Interactions between refrigeration temperatures, energy consumption in a food plant and microbiological quality of the food product: Application to refrigerated stuffed pasta

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ABSTRACT

Food refrigeration is essential to maintain microbiological quality but it accounts for high energy impact. An integrative modelling approach was developed to estimate the impact of increasing refrigeration temperature in the processing plant, on energy consumption, products temperatures, and the food product microbiology. The food product was a pasteurized refrigerated fresh pasta. The microbial indicators considered were *Bacillus cereus* for safety and total aerobic microflora for spoilage, with limits at consumption of respectively 10^5 CFU g^{-1} and 10^6 CFU g^{-1}. Through six scenarios, the impacts of temperatures ranging from −2 °C to 8 °C in the cooling tunnel, and from 4 °C to 6 °C in the end products cold room storage in the processing plant, were simulated. The same refrigeration conditions throughout the entire cold chain up to the consumer, based on temperature and residence time data of a field study, were applied to all these processing plant refrigeration scenarios. Fixing 8 °C to the cooling tunnel and 6 °C to the cold room reduced the absorbed electrical power by ~20% with ~10% increase of microbiologically defective products at time of consumption. Increasing cooling tunnel temperature saved more energy than increasing cold room temperature for the same impact on microbiology. The modelling approach presented could help food companies to design the best strategy to reduce refrigeration energy consumption in their processing plant.

1. Introduction

The use of refrigeration for food preservation is continuously increasing in developed and developing countries, representing important energy consumption. Cooling and freezing represent about 30% of electricity consumption in the EU food industry (Monforti-Ferrario et al., 2015).

Public authorities and industrials are looking for solutions to reduce the energy consumed by refrigeration facilities, for example, by developing more efficient new technologies (Tassou, Lewis, Ge, Hadawey, & Chaer, 2010) or by the installation of doors on opened display cabinet in supermarkets (Laguerre, Chaomuang, Dinis Gaspar, & Dinho da Silva, 2019). Another solution is to modify the operating conditions, for example, by increasing the thermostat setting of a refrigerated equipment (Duret et al., 2018; Guillier, Duret, Hoang, Flick, & Laguerre, 2016; Zanoni & Zavanella, 2012), which implies accepting higher refrigeration temperatures at some steps of the cold chain. However, because of accelerated product quality alteration caused by higher temperatures, the global cost due to food waste or microbial safety issues may increase (Zanoni & Zavanella, 2012). For this reason, to implement such measure in the cold chain, the industry must have an adequate estimation of the impact of an increase in temperature on energy consumption on the one hand and on food spoilage and safety on the other hand, considering relevant hazards and the regulations. This information is all the more important as it is commercially difficult for the food industry to reduce food products shelf life.

Food product temperature and energy consumption have been extensively studied in refrigerated transport (James, 1996; Moureh,

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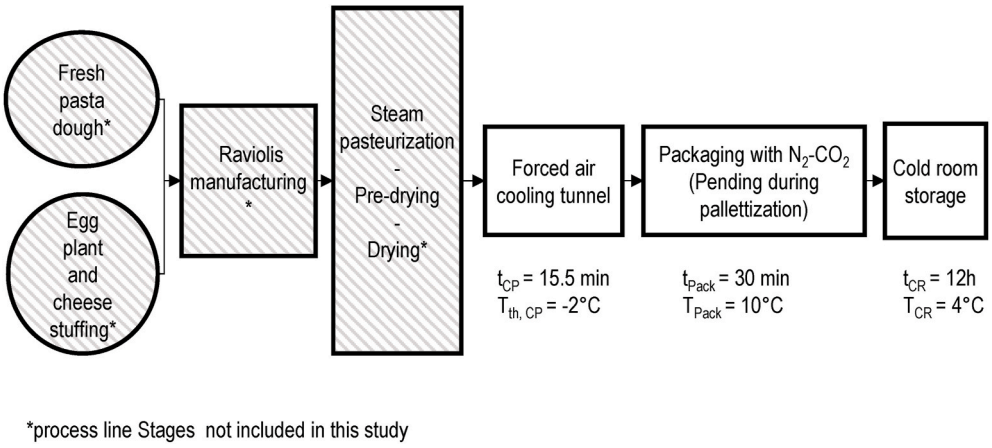

Fig. 1. Processing line (crosshatched steps were not included in the model), step duration and setting temperature of the baseline scenario are indicated.

Tapsoba, & Flick, 2009), storage cold room (Coldrey et al., 2018; Duret, Hoang, Flick, & Laguerre, 2014; Gruyters et al., 2018; H.-M.; Hoang, Duret, Flick, & Laguerre, 2015), display cabinet (Ben-abdallah et al., 2018; Chaomuang, Flick, & Laguerre, 2017; Jouhara et al., 2017) and domestic refrigerator (O. Laguerre & Flick, 2010). In contrast, few studies on temperature and energy consumption were carried out on the food plant stage of the cold chain (Brito, Lopes, Reis, & Alves, 2014; Duret et al., 2020; Evans et al., 2014). Food safety, food waste and energy consumption of the cold chain have been combined in a previous study (Duret et al., 2018) which considered the cold chain of ready-to-eat cooked ham without the processing plant, from transport to domestic refrigerators. In their study, the authors showed the complex relationship between operating conditions, energy consumption, food temperature and microbial spoilage and safety. For example, results showed that the modification of the thermostat of the domestic refrigerator had a high impact on food safety and food waste and a limited impact on the electrical consumption, while the modification of the airflow rate in the display cabinet had a high impact on electrical consumption and a limited impact on food safety and food waste. However, the post processing cold chain temperatures are submitted to strict legislation requirements, in particular for ready-to-eat products at risk of contamination by *Listeria monocytogenes*, while there are more flexibilities at the level of the processing plant with recommendations from a guide of good manufacturing practices (Synafap, 2011).

Due to the high numbers of refrigeration temperatures values that can be selected at the different steps of processing in the plant, testing their impacts on quality and safety by shelf life studies would not be feasible. Therefore, the objective of the present study is to integrate in a unique modelling approach, energy consumption of the refrigeration equipment in a processing plant, growth of microbial food spoilage as well as growth of pathogenic bacteria as indicators of commercialization relevance and microbial safety, respectively. The food product considered was a pasteurized refrigerated fresh pasta, representing a case of minimally processed chilled food or Refrigerated Processed Food of Extended Durability (REPFED) (Del Torre, Della Corte, & Stecchini, 2001). The foodborne pathogenic bacteria *Bacillus cereus* is a relevant hazard for REPFEDs (Webb, Barker, Goodburn, & Peck, 2019), for starchy foods in general (EFSA, 2005), and for fresh pasta in particular (Del Torre et al., 2001). There is no food safety criteria for *B. cereus* in EU regulation on microbiological criteria for foodstuffs, except for infant food formulae (EC regulation 2073/2005 and its amendment 1441/2007). However, in France *B. cereus* represents the second cause of foodborne outbreaks since 2012 (Santé-Publique-France, 2019) and a food safety alert limit has been fixed by the French government for *B. cereus* at 10^5 CFU g^{-1} (DGAL, 2009).

The name "*B. cereus*" is currently used for both a group of several species genetically very similar (*B. cereus sensu lato*) (Logan & De Vos, 2009) and for the species *B. cereus* itself (*B. cereus sensu stricto)*. All the species constituting *B. cereus sensu lato* have the capacity to produce the same diarrheal toxins as *B. cereus sensu stricto* (Guinebretiere et al., 2008) and most are not distinguished by the ISO-7932 standards for enumeration of *B. cereus.* These species, and not only *B. cereus sensu stricto*, are therefore all targeted by the French food safety alert limit (DGAL, 2009). This is the case in particular for *Bacillus weihenstephanensis,* a psychrotrophic species of *B. cereus sensu lato* particularly relevant for refrigerated foods. In this study the name "*B. cereus*" will be used for all the species of *B. cereus* sensu lato corresponding to the ISO-7932 criteria. More information on the phylogenetic structure of *B. cereus sensu lato* and its different species can be found in (Guinebretiere et al., 2008).

The study includes the investigation of the refrigeration temperatures distributions of the product in the processing plants, of the energy consumed by the corresponding equipment, of the impact of temperatures on the microbiology of the product, and a modelling approach to combine these three sets of information. A comprehensive understanding of the microbial ecology of the product was not a purpose of the study.

2. Materials and methods

2.1. Overview

This study proposes an experimental and numerical characterization through a process line and a cold storage in the food plant of (1) the food product temperature, (2) the total aerobic microflora, visible spoilage, *B. cereus* counts, and (3) the absorbed electrical power of the refrigeration processes as an indicator of energy consumption. The following sub-sections present the studied product, the processing line and the food plant characteristics (sub-section 2.2), the data of temperature and energy consumption used to develop the model (sub-section 2.3), the microbiological analysis and experiments (sub-section 2.4), the modelling methodology (sub-section 2.5) and the tested scenarios (sub-section 2.6).

2.2. Product, processing line and food plant

Product consisted in an eggplant and cheese stuffed fresh ravioli, which should be cooked before consumption. It had a use by date of 49 days after processing and a recommended storage temperature of 4 °C. Stuffing was purchased as a sterilized product by the company while pasta was prepared on site with flour and water. Each ravioli weighed around 6 g and was packed in 250 g pouches flushed with a gas mixture containing 50% N_2 and 50% CO_2. However the flushing failed to remove all the oxygen from the pouches (Fig. S2).

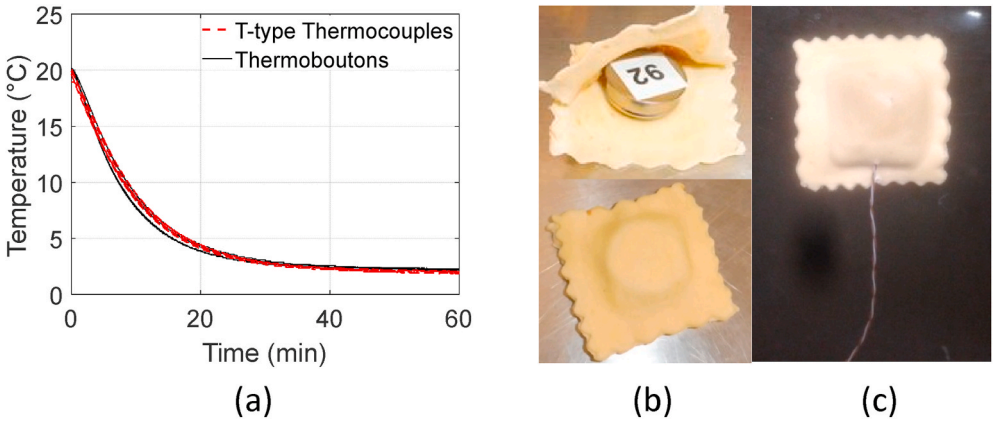

Fig. 2. Temperature evolution (a) of products instrumented with thermo-buttons (black line – pictures (b)) and T-types thermocouples (red dashed lines – picture (c)). Laboratory experiment with product initial temperature at 20 °C and air temperature at 2 °C. Three repetitions each were conducted. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

The processing line (Fig. 1) consisted in preparation of the pasta dough, stretching the dough to make ravioli with the ready-to-use eggplant and cheese stuffing, steam pasteurization of the ravioli, pre-drying, drying, forced air cooling, packaging with a flushing of a N_2/CO_2 mixture. After packaging and before cold room storage, pouches were filled in boxes and then placed in a pallet (pending during palletization). Cold room storage concerned the storage within the plant before cold transport. The part of the food plant concerned by this study includes the last three steps of Fig. 1 (forced air cooling tunnel, packaging and pending during palletization, cold room storage) under which the current duration (15.5 min, 30 min, 12 h respectively) and the setting temperature (−2 °C, 10 °C, 4 °C respectively) of the facility are shown. This duration and setting temperature are considered as the baseline scenario.

2.3. Experimental temperature and energy consumption data

2.3.1. Preliminary measurements

Thermo-buttons (Progesplus, 22L type, precision ± 0.5 °C, temperature range –40-85 °C), previously calibrated at 6 different temperatures (−5 °C, 0, 5, 10, 20 and 30 °C) were used for the temperature monitoring because of their ease of use and robustness. The thermo-buttons replