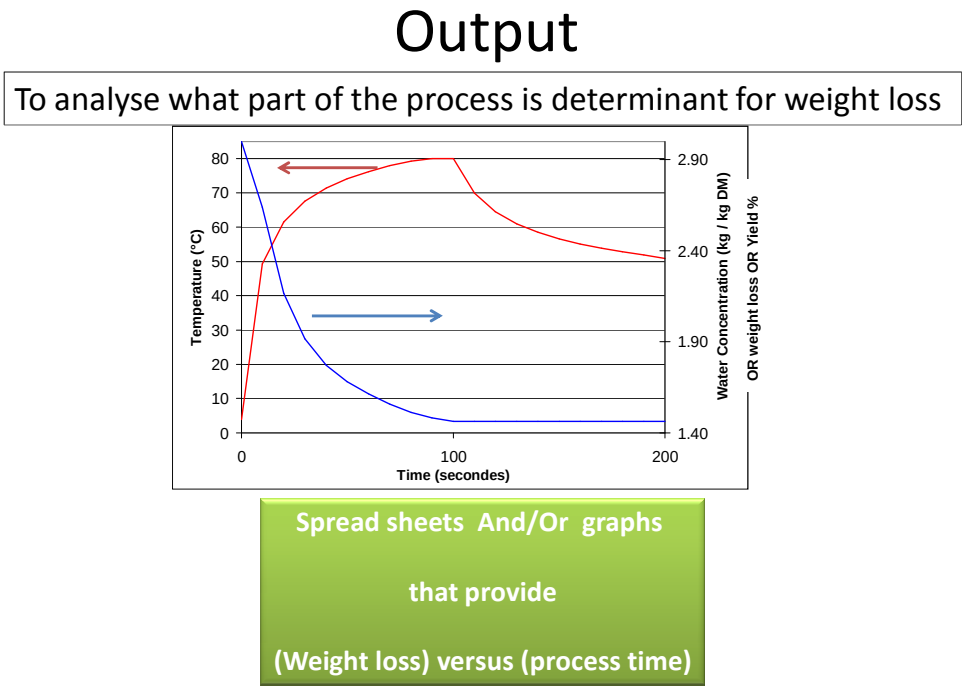

Figure 5: Graphs to a small* sample, Weight loss versus process time

*Note: for bigger products the time scale would be larger.

The only **limitation** concerns the size of the samples that should not be smaller than 50x50x20 mm, otherwise the temperature measurement at core is not precise.

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4.4. Cereal models

Bran bread model

Bran bread model is a general model food developed within the DREAM project that meant to study the influence of added fibres on the properties of bread dough and the subsequent qualities of the bread (volume, crumb structure and instrumental structure).

On one hand the main **benefit** of the model is that this model food is a standardised tool to assess the effects of bran on bread quality, and it allows to speed up the development of higher fibre products. But on the other hand a few **limitations** have to be assigned at the current stage of the Bran bread model. It relies on the availability of process equipment and control (such as measurement of temperature during the process) and of measuring devices for bread quality (for example volume and instrumental hardness). Besides, the model has only been validated for pan bread, and it would need further validation work to be applicable for free-standing types of bread. Finally, it has only been validated for the straight dough method.

The bran bread model is a helpful assistant for management of incorporation of fibres into bread dough and for:

- researchers in breadmaking,
- ingredient suppliers,
- bakery production or technical managers,
- from medium to larger bakeries (more than 20-50 employees) that have the required equipment and know-how.

There are some circumstances that are necessary for representing the model food, either for the production or for the analyses. For the production, the following equipment is needed:

- farinograph, dough expansion tool
- spiral mixer, rounder (optional), moulder, set of pans
- proofing cabinet, oven

For the analyses, a method to measure the bread volume (seed displacement or laser) and the instrumental hardness is required. An image analyser (e.g. C-CeII) is optional.

In the model, it is expected to **input** the level of added fibres (0, 10 or 20%) and the amount of water added in the dough. The **outputs** concern the quality of the bread: volume and density, instrumental hardness and compression-relaxation test results, and the crumb structure that is currently not available in bakeries.

A detailed production protocol is provided for the users which contain all the parameters that are necessary for the food model. Table 3 summarizes the recipe of the model including all the ingredients and their proper masses. In Table 4 the protocol for the baking process is described.

Table 3: Recipes for the process of the Bran bread model

Ingredients	Mass (g)
Wheat flour	1600-2000
Distilled Water	Based on Farinograph water absorption (1320-1560 used for validation trials)
Ascorbic acid (E 300)	100 ppm
Salt (NaCl)	36
Fat (margarine)	60
Instant Dried Yeast	30
Wheat Bran	0-400
Total	**3546-3786**

Table 4: Protocol for baking process of the Bran bread model

Dough temperature	25±1 ˚C
Mixing (Diosna spiral mixeror equivalent)	4 + 6 min (slow/fast)
Dough rest time, temperature and humidity	10 min / 35°C / 75%
Scaling : Dough weight Manual or mechanical rounding	350±2 g
Intermediate rest	10 min/room temp/ambient humidity
Moulding	With a bread moulder
Dough pieces are placed in the steel pans or tins	
Proofing time, temperature and humidity	Time as required for 5cm height for control dough in expansion tool. 35°C / 80%
Baking time and temperature (oven)	25±2 min / 235±15°C
Steaming	recommended

MIXING

When operating a bran formula : before mixing, the flour and the bran should be mixed together in the mixer three minutes without water in order to get a good bran dispersion. Add yeast, margarine, salt then water (in appropriate temperature) to the bowl of mixer. The adding levels of water are 66%; 70%; 78%. Mix according to process details (Table 4) and measure the dough temperature after mixing.

1st PROOF (Dough rest)

As soon as mixing is completed place the mixed dough in a container to the fermentation – total rest time is 10 minutes.

SCALING and ROUNDING

Divide dough into 350 g pieces with a scraper or a knife. Round dough pieces in a conical rounder /or by hand.

INTERMEDIATE PROOF

Let stand the dough pieces 10 minutes on the bench avoiding skinning.

MOULDING

Mould the dough pieces in order to get an elongated dough piece of 20 centimetres and place them into the pans.

2nd PROOF

Put the pans into the fermentation cabinet and let them proof according the process details (Table 4).

BAKING
Load the pans to the pre-heated oven (according to process details) and bake them according the instructions (Table 4).
PACKING and COOLING
Take the breads out of pans and let them cool for 2 hours. Store the cooled loaves in plastic bags until measured on the following day.
MEASURING
The breads are weighted, volume is measured and the compression –relaxation test or instrumental hardness tests completed (with Texture analyser or Instron). Crumb image analysis is optional.

During the development process the model was tested several times and it was validated by the model developing team. Many experiences were collected through these processes which are summarized below by process steps as **advises for using the model**:

MIXING:

- The baking conditions should be kept exactly the same when repeating the experiment.
- Raw materials needs to be the same for all experiments and in all laboratories taking part in the experiment
- Water amount needs to be determined by farinograph or equivalent method before baking. The method should be the same for all laboratories taking part in the experiment.
- The suitable temperature for water needs to be determined by test mixing, depending on the fibre content, the mixer heat up the dough differently.
- Measure the dough temperature after slow mixing phase in order to compare the temperature increase between mixers.
- Distilled water was used in order to minimize the difference in water quality.
- Dough temperature should not differ more than±1°C from the desired dough temperature.
- 100 ppm of ascorbic acid based on 1kg of the blend was used to improve the bread quality.

1st PROOF (Dough rest):

- The mixed dough is quickly scored (the proposed descriptors are: stickiness, consistency).

SCALING and ROUNDING:

- Scale the individual dough pieces with as less flour as possible on the bench.
- Hand or mechanical rounding should generate a ball shaped dough piece with a smooth skin on the top and no tears.

INTERMEDIATE PROOF:

- The dough pieces should be protected from air currents. The intermediate rest should be done at bakery temperature 20-22 °C

MOULDING:

- Target is an elongated cylinder with no tears, a nice seam and with a length a little bit higher than the pan length. Moulding should be completed in less than 10 min. Dough piece are a little bit longer than the pan. Put the dough piece seam down in the pan.
- A spray release agent has to be used for pan greasing. Avoid excessive oiling.

2nd PROOF:

- Prove the control sample to 5 –5.2 height in the dough expansion device (Chopin or Maes). Note the proof time. Prove all other doughs to the same time as the control

BAKING:

- A look should be taken on the bottom crust in order to check if there is no excessive coloration.
- Steaming is recommended especially for electric and convected ovens in order to get a shiny crust colour.

