SIMULATION OF GREEN BEANS (*Phaseolus vulgaris, L.*) QUALITY LOSS THROUGHTOUT THE FROZEN FOODS DISTRIBUTION CHAIN

Martins, R.C., Almeida M.G., Silva C.L.M.[(1)]

Rui C. Martins: Escola Superior de Biotecnologia
Universidade Católica Portuguesa
R. Dr. António Bernardino de Almeida
4200-072 Porto
Portugal
Tlf. +351 22 558 00 43
Fax: +351 22 509 03 51
e-mail: rmcm@morango.esb.ucp.pt

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INTRODUCTION

Frozen vegetables are exposed to a wide variety of different environmental temperature conditions along the distribution chain. These are responsible for both nutritional and sensory quality losses of frozen products. Quality losses are difficult to quantify, due to the chaotic temperature spectrum to which frozen foods are exposed until consumption. This explains why shelf life dating of frozen foods is a difficult task. For example, experimental studies to characterise quality losses throughout the distribution chain require an enormous amount of resources, and therefore are rarely performed.

A cost-effective solution to the problem may be by computer simulation. With the use of object-oriented computer models, the prediction of quality losses throughout the frozen chain is feasible. By building models it is possible to understand why, where and how quality losses occur. Thereafter, the model can be used as a tool to study the frozen chain, optimise quality retention, and shelf life dating.

Although the simulation of such complex systems is a vast subject, the present work presents an overview of the main computational resources, model components, how they work and interact, in order to achieve computer simulations more and more near the reality.

FINITE ELEMENTS METHOD

With this method, the physical domain is approached by a mesh [1], where heat transfer and quality changes differential equations are solved. Using this numerical method, it is possible to simulate both temperature and quality loss of frozen green beans.

THERMAL PROPERTIES

Thermal condutivity (k) and thermal capacity (Cp) change significantly during phase transition.

The FEM needs mathematical relationships with respect to temperature, in order to simulate phase change. Therefore, thermal capacity was determined, by differential scanning calorimetry, and thermal conductivity by reverting the FEM problem.

MODELLING TIME-TEMPERATURE SPECTRUM

The modelling the time-temperature spectrum is necessary to characterise the temperature oscillations to which frozen foods are subjected. With this technique it is possible to define the probabilities of occurring temperature abuses and simulate them, as well.

TIME-TEMPERATURE DISTRIBUTIONS

Time-temperature distributions are necessary to characterise statistically the residence time and temperature at each step of the distribution chain. With these statistical distributions it is possible to simulate stochastically the residence time and temperature by the Monte Carlo method.

QUALITY LOSS

Frozen vegetables are well known for their nutritional and sensory quality. However, when they are exposed to temperature abuses, quality loss is accelerated. For example, a major colour and vitamin c degradation occurs during the transportation from the shop to the consumer's home. The quality degradation kinetics can be implemented in the FEM triangular element. This allows simulating quality loss across the entire physical domain.

The following quality degradation kinetics are currently integrated: (i) colour, (ii) chlorophyll's, (iii) vitamin C, (iv) starch degradation, (v) reduced sugars increase, (vi) texture and, (vii) ice recrystallisation [2].

INTEGRATED MODEL

Each described component (object) can be integrated into a computational model. The different model objects interact with each other in order to generate a scenario, where the simulation occurs. For example, with the time temperature spectrum models, it is Possible to create the different scenarios of the frozen distribution chain, such as, refrigerated lorys, freezers and human interaction. Then another object, such as a green beans package, can pass throughout the different scenarios and quality loss can be estimated [3].

With this abstration level, it is possible to define at the most elementary model level (the triangular element), all the physical laws and stochastic processes. As calculations are made, there is the propagation of uncertainty to the higher level object models, and such an extreme chaotic fenomena emerges, giving to the observer an apparent complex solution. However, these types of simulations require high computational power. Therefore, the simulation programs were written in C++, and implemented in a LINUX cluster, with a BEOWULF architecture, using the software Parallel Virtual Machine [4].

CONCLUSIONS

Computational models can simulate quality loss along the frozen food distribution chain. This engineering tool will allow in the future to characterise the different configurations of the distribution chain, to optimise quality retention, reduce operational costs, and increase the level of accuracy of shelf-life dating of frozen foods.

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