PACKING and COOLING:

- Just after deloading loaves should be put onto a wire rack or a clay to avoid condensation on the bottom crust in a tempered room. Complete cooling needs 90 minutes for control & 120 min for high fibres breads.

MEASURING:

- Volume is measured by seed displacement method or by light volume scanner.
- Breads for textural measurements should be sliced. Thickness of one slide is 30 mm. The samples for textural measurements should be cut with round cutter. Diameter of the sample and diameter of the probe are both 50 mm.
- Efficiency of slicing is of a major importance for crumb image analysis.

The validation of this model has been very challenging within the DREAM project, because the baking conditions in the different bakeries were different, even though the protocol was very clear. Moulders, proofing cabinets and ovens were not the same, so the variations in specific volumes was quite wide. This case could occur in every time if the conditions and the parameters are not definitely the same with the ones recorded in the model description.

The model gives detailed instructions for validating a high fibre baking process in several bakeries. The specific volume/density of the bread is used to compare the baking system in different bakeries. Also, if a single bakery needs assistance in building up a high fibre baking process, the GMF bread model can be utilized. Also, if two bakeries need to compare their baking process, the validated GMF bread can be utilized.

The GMF bread model has been successfully used in practice. It was used as a template product for experiments of adding modified fibre (VTT) into the wheat bread and analysing the rheology of the product. To validate the model, a ring test between four laboratories was completed. In spite of the challenges mentioned above, the ring test gave a lot of information about the validation process, and the aspects that needs to be taken into account in the process.

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Digestive biscuit model

Another cereal model was developed within the DREAM project but for biscuits. The Digestive biscuit model is a general food model designed to study the effects of recipe and process on final product quality and nutritional properties. It provides a standardised approach to facilitate comparison of research findings between users. Besides, it can be used to develop high fibre biscuit products to deliver nutritional benefits with acceptable sensory characteristics. It is also a good tool to evaluate new ingredients, and provides a standardised basis for nutritional studies.

The model has several **benefits**. First of all, this model is a standardised system to assess different modifications on biscuit properties, especially in the context of fibre enrichment. Even though it is publicly available, this model is commercially relevant, as it provides confidence in applicability of results and high quality samples suitable for use in feeding trials. However, its use relies on the availability of pilot scale production facilities, especially the travelling oven.

The **targeted users** of the model are biscuit manufacturers, researchers in bakery and nutrition science, as well as bakery ingredient and equipment suppliers.

As for other food models there are some conditions that the user must comply with and there are some **equipment and tools** that are necessary for carrying out any work with them. For the production, the following equipment is required:

- Mixer (e.g. Hobart mixer with paddle attachment)
- Rotary moulder

- Travelling oven

Besides, analytical equipment is necessary for the different analyses:

- Colour: colour meter (e.g. Minolta CR310)
- Texture: Texture profile analyser (e.g. Stable Microsystems TA-XT2)
- Moisture content: Moisture oven and precision balance, or NIR instrument
- Dimensions: presentation apparatus with ruler scale
- Mass: balance

The typical applications of the model concern variations from the standard model such as fibre addition (type and amount), water addition and oven settings characterised by a heat flux profile. The **outputs** of the model are:

- Colour (L*, a*, b* values for top and bottom surface)
- Texture
- Moisture content
- Dimensions and mass

A clear production protocol was developed within the DREAM project for the Digestive biscuit model food with a recipe and the detailed process steps and parameters. These conditions are summarized in Table 5 and Table 6.

Table 5: Recipe of the Digestive Biscuit Model

Ingredient	Proportion of flour mass (%)
Ingredients for stage 1 mixing	
Palm fat	37
Granulated sugar	25
Iso-glucose syrup	3.5
Malic acid (37% w/w)	2.4
Water	14*
Ingredients for addition in stage 2 mixing	
Biscuit flour	100
Wholemeal flour	29
Salt	0.7
Soda	2.2

Ammonium bicarbonate	0.2

*Reserve a small amount of this water to dissolve the ammonium bicarbonate for stage 2.

The following protocol is given as an example of what is applied at Campden BRI. The process may be adapted according to available equipment.

Table 6: Process of the Digestive biscuit model

<table>
<tr><td>Dough mixing</td><td>The dough is mixed with a Hobart mixer, equipped with paddle attachment. The ingredients are added at each stage (according to the recipe) with the following speeds:
<table>
<tr><td>Stage 1</td><td>Speed 1, 30 seconds</td></tr>
<tr><td></td><td>Speed 3, 3 minutes, scrape down</td></tr>
<tr><td>Stage 2</td><td>Speed 1, 30 seconds, scrape down</td></tr>
<tr><td></td><td>Speed 1, 30 seconds</td></tr>
</table></td></tr>
<tr><td>Dough resting</td><td>20 minutes in a sealed container (e.g. plastic bag).</td></tr>
<tr><td>Moulding</td><td>R Tech bench top rotary moulder.

72 mm diameter circular moulds, 3.5 mm depth, 18 docking pins.</td></tr>
<tr><td>Baking</td><td>Spooner forced convection travelling oven

Baking on wire mesh oven band or wire mesh trays.

Adjust oven conditions to achieve a target colour of L*=60 to 63 for control recipe. Typical values used at Campden BRI are shown in the following table:
<table>
<tr><td></td><td>Zone 1</td><td>Zone 2</td></tr>
<tr><td>Indicated temperature</td><td>220°C (actual 190°C)</td><td>200°C (actual 190°C)</td></tr>
<tr><td>Dampers</td><td>In: Closed</td><td>Out: Open</td></tr>
<tr><td>Top heat</td><td>3/4, 3/4</td><td>1/2, ¼</td></tr>
<tr><td>Bottom heat</td><td>High, High</td><td>1/2, ½</td></tr>
<tr><td>Time</td><td colspan="2">5 – 6 minutes</td></tr>
</table></td></tr>
</table>

The following **measurements** are necessary to carry out for receiving the outputs that were described in the beginning of the model description. These measurements below were carried out by the model developing team in the DREAM project:

Dimensions and mass

The height, length, width and mass are measured for 10 replicate biscuits from the same batch, measured together and reported as the total values for 10 biscuits.
Mass is measured by placing 10 biscuits on a calibrated balance. The total mass is measured to a precision of 0.01 g.

Height (thickness) is measured by stacking 10 biscuits on their edge against a ruler. The base of the stack is placed against a flat surface aligned with the zero graduation. A gauge with a flat, parallel surface is moved to rest against the top of the stack and the total height of the stack is read from the ruler to a precision of 1 mm.

Length is measured by placing the biscuits on a long ruler, aligned perpendicular to the edge of the ruler (i.e. perpendicular to the way the biscuits come out the rotary moulder, in our case with the writing perpendicular). Slide the gauge to rest against the edge of the tenth biscuit and record the length to a precision of 1 mm.

Width is measured by placing the biscuits on the long ruler so that they are aligned in parallel to the ruler (facing in the direction the biscuits would come out of the rotary moulder, in our case with the writing parallel). Slide the gauge to rest against the edge of the tenth biscuit and record the width to a precision of 1 mm.

Colour

The top and bottom colour are measured for 5 replicate biscuits, using a Minolta CR310 chromameter (Konica Minolta). The method provides an objective measurement of the average colour for a circular region 50 mm in diameter, using a tristimulus approach with wide area illumination and a 0° viewing geometry. The instrument should be regularly calibrated against a reference white tile supplied with it. The instrument can be configured to measure results for CIE illuminants C or D65. For this work, the instrument should be configured for illuminant C, in accordance with the local methods used by both Campden BRI and United Biscuits.

Place the measurement head centrally against the top surface of a biscuit and measure the colour. Repeat the measurement for the bottom surface of the same biscuit. Repeat the measurements for at least 5 replicate biscuits from each batch.

The values should be reported as L*, a* and b*, and recorded to a precision of 0.01 units.

L* represents lightness, varying from 0 for black to 100 for white.

a* measures redness when positive, greenness when negative, on a scale from -100 to +100.

b* measures yellowness when positive, blueness when negative, on a scale from -100 to +100.

Moisture content

Moisture content of biscuits may be determined either by measurement of the loss in weight during drying in an oven (at 103°C for 12-20 hours), or by use of a near infrared reflectance method, calibrated against such a method.

The following is the oven drying protocol as applied at Campden BRI:

Samples are dried in numbered metal dishes, for which matching, tight-fitting metal covers are available. Before use, the dishes and covers are dried in an oven for at least 1 hour and then placed in desiccators to cool. For each sample, two biscuits are placed in a sealed polythene bag and reduced to crumb size by hand. A clean, dry dish and cover are weighed to a precision of 0.001 g. Three 5 ± 1g subsamples of the crumbled biscuits are placed in separate dishes and each weighed. The open dishes containing the biscuit samples, and the lids are placed in an electrical air drying oven at a temperature of 103 ± 2°C and left to dry for 12-20 hours, typically overnight. The temperature is measured with a thermometer mounted at the top of the oven, and is recorded at the start and end of the drying period. At the end of the drying period, the dishes are removed from the oven, the corresponding covers are immediately placed on top and the dishes are placed in desiccators to cool for 30 minutes. The final weight of each dish, sample and cover is measured. The moisture content is calculated as the difference in weight of each subsample before and after drying, expressed as a percentage of the initial weight of the subsample. Results are presented for the triplicate subsamples.

Texture

Texture measurements are performed with a Stable Micro Systems Ta-XT2 plus (Stable Micro Systems Ltd., Godalming, U.K.), fitted with a 5 kg load cell.

Measurements are made for 10 replicate biscuits. Place each biscuit top side up on a base with a 10 mm diameter hole and centred under the probe at a position avoiding the holes and writing close to the centre of the biscuit. Test using the following instrument conditions:

Probe type:	Cylindrical with 2mm diameter and a flat tip.
Anvil:	Flat plate with 10mm circular hole beneath probe.
Pre-test speed:	5 mm/s
Test speed:	0.5 mm/s

Post-test speed:	5 mm/s
Distance:	10 mm

Calculate the following texture parameters from the measured force-distance data:

Parameter	Property	Region of trace for which calculated
Firmness 1	Area under force - time curve (g.s)	Total
Firmness 2	Area under force - time curve (g.s)	To 3mm probe distance
Crunch 1	Number of peaks / mm	To maximum force
Crunch 2	Number of peaks / mm	To 3mm probe distance
Crunch 3	Length of force trace	To 3mm probe distance
Crunch 4	Length of force trace	To maximum time

Before using the model some **practical advices** are intended to help the proper application. To enable production of biscuits of commercially relevant quality, the model requires the use of a travelling oven. The settings of the oven and the heat flux profile achieved are critical process conditions. However, due to variations in the type and specification of oven available to each user, it is not practical to specify specific oven settings. Examples are given for the oven used at Campden BRI, but conditions should be adjusted for each oven to achieve the target colour for the control recipe. The model can then be used to assess variations from the control.

It may be necessary to make adjustments to the water content of the recipe to allow for variations in flour properties. No standard method is available for measurement of biscuit dough consistency, and adjustments to water content should be made based on local procedures for assessment of dough consistency.

Considering also the practical experiences, there are some **failures to be avoided** listed here for the user. The texture parameters specified have been chosen to be appropriate for characterisation of a “short” texture typical of the model product. For some applications of the model, using recipe variations, other types of texture may be achieved, for which alternative choices of parameters may be appropriate. For example, in applications of the model to recipes with added inulin soluble fibre, a harder texture was achieved, with a large initial force peak. In such cases, additional parameters have been used to characterise this initial peak, and “crunch” measurements to 3 mm are a more appropriate choice than those to maximum force, which occurs earlier than for the control biscuit texture for which the standard parameters were designed.

The model can be used for many analyses and other different applications in the food sector mainly in the cereal field. In this guideline we present some **examples on the utilization of the results** and of the outputs of the model:

- Studies of recipe and process effects the final product quality and the nutritional effects.
    - Effect of oven temperature and heat flux profile on moisture and colour development during baking. Work has been carried out within the DREAM project using a heat flux probe to measure profiles under a range of conditions, and with a hyperspectral NIR imaging system to provide measurements of moisture distribution within biscuits at multiple stages of baking.
    - Effect of fibre addition on biscuit quality, particularly texture. Examples studied within the DREAM project include fibre type (inulin, several types of bran), fibre quantity, bran particle size and interactions between fibre addition and water addition. Other potential applications include a wider range of fibre types and fibre pre-treatments.
    - Variations in fat, for nutritional or sustainability purposes.
    - Standardisation between users to aid comparison of research findings. For example, within the DREAM project, the model has enabled collaboration between United Biscuits and Campden BRI using a common model product and assessment methods, and provides a basis for future collaboration to ensure that research findings at Campden BRI are applicable at pilot and commercial scale by United Biscuits.
- Development of high fibre biscuit products to deliver nutritional benefits with acceptable sensory characteristics
    - Trials of fibre types, pre-treatments, or recipe adjustments to compensate for effects on biscuit sensory characteristics.
- Evaluation of new ingredients
    - For ingredient suppliers, a standardised model system provides the opportunity to test effects of ingredients within a commercially relevant, but publicly available system, and to report claims on a common basis.
- Production of biscuit samples for nutritional or other studies
    - Within the DREAM project, the model has been used by United Biscuits to produce samples for sensory assessment within their own company, for nutritional studies by VTT, and for development and evaluation of new texture and structure characterisation methods and models by INRA.

- Production of samples for animal or human feeding trials, or in-vitro models, for example to study effects of fibre, fortification of foods with nutrients such as vitamins, physiological trials of digestibility etc.

The model is relatively new and has, thus far, therefore only been used within the DREAM project. Applications carried out so far have included for example studies of effects of oven heat flux on colour and moisture development. A good relationship was demonstrated between surface heat flux, colour and moisture content for top and bottom surfaces, several stages of baking, and a range of oven settings. It also can be used as a hyperspectral NIR imaging method for measurement of moisture distribution within biscuits. A calibration was developed for the model product to demonstrate the capability of this new method. The method was developed at Campden BRI, and has been successfully demonstrated at United Biscuits. The same approach could now also be applied with confidence to other biscuit types. Studies have already been carried out on the effects of bran and inulin addition, particle size and water content on biscuit properties in trials at Campden BRI and United Biscuits. Furthermore, the model has been applied for production of samples for digestibility and texture measurement research for use by other partners within the project. The availability of samples produced to a defined protocol provides an improvement on use of commercial samples, for which details of recipes and production methods are not available, or are subject to commercial confidentiality.

More information:

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ERH CalcTM

ERH CalcTM is a software model (outside DREAM) for the baking industry, developed by the FMBRA (Flour Milling and Baking Research Association) in the early 90's. It is designed to calculate the theoretical ERH of a formulation and estimate its mould-free shelf life. Variables such as storage temperature and sorbate level can be specified. ERH CalcTM is meant to be used by technologists and researchers in baking companies.

Regarding to the **benefits** of the model, it enables to check easily and quickly if a formulation provides enough shelf life. If not, the formulation can be changed and a new prediction calculated. Therefore, it saves a lot of time and effort compared to a trial an error approach, and allows to try more formulations in the same time. Besides, it is a good training material for staff unfamiliar with cake technology. However, there are several **limitations** to the use of this software:

- It assumes all the major mould species are present on the baked product surface and at very high concentrations. This does not occur in practice, so ERH CalcTM will always err on the shelf life simulation.
- The predictions are made assuming that the product is wrapped in an impermeable film, so that moisture will equilibrate in the pack. This is not always the case in practice, so moisture losses can be underestimated.
- The amount of sugar that goes into solution can greatly vary according to the formulation and the process, but this is not taken into account in this model.
- There is no option to use other preservatives than sorbate.
- Storage temperature data is based on 4 temperatures, with extrapolation between temperatures.
- Original model data was taken 40 years ago. Baked products and ingredients have changed over this period.

For the operation of the model there are some inputs that are necessary to enter for receiving outputs of the analysis. The following **inputs** are required in the model:

- Ingredients in the recipe. The program has a water activity database for many components, but the user can input his own data if preferred.
- Storage temperature
- Sorbate level
- pH after baking

The **outputs** of the model are the theoretical ERH and the mould-free shelf-life of the product. The latest version of ERH CalcTM includes features such as Composite Products, that can give an indication of moisture movement in multi-component products, and Packaging routines, where the moisture losses through the wrapping material can be assessed.
This tool is used by many companies to check if their formulations provide enough shelf life. Campden BRI use it to train companies in shelf life issues. It is also very useful as a demonstration tool. In practice, the user selects a product route (e.g. baked products, baked fillings, composite products etc.), then chooses maximum 20 ingredients (a non-exhaustive list is given in Table 7) and finally the quantities (weight in g). The recipe can be easily modified for further trials, and the results can be saved or printed. The ERH and the estimated shelf life of the recipe are then displayed by the software. The moisture losses (from baking, cooling and storage for example) can be specified, and then taken into account in the estimation. (Figure 6)

Table 7: Examples of possible ingredients of ERH CalcTM

Flour	Carrot	Invert sugar syrup
Sugar	Cocoa	Nuts
Egg (whole)	Coconut	Sorbitol syrup
Egg (albumen only)	Ground almonds	Soya flour
Fat / oil	Dates	Spirits / cherry
Margarine / butter	Dextrose	Starch
Skimmed milk powder	Fruit (soaked)	Sultanas / raisins
Baking powder	Glucose syrup	Tartaric acid
Salt	Glycerol	Water

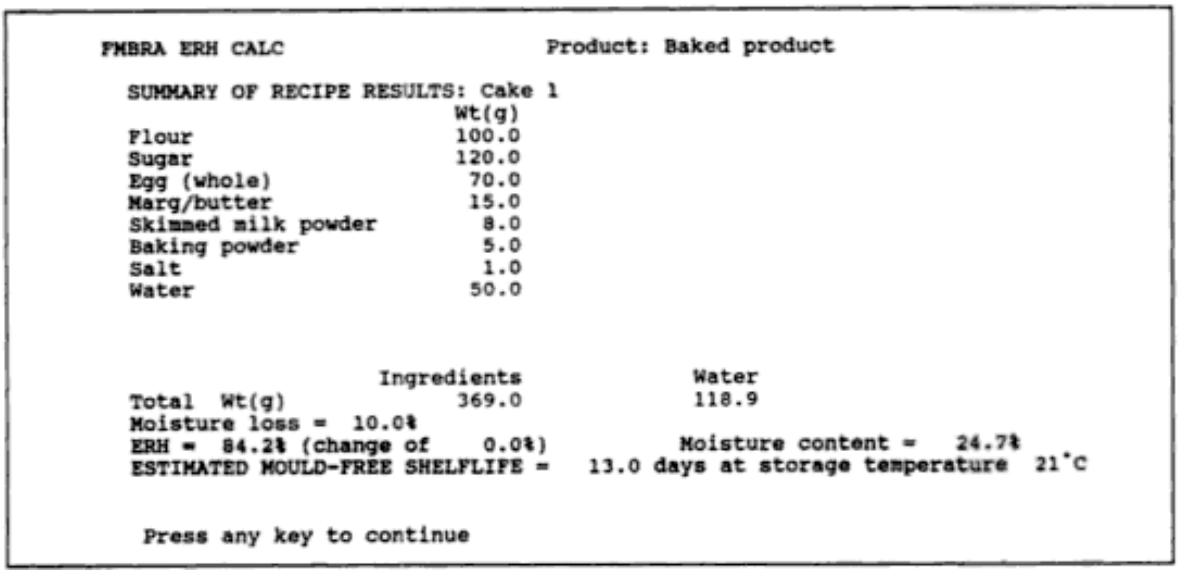

Figure 6: ERH and mould-free shelf life display

There are some **advises for using the model** based on the practical experience carried out so far. To use this tool as efficiently as possible, it is important to compare predictions from the model with real measures. With this additional information, the user will be better skilled to interpret the information produced by the model. For example, as explained in the limitations, the model assumes that all the major moulds species are present on the product at high concentrations. Companies with good hygienic practices will therefore always get more shelf life than what ERH CalcTM predicts. This gap can be determined by real measurements and estimated with experience.

The users should consider that there are also some **failures that should be avoided** when using ERH CalcTM. First of all, it has to be noticed that there are limits for water activity where no data exist in the model (approximate values: below aw 0.75 and above 0.95). Secondly, the product can dry during shelf life, which changes the water activity and hence the shelf life. ERH Calc TM cannot predict this situation.

As ERH CalcTM has been developed in the early 90's, it has been applied successfully in different practices, such as cake shelf-life for reduced-sugar formulations, use of humectants other than sucrose, effect of different raising agents using acid-base reactions, that thereby change the pH of the cake, routine work to determine the "best before" date for new cake products.

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4.5. General models

4.5.1. Predictive microbiological models

Microbial models can be categorized in three types of models (Whiting R.C., 1995):

Primary models describe changes in microbial numbers or other microbial responses with time. The model may quantify colony forming units per ml, toxin formation, or substrate levels (which are direct measures of the response), or absorbance or impedance (which are indirect measures of the response). A mathematical equation or function describes the change in a response over time with a characteristic set of parameter values.

Secondary models describe the responses by the parameters of these primary models to changes in environmental conditions such as temperature, pH, or water activity.

Tertiary models are computer software routines that turn the primary and secondary models into "user-friendly" programs for model users in the forms of applications software and expert systems. These programs may calculate microbial responses to changing conditions, compare the effects of different conditions, or contrast the behaviour of several microorganisms.

Several predictive microbiological models have been developed so far. **Sym'Previus** is a decision making tool to evaluate impact of process and storage on bacterial behaviour in food based on industrial data, food physico-chemical features and on targeted spoilage or pathogenic contaminants. This tool was developed with the collaboration of 12 partners from food industrials, technical institute and research groups. At present the tool is hosted in ADRIA Développement, France. **FORECAST** microbial growth model is developed by Campden BRI

and it is based on the model of the growth of the pathogens. The FORECAST system contains a range of kinetic growth models for single genus or mixed groups of microbial flora associated with food spoilage. **ACID CLUB Models** is also developed by Campden BRI UK. This microbial system contains three growth/no growth models for groups of organisms associated with acid preserved products. **Pathogen Modelling Program (PMP)** is based on extensive experimental data of microbial behaviour in liquid microbiological media and food and developed by the Agricultural Research service at the United States Department Of Agriculture. There is an EU funded national database called **ComBase** that contains an increasing number of growth and survival curves of microorganisms.

In the following section the above mentioned model software are discussed in more details to get a greater insight into their operation.

Sym'Previus

Sym'Previus is a user-friendly software which automatically estimates the microbial safety of recipes and thermal processes using predictive microbiology approach taking into account food industrial issues and relevant microbiological criteria in food. Sym'Previus is an extensive decision support system that includes a database and predictive models for growth and inactivation of pathogenic bacteria and some spoilage microorganisms.

Predictive microbiology is today recognized by the European food law regulation (EC) N2073/2005 on criteria for foodstuffs. The decision making tool that is being discussed complies with EC regulation and it enables to:

- ✓ accelerate food innovation,
- ✓ simulate microbial growth or inactivation in food,
- ✓ optimize thermal processes,
- ✓ reinforce HACCP plan,
- ✓ determine and ensure food shelf-life.

Sym'Previus is intended for participants of many of the food sectors including food scientists, food managers/food production managers, SMEs and it is also intended for regulation authorities. All of these different sectors can use this microbial model for their own speciality. For example food scientists can use Sym'Previus for the validation of food safety and sanitary control plan. It is used in the optimisation of food formulation and microbial stability by food quality managers and food production managers, and in addition to that, SMEs can utilize the

model for the determination of microbial growth boundaries as a function of environmental factors and assessment of food shelf-life for pre-registered dynamic scenario.
Sym'Previus is a **web based tool**. There are some parameters that are necessary for the model application. Basically it uses different physico-chemical properties in its system such as aw, pH, concentration of lactic acid or other inhibitors and also process parameters like time, temperature, acidification profile and water loss during cooking. These are the parameters that are required for the correct calculations. A couple of challenge tests should also be performed on the produced food matrices or on the targeted pathogens.

Like all of the model softwares, Sym'Previus also works with input parameters for simulating the behaviour of the microorganisms in food. The expected **inputs** are the following:

- process diagram with characterized steps (pH monitoring, temperature recording, waiting time etc.),
- targeted pathogen or spoilage flora,
- growth rate determined in food after artificial inoculation of characterised strain (challenge test).

Then after calculation, the following **outputs** can be received and can be recognised with the model:

- identification of HACCP critical points,
- growth/no growth boundaries to identify a given bacterial growth potentiality based on food characteristics,
- growth fitting and determination of growth rate,
- growth simulation for static/dynamic condition with or without cold chain break accidents during storage,
- determination of bacterial destruction during heating process,
- optimisation of food recipe or process,
- determination of food microbial shelf-life and probability to overpass targeted level of contamination during storage.

It can be mentioned as a limitation that simulations of Sym'Previus are determined for characterized strains with known growth cardinal values or thermal resistance. Strains of major pathogens are available as for instance a total of 13 strains of foodborne *Listeria monocytogenes* are already available in the tool which gives a good estimation of intra-species variability response in food.

However the software is user friendly and it is easy to use, it is important to mention some practical advices for using the model and some examples on possible failures, if there is any.

On one hand, in case of **practical advices**, challenge tests acquisition should respond to reported guidelines on bacterial inoculation, sample preparation, physico chemical controls and the characterisation of annex flora which could impact the behaviour of targeted microorganisms. As for instance growth kinetics should be recorded on 15 enumeration points in triplicate with particular attention at the beginning and the end of stationary phase. On the other hand, the following failure should be avoided: the user should consider the fact that too few numbers of bacterial counts acquired during the challenge test will not allow correct fitting of experimental data with mathematical models and thus will not enable to add value to challenge test with further simulations for various conditions of storage.

More information:

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FORECAST

Growth of spoilage organisms can be modelled using the Campden BRI developed microbial growth system known as FORECAST. The FORECAST system contains a range of kinetic growth models for single genus or mixed groups of microbial flora associated with food spoilage. Separate models are available for:

- Pseudomonas
- Bacillus spp.
- Enterobacteriaceae
- Yeasts (in chilled foods)
- Yeasts (in fruit/drinks)
- Lactic acid bacteria
- Meat spoilage
- Fish spoilage
- Fresh produce TVC
- Fresh produce Enterobacteriaceae
- Fresh produce lactic acid bacteria
- Fresh produce Pseudomonas
- Enterobacteriaceae death model
- Bacillus (acid foods)

- Aspergillus niger
- Aspergillus ochraceus
- Cladosporium herbarium
- Eurotium repens
- Mucor racemosus
- Penicillium corylophilium
- Penicillium aurantiogriseum
- Rhizopus spp

The range of conditions over which predictions can be given are listed in the Annex 2. As most of the predictive microbial models, FORECAST can also be used in product development to assess stability of new recipes with respect to spoilage organisms. The greatest benefit of this kind of application is cost effectiveness. Using the software the areas can be identified where challenge testing should be undertaken. Furthermore, FORECAST is a tool in HACCP and risk assessment plan development, because rapid assessment of product safety and stability could be provided and the models could also be a tool in trouble shooting to assist with non-conforming manufacturing protocols.

The model system could be useful for all the users who work in the field of the above mentioned areas, such as for food and drink manufacturers, retailers or environmental health officers.

In order for a prediction to be produced the following **input parameters** must be provided:

- microorganism of concern,
- initial concentration of organisms,
- pH of food,
- aw or salt level of food,
- storage temperature,
- storage time.

It is important to pay attention on the correction of the input data, because incorrect data of the recipe formulation can cause some failures in the calculation. After calculation the predicted growth curves can be provided which can be used to determine the shelf-life of the products and the best storage conditions. These **outputs** can be utilized for setting the maximum level of organism present at the end of shelf-life, or comparing the stability of different recipes. Results can also be used for assessing the impact of changes in product formulation or in determining the effect of any breakdown in product manufacturing and distribution such as abuse storage temperatures.

It should be noted and the user should keep in mind that in most microbiological predictive models, the predictions can be 'fail-safe' i.e. they predict growth is likely to occur faster than it would actually occur in reality. This is because models can only predict the effects of limited factors on microbial growth i.e. pH, aw, temperature and sometimes preservatives. Foods will often have additional antimicrobial factors which cannot be taken into account in the model predictions. (Campden BRI, 2011)

More information:

The models are accessed by a bureau service at Campden BRI, l.everis @campden.co.uk

ACID CLUB Models

ACID CLUB Models are developed for acidified foods based on three groups of acid tolerant organisms. The ACID CLUB system contains three growth/no growth models for groups of organisms associated with acid preserved products. The model system gives very quick, efficient and cost effective methods for assessing the potential growth of microorganisms under specific conditions without needing practical studies.

The models are termed for:

- cold fill spoilage (yeasts, moulds, lactics)
- cold fill pathogens (E. coli, S. aureus, Salmonella)
- hot fill spoilage (Bacillus/Clostridium sporeformers)

The ranges of conditions over which predictions can be given are listed in Annex 3. ACID CLUB Models are designed for the same purpose as FORECAST that food and drink manufacturers or retailers can easily use. The following **applications** are as follows:

- In product development to assess stability of new recipes with respect to spoilage organisms
- To identify areas where challenge testing should be undertaken
- As a tool with HACCP and risk assessment plan development
- Trouble shooting to assist with non-conforming manufacturing protocols.

For a correct calculation there are some input parameters that the user should precisely provide for the requested reliable results. Incorrect data on recipe formulation can present false results. These are the expected **inputs** of the model: pH of food, aw or salt level of food and preservative level, then as an **output**, the predicted stability of the product is given during ambient storage.

The same limitation is applied for ACID CLUB Models like for FORECAST and for most microbial predictive models, as whilst modelling of the accurate predictions of the growth of organisms in the majority of foods, there are occasions when there are discrepancies between the model and the observed growth. These discrepancies are most often described as ‘‘fail-safe’’, i.e. the observed growth is slower than predicted by the model (Wilson P.D.G. et. al, 2002). The current predictive models are often overly fail-safe, which means that they predict much higher pathogen numbers many times than would be present in real food with microbial competition. Still, it’s better to over-predict the growth rate of a pathogen than to under-predict it.

ACID CLUB Models contain the same possibilities for utilizing the outputs of the model as the FORECAST model. Food and drink manufacturers and retailers can use this model as a solution for setting maximum level of organism present at the end of shelf-life, for comparing the stability of different recipes, assessing the impact of changes in product formulation and for determining the effect of any deviation in product recipe during product manufacture.

More information:

The models are accessed by a bureau service at Campden BRI, l.everis @campden.co.uk

Pathogen Modelling Program (PMP)

The Pathogen Modelling Program (PMP) is a model package with several types of models. PMP is available free of charge and it is probably one of the most widely used predictive microbiology application software. Pathogen Modelling Programs can be helpful in setting critical limits, determining hazard severity, and justifying corrective actions.

The software allows growth or inactivation of pathogens to be predicted for different combinations of constant temperature, pH, NaCl/aw and, in some cases, other conditions such as organic acid type and concentration, atmosphere, or nitrate.

The majority of PMP are growth models but survival (non-thermal inactivation) models, thermal inactivation models and cooling models are also contained to the program. The models are based on extensive experimental data of microbial behaviour in liquid microbiological media and food under various environmental conditions. The model predictions were developed for a specific range of environmental conditions. The accuracy of predictions made inside this range is known, but the software does not permit values outside this range of temperature to be entered.

The application boundaries of the PMP models are summarized in Annex 4.

The different kind of models need slightly different input parameters as they base on different calculations. The growth model vary the atmosphere (aerobic, anaerobic), temperature, pH, water activity, and in some cases nitrite and other additives. The survival models predict the inactivation of bacterial pathogens as a function of temperature, NaCl, pH, nitrite and lactic acid. Thermal inactivation models need temperature, pH, NaCl and sodium pyrophosphate parameters for its prediction. Last but not at least cooling models can evaluate the combinations of time and temperature in the cooling profile box.

Here is an overview on the list of the input parameters that are required for some of the models and some adjustments that user must set before starting modelling:

- temperature
- pH
- water activity/NaCl concentration
- initial level and level of interest *
- lag and lo lag options for growth models **

*The “Initial Level” is an arbitrary value that user can set to indicate an actual or assumed initial level of bacteria in the sample at the beginning of the growth scenario. The lowest and highest values that user can select are restricted based on the levels used to generate the model data. The “Level of Interest” is an arbitrary level that user select for a target level of growth. There is no recommended Level of Interest.

**Selecting the ALag@ option will result in a prediction of the Lag Phase Duration (LPD) based on the experimental data for the model. Selecting ANo Lag@ will remove the period of time for the calculated Lag Phase, and will begin predictions with immediate growth of the bacteria.
In case of modelling with PMP, in many cases, user will not find a model that exactly matches the concrete food product formulation. In case of predicting the behaviour of the microorganism in a selected product that has multiple forms, user should choose the model that is closest to the proper product. (Campden BRI, 2011)

More information:
http://pmp.arserrc.gov/PMPHome.aspx

ComBase

The purpose of ComBase is to provide an extensive electronic database for food microbiology observations. The user friendly predictive tools collected together are freely available and

accessible to the wide community, as this system is internet based and predictions are generated online.

Pathogen predictions can be carried out using the ComBase system. The software includes several curves/data on growth, survival or inactivation of microorganism in foods. Data has been obtained from the literature or provided by supporting institutions.

ComBase can be helpful mainly for the following applications:

- predicting and improving the microbiological safety and quality of foods,
- designing, producing and storing foods economically,
- assessing microbiological risk in foods.

The internet based system contains two free accessible parts: **ComBase Predictor** and **Perfringens Predictor**. The main types of models contained to the ComBase Predictor are: growth models, thermal inactivation models and non-thermal survival models. These models are developed to predict the response of several pathogenic and spoilage microorganisms to different factors (temperature, pH, salt, etc.). The Perfringens Predictor is designed to predict the response of Clostridium Perfringens in large size of cooked meat product during cooling.

The criteria of the Combase Predictor include the type or species of organism, the different factors (pH, temperature, water activity (or NaCl concentration), and in some cases as a forth factor carbon dioxide or organic acids). User can choose from a huge number of microorganisms and can define the criteria of the proper case. After calculation, the **output** will be a growth or survival rate, or the profiles of the concentration of microorganisms (both spoilage organisms and pathogens) as a function of time under given conditions.

Predictive models accessible in the model collection can be a useful set of tools for the industry, academia and also for regulatory agencies.

More information:
http://www.combase.cc/index.php/en/

4.5.2. Heat treatment models

In the food industry spoilage of the foods is mainly caused by different microorganisms, therefore the primary function of the heat treatment is to eliminate all the possible microbial hazards. Although, the higher temperature results faster destruction of microorganisms, therefore a shorter treatment on higher temperature can be equivalent with longer treatment on lower temperature from the aspect of the safety, but the two different processes provide food products with different quality and with different taste. Furthermore, usually the product treated for shorter time preserves those characteristics that are more valuable for the consumers.

Modelling softwares are proper tools for analysing heat treatment data with computer's help, which provide quick solution in process designing for allocating exact estimation for the differences and/or changes that effect food safety. Despite of time-consuming real measurements on foods, calculations can be carried out easily by modelling the effect of the different changes of any product components, shape and the size of the packaging, process parameters and changes of any sterilized factors. Heat treatment models can serve cost- and time-effective electronic opportunities for determining the parameters of the heat treatment. By models, quick and reliable answers can be taken for determining the critical point and for process controlling. Furthermore, the hazards can be quantified and ranked through the whole cold chain. The microbiological regulation defines that the real shelf-life of the food product must be verified for which heat treatment models offer modern, cost- and time-consuming solutions which also reduce the number of the microbial analyses and tests. Taking full advantage of the opportunities of the model, the user can benefit long term advantages on the market.

CTemp

CTemp model is developed by Campden BRI which is a finite difference heat transfer model for foods heated inside containers. Since its introduction in 1989 by Camden BRI, CTemp has been used to predict thermal processes in many hundreds of different product types.

CTemp is a program for calculating the temperatures within packaged foods during thermal processing using the finite difference calculation method. The model allows prediction of heat transfer into containers of food and can be used for design of new heat processes or dealing with process deviations when things go wrong in factories.

In view of this fact the targeted users of the model are the producers of foods that are heat processed inside containers, like cans, bowls, jars or pouches of any food who can utilize the

results to design heat processes to meet safety or spoilage control objectives or make decisions on release of batches subjected to abnormal heating.

One of the main benefits of the model is that it can ensure that heat processes are safely designed and whether abnormal batches e.g. those suffering from a temperature drop during processing are safe to release or not.

The key features of CTemp are:

- Temperatures and lethalities can be predicted in foods that heat by conduction, convection or broken heating modes.
- The data input routines are compatible with any data logger output file following manipulation in a spreadsheet package to save the data as a comma separated file (.csv).
- Process can be optimised against defined quality criteria (e.g. browning reactions) by adjusting the retort profile to maximize or minimize the calculated quality parameter.
- Process deviations can be assessed retrospectively, allowing informed decisions about the destination of batches of product.
- "What-if "analysis to simulate the worst likely production conditions; makes process establishment safer and less time consuming.
- Calculation of energy usage and CO2 produced during process cycles.

CTemp can be applied in more situations. CTemp has been thoroughly tested on combinations of product, package and process. This includes fruits, vegetables, meats, fish, pasta, sauces, pastes, petfoods and rice in cans, glass jars, pouches or trays. It can be used 0for processing media such as steam, steam/air, water immersion or raining water. In addition to that the program is applicable for batch or continuous processes for packaged foods in retorts or hydrostatic and reel and spiral cookers.

For the calculations of the above listed applications the program expects some product input, like heat penetration data such as time/temperature of the cooker and temperature of the product from a comma separated variable data file. After calculation the model provides Fo or pasteurisation values as an output to asses microbiological kill (or it provides cook values for quality e.g. vitamin destruction). Alternatively the software can be used to choose cook times required to achieve defined heat process objectives.

As CTemp is a computer software, some **minimum specifications** are requested related to the users' computer by which the program is used. For the analyses the following requirements are determined:

- Pentium III PC

- 128 Mb RAM
- 30 Mb Hard-disk space
- 1024 x 768 resolution monitor
- Windows Me, 2000, XP, Vista or NT4 Operating System

However CTemp is easy to use, an 86 page manual is available for users in which detailed description is written of the use of the model. The **basic process** is as follows:

- The software is used for estimation of heating factors (fh) values for the selected worst case data set.
- The fh value is converted into a thermal diffusivity value.
- The software models against the experimental data to determine best sphere size on which to base predictive modelling of the lag phase of heating.
- The thermal diffusivity value is used in a finite difference model to track core temperature.
- The predicted core temperature profile is then used to generate a general method F value.

It has to be noted that the software can be widely used as it can predict product heating rates for i) changes in cooker temperature ii) changes in cook time iii) changes in come up time iv) changes in initial product temperature but it cannot predict heating when the following occur: changes to the recipe, changes in particle size, changes in agitation rate, changing the cooker type.

The software has been sold to many food manufacturing companies worldwide so far. It is routinely used for process design and process deviation work setting up 1000's of food processes. However the model is easy to use, it should be used with care when dealing with decisions on food safety. It is recommended that users have an appropriate background training e.g. Campden BRI's Thermal Process Validation course and a minimum of one days training on the software is advised. This kind of training is actually recommended because for real data analysis any failure is potentially fatal to consumers. The performance of the model is heavily dependent upon the quality of heat penetration data that is put into it.

More information:

http://www.campden.co.uk/news/feb10e.htm

5. Conclusions

Although the use of food models is increasing there is a need for systematic activities to make the potential users in the food industry, food control and risk assessment institutions and research organisations of the food models aware about the potential applications, because the main barrier of using models is the lack of knowledge. This document is intended to provide practical guidance both for the users of the models and the model developers and also inform the users, particularly food SMEs about application opportunities and benefits of food models.

Therefore, this guideline is intended to give an overview on modelling in general and on the specific modelling tools/softwares with a focus on models developed within a the DREAM project supporting the practical application.

It is essential that during the development of a model a systematic, well-designed procedure should be followed which include at least the following main steps - the elaboration of a precise statement of purpose, designing, developing, validation, verification practicability testing and maintenance of the models - to ensure that the models provide outputs on scientifically sound bases, accurate, reliable and meets the needs of the targeted users and are in line with practical applicability requirements and consider their practical constraints. A model developed for the industry meet the following requirements:

- practically applicable outputs that are clearly described for the user;
- quick availability of the results (typically within maximum one day) which should be as product specific as possible;
- easy handling and application by a technically experienced but not specialised ordinary member of the industry staff (by a food technologist or food engineer);
- results should be as reliable and precise as possible;
- the modelling activity should not require expensive, specific equipment, which can't be exploited properly;
- confidentiality needs of the providers of the inputs should be considered.

In summary, food models are useful tools for the product and process development, for the assessment of the safety of product/process design, and can help in understanding the impact of process parameters on final characteristics of the food and yield. However, their use requires an appropriate level of expertise, competence, skills and clear practical guidance.

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7. Glossary

Term	Definition
aw	The water activity (aw) of a food is the ratio between the vapour pressure of the food itself, when in a completely undisturbed balance with the surrounding air media, and the vapour pressure of distilled water under identical conditions. A water activity of 0.80 means the vapour pressure is 80 % of that of pure water. The water activity increases with temperature. The moisture condition of a product can be measured as the equilibrium relative humidity (ERH) expressed in percentage or as the water activity expressed as a decimal.
Basic Knowledge Models (BKMs)	BKMs are elementary food models describing specific aspects of GMFs, through heuristic or mathematical approaches; for example, BKMs describe the role played by temperature, pressure, chemical composition, etc. in a GMF's structure and resulting material properties.
Computer model	A computer program that can predict the behaviour of a food under different circumstances.
Drip loss	The loss in weight of food products owing to extruding and dripping away of tissue juices, such as meat juices lost during the thawing of frozen meat.
D-value	The decimal reduction time, or the time that is required to destroy 90% of the organisms. This value is numerically equal to the time for the survivor curve to transverse one log cycle.
Electrical conductivity	Electrical conductivity is the measure of the amount of electrical current a material can carry.
F-value	The log reduction in cell numbers over a time-temperature profile, expressed at a specific reference temperature.
Generic Model Foods (GMFs)	GMFs are realistic physical models in which several parameters can be varied, leading to a series of well-defined samples. GMFs' structure and chemical composition are determined and relationships between structure and chemical composition and functional properties are characterised. GMFs are standard product types with defined production methods and end product specifications.
Growth Rate	The change in bacterial numbers over time, typically expressed as log10 CFU/hour. To convert this value to Generation Time, divide 0.301 by the Growth Rate.
HACCP	A system to identify, evaluate and control hazards to an acceptable level of risk.

Integrated Knowledge Models (IKMs)	IKMs are dynamic networks - software systems – integrating the operating rules of BKMs, technical expert knowledge, food properties and food processing data from the GMFs.
Lag Phase (Duration)	The time required for the cell population to adjust to the broth or food environment and begin growth.
Model	A simplified representation of a system or phenomenon, as in the sciences or economics, with any hypotheses required to describe the system or explain the phenomenon, often mathematically.
Pathogen	A disease-causing organism.
pH	pH is a measure of hydrogen ion concentration; a measure of the acidity or alkalinity of a solution. Aqueous solutions at 25°C with a pH less than seven are acidic, while those with a pH greater than seven are basic or alkaline. A pH level of is 7.0 at 25°C is defined as 'neutral' because the concentration of H3O+ equals the concentration of OH− in pure water.
Primary microbial models	Models that describe changes in microbial numbers or other microbial responses with time. The model may quantify colony forming units per ml, toxin formation, or substrate levels (which are direct measures of the response), or absorbance or impedance (which are indirect measures of the response). A mathematical equation or function describes the change in a response over time with a characteristic set of parameter values.
Realistic model	Physical models in which several parameters can be varied, leading to a series of well-defined samples for each given type of foods. A fabrication protocol is provided for the model. It has a well characterised structure and chemical composition, and the relationship of its attributes and the functional properties are well described.
Realistic food model	An ”artificial” product which is very similar to the real food with well-known characteristics, prepared according to a defined recipe.
Secondary microbial models	Models that describe the responses by the parameters of these primary models to changes in environmental conditions such as temperature, pH, or water activity.
Simulate	Imitate or reproduce the appearance, character, or conditions of.
Simulation:	The representation of the behaviour or characteristics of one system through the use of another system, esp. a computer program designed for the purpose.
Tertiary microbial models	Models that are computer software routines that turn the primary and secondary models into "user-friendly" programs for model users in the forms of applications software and expert systems. These programs may calculate microbial responses to changing conditions, compare the effects of different conditions, or contrast the behaviour of several microorganisms.

Toxin	A compound produced by a bacterium that can cause illness in a living organism. Examples are enterotoxins that affect the intestine and neurotoxins that attack the nervous system.
Valid	Well-founded and applicable to the case or circumstances...
Validation	Model validation is usually defined to mean "substantiation that a computerised model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model"
Validity	In science and statistics, validity has no single agreed definition but generally refers to the extent to which a concept, conclusion or measurement is well-founded and corresponds accurately to the real world.… In the area of scientific research design and experimentation, validity refers to whether a study is able to scientifically answer the questions it is intended to answer.
Verify	Make sure or demonstrate that (something) is true, accurate, or justified.
Verification	Model verification is often defined as "ensuring that the computer program of the computerized model and its implementation are correct".
Z-value	The change in temperature necessary for a 10-fold reduction in the D-value.

8. List of abbreviations

aw	water activity
BKM	Basic Knowledge Model
CV	coefficient of variance
CWM	cell wall content of the apple
DFD	Dark, Firm and Dry
DPn:	number average degree of molymerization of the procyanidins.
DREAM	Design and development of REAlistic food Models with well-characterised micro- and macro-structure and composition
FDM	Fat-in-Dry-Matter
fh	heating factors
FOM	Fat-O-Meat'er
F.U.O.	Flow of Unit Operations
GDL	glucono-delta-lactone
GLS	glucosinolates
GMF	Generic Model Food
IKM	Integrated Knowledge Model
IS	ionic strength
KI	*Potassium* iodide
MNFS	Moisture-in-Non-Fat-Substance
NaCl	Sodium chloride
NIT	Near Infrared Transmittance
NIR	Near Infrared Reflectance
Nmax	parameters of the binding isotherms obtain don purified cell walls and procyanidins
PF	partition factor
PPf	concentration in the juice
PSE	Pale, Soft, and Exudative
SMEs	small and medium-sized enterprises
SNF	Solid-Non-Fat
Tot	concentration in the juice as present in the apple
T	temperature

9. Annexes

Annex 1

Growth Factors For Selected Bacteria

ORGANISM	TEMP °C[a]	pH[a]	a_W[a]
Salmonella spp.	5.2 / 35-43 / 46.2	3.8 / 7.0-7.5 / 9.5	0.94 / 0.99 / >0.99
Clostridium botulinum			
A & B	10 - 50	4.7 - 9	>0.93
nonproteolytic B	5 - ?	-[b]	NR[c]
E	3.3 - 15-30	-[b]	>0.965
F	4 - ?	-[b]	NR[c]
Staphylococcus aureus	7 / 37 / 48	4.0 / 6.0-7.0 / 10	0.83(0.9) / 0.98 / >0.99
Campylobacter jejuni	32 / 42-43 / 45	4.9 / 6.5-7.5 / ca9	>0.987 / 0.997 / -
Yersinia enterocolitica	-1.3 / 25-37 / 42	4.2 / 7.2 / 9.6	- / - / 5% NaCl
Listeria monocytogenes	-0.4 / 37 / 45	4.39 / 7.0 / 9.4	0.92 / - / -
Vibrio cholerae O1	10 / 37 / 43	5.0 / 7.6 / 9.6	0.970 / 0.984 / 0.998
V. cholerae non-O1	-[b]	-[b]	-[b]
Vibrio parahaemolyticus	5 / 37 / 43	4.8 / 7.8-8.6 / 11	0.940 / 0.981 / 0.996
Clostridium perfringens	4 / 43-47 / 50	5.5-5.8 / 7.2 / 8.0-9.0	0.97 / 0.95-0.96 / 0.93
Bacillus cereus	4 / 30-40 / 55	5.0 / 6.0-7.0 / 8.8	0.93 / - / -
Escherichia coli	ca7-8 / 35-40 / ca44-46	4.4 / 6-7 / 9.0	0.95 / 0.995 / -
Shigella sonnei	6.1 / - / 47.1	4.9 / - / 9.34	- / - / 5.18% NaCl
Shigella flexneri	7.9 / - / 45.2	5.0 / - / 9.19	- / - / 3.78% NaCl

a. minimum / optimum / maximum values.
b. The value, though unreported, is probably close to other species of the genus.
c. NR denotes that no reported value could be found, but for most vegetative cells, an a_W of >0.95 would be expected.

Values taken from:
ICMSF(1996) Microorganisms in Foods 5: Characteristics of Microbial Pathogens, Roberts, T. A., Baird-Parker, A. C. a B. (eds.), Blackie Academic & Professional, London [ISBN 0 412 47350 X]

Microbial Survival in the Environment, E. Mitscherlich and E.H. Marth (eds.), Springer-Verlag, Berlin and Heidelberg, 540-13726-2 Springer-Verlag, Berlin, New York, Tokyo] [ISBN 0-387-13726-2 Springer-Verlag, Heidelberg, Berlin, T

Spoilage models available in the FORECAST modelling software

Model	Temperature (°C)	NaCl (% aq)	Equivalent Aw	pH	Other Conditions
Pseudomonas	0 - 15	0.0 - 4.0	1.00 - 0.977	5.5 - 7.0	Fluctuating temperature, pH, salt
Bacillus spp.	5 - 25	0.5 - 10	0.997 - 0.935	4.0 - 7.0	Fluctuating temperature, pH, salt
Enterobacteriaceae	0 - 27	0.5 - 10	0.997 - 0.935	4.0 - 7.0	Fluctuating temperature, pH, salt
Yeasts (chilled foods)	0 - 22	0.5 - 10	0.997 - 0.935	2.6 - 6.0	Fluctuating temperature, pH, salt
Yeasts (fruit/drinks) (time to growth)	0 - 22	-		2.0 - 7.0	0 - 60% Sucrose (w/v) 0 - 20% Ethanol (v/v) Potassium sorbate 0 - 1000(ppm)
Lactic acid bacteria	2 - 30	0.5 - 10	0.997 - 0.935	3.0 - 6.0	Fluctuating temperature
Meat spoilage	2 - 22	0 - 6	1.00 - 0.964	4.6 - 7.0	0 - 240 KNO_2 (ppm) Fluctuating temperature, pH, salt
Fish spoilage	2 - 22	0 - 6	1.00 - 0.964	4.5 - 8.0	Fluctuating temperature, pH, salt
Fresh produce TVC	2 - 25	-	-	-	
Fresh produce Enterobacteriaceae	2 - 25	-	-	-	
Fresh produce lactic acid bacteria	2 - 25	-	-	-	
Fresh produce *Pseudomonas*	2 - 25	-	-	-	
Enterobacteriaceae death model	52 to 64	0 - 8	1.00 - 0.95	4.0 - 7.0	Predicts D value
Bacillus (time to growth)	8 - 45	0.5 - 10	0.997 - 0.935	4.0 - 7.0	
Bacillus (time to growth)	5 - 45	1.33-17.5	0.845-0.988	3.48-5.03	
Aspergillus niger	NA	NA	0.80-0.97	4.67-7.56	K sorbate and Ca propionate 0-0.5%
Aspergillus ochraceus	NA	NA	0.80-0.97	4.67-7.56	K sorbate and Ca propionate 0-0.5%
Cladosporium herbarium	NA	NA	0.80-0.97	4.67-7.56	K sorbate and Ca propionate 0-0.5%
Eurotium repens	NA	NA	0.80-0.97	4.67-7.56	K sorbate 0-0.5%
Mucor racemosus	NA	NA	0.80-0.97	4.67-7.56	K sorbate and Ca propionate 0-0.5%
Penicillium corylophilium	NA	NA	0.80-0.97	4.67-7.56	K sorbate and Ca propionate 0-0.5%
Penicillium aurantiogriseum	NA	NA	0.80-0.97	4.67-7.56	K sorbate and Ca propionate 0-0.5%
Rhizopus spp	NA	NA	0.80-0.97	4.67-7.56	K sorbate and Ca propionate 0-0.5%

Annex 3

Models available for acidified foods in ACID CLUB modelling software

Organisms	Prediction categories/time to growth (G)	pH	Aw	Salt % w/v	Preservative ppm
Cold fill spoilage (yeasts, moulds, lactics)	Cat 1 = G in 14d Cat 2 = G in 15 - 30d Cat 3 = G in 31 - 60d Cat 4 = G in 61 - 182d Cat 5 = NG in 182d	2.8 - 5.0	0.85 - 1.00	0.5 - 18	Benzoate Sorbate 0 - 2000 (in total)
Cold fill pathogens (*E. coli, S. aureus, Salmonella*)	Cat 1 = G in 120d Cat 2 = NG in 120d	3.9 - 5.0	0.87 - 1.00	0.5 - 16	Benzoate Sorbate 0 - 2000 (in total)
Hot fill spoilage (sporeformers)	Cat 1 = G in 14d Cat 2 = G in 15 - 30d Cat 3 = G in 31 - 60d Cat 4 = G in 61 - 182d Cat 5 = NG in 182d	3.7 - 5.2	0.86 - 1.00	0.5 - 18	Benzoate Sorbate 0 - 2000 (in total)

Key: G = Growth NG = No Growth

Annex 4

PMP Growth Models					
Model	Temp (°C)	NaCl (%aq)	a_w	pH	Other Conditions
Aeromonas hydrophila aerobic	5-42	0.5-4.5	0.997.0.974	5.3-7.3	0-150ppm $NaNO_2$
Aeromonas hydrophila anaerobic	5-30	0.5-3.5	0.997-0.980	5.3-7.3	0-150ppm $NaNO_2$
Bacillus cereus aerobic	5-42	0.5-5.0	0.997-0.970	4.7-6.5	0-150ppm $NaNO_2$
Bacillus cereus anaerobic	5-42	0.5-5.0	0.997-0.970	5.0-9.0	0-150ppm $NaNO_2$
Clostridium botulinum (non-proteolytic) time to turbidity	5-28	0-4.0	1.00-0.977	5.0-7.0	-
Clostridium botulinum (non-proteolytic) time to toxin in fish	4-30	-	-	-	-
Clostridium botulinum -proteolytic) time to turbidity	15-34	0-4.0	1.00-0.977	5.0-7.2	-
Clostridium perfringens	19-37	1.0-3.0	0.996-0.983	6.0-6.5	Sodium pyrophosphate 0.1-0.2%
Escherichia coli O157:H7 aerobic	5-42	0.5-5.0	0.997-0.970	4.5-8.5	0-150ppm $NaNO_2$
Escherichia coli O157:H7 anaerobic	5-42	0.5-5.0	0.997-0.970	4.5-8.5	0-150ppm $NaNO_2$
Listeria monocytogenes (NaCl) aerobic	4-37	0.5-10.5	0.997-0.928	4.5-7.5	0-150ppm $NaNO_2$
Listeria monocytogenes (NaCl) anaerobic	4-37	0.5-5.0	0.997-0.970	4.5-8.0	0-150ppm $NaNO_2$
Listeria monocytogenes (aw) aerobic	4-37	-	0.997-0.928	4.5-7.5	0-150ppm $NaNO_2$
Listeria monocytogenes (aw) anaerobic	4-37	-	0.997-0.970	4.5-8.0	0-150ppm $NaNO_2$
Salmonella aerobic	10-30	0.5-4.5	0.997-0.974	5.6-6.8	
Staphylococcus aureus aerobic	10-42	0.5-12.5	0.997-0.911	4.5-9.0	0-150ppm $NaNO_2$
Staphylococcus aureus anaerobic	12-42	0.5-12.5	0.997-0.911	5.3-9.0	0-150ppm $NaNO_2$
Yersinia enterocolitica aerobic	5-42	0.5-5.0	0.997-0.970	4.5-8.5	0-150ppm $NaNO_2$
Shigella flexneri aerobic	10-37	0.5-5.0	0.997-0.970	5.0-7.5	0-150ppm $NaNO_2$
Shigella flexneri anaerobic	12-37	0.5-5.0	0.997-0.977	5.5-7.5	0-150ppm $NaNO_2$

Survival models					
Model	Temp (°C)	NaCl (% aq)	a_w	pH	Other Conditions
Escherichia coli O157:H7	4-37	0.5-15	0.997-0.887	3.5-7.0	Lactic acid 0-2.0% $NaNO_2$ 0-75ppm
Listeria monocytogenes (NaCl)	4.42	0.5-19	0.997-0.845	3.2-7.3	Lactic acid 0-2.0%$NaNO_2$0-150ppm
Salmonella	5-42	0.5-16	0.997-0.887	3.5-7.2	$NaNO_2$ 0-200ppm
Staphylococcus aureus	4-37	0.5-20	0.997-0.834	3.0-7.0	Lactic acid 0-2.0 $NaNO_2$0-200ppm

Thermal Death Models					
Model	Temp(°C)	NaCl (% aq)	a_w	pH	Other Conditions
Clostridium botulinum (non-proteolytic)	70-90	0-3.0	1.00-0.983	5-7	Sodium pyrophosphate 0.1-0.3%
Escherichia coli O157:H7	55-62.5	0-6.0	1.00-0.963	4-8	Sodium pyrophosphate 0.1-0.3%
Listeria monocytogenes NaCl	55-65	0-6.0	1.00-0.963	4-8	Sodium pyrophosphate 0.1-0.3%

Other models		
Model	Temperature (°C)	Model capability
Clostridium botulinum (proteolytic) cooling profile growth model	-	Calculates increase in numbers during cooling of beef broth
Clostridium perfringens- cooling profile growth model		Calculates increase in numbers during cooling of beef broth, cured chicken or cured beef
Salmonella typhimurium Irradiation (3 models)	-20 to 10	Predicts decline in numbers following 0-3.6 kG treatment in chicken meat
Escherichia coli O157:H7-Irradiation	20 to 10	Predicts decline in numbers following 0-2.0 kG treatment in chicken beef tartar

[Your coordinates] Roland Pons
ICC
Marxergasse 2
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AUSTRIA

[City, date,] 04/12/2012

Dear DREAM Coordinator,

By this letter, I confirm that I reviewed the report of the deliverable D7.3: "Draft practical guideline on use of models" of the DREAM (Design and development of REAlistic food Models with well characterised micro- and macro-structure and composition) project n°222654.

Sincerely,

[Your signature]

Great piece of work. I learned a lot. Very useful to food producers and QM, official control and research.

I hope this work will be widely published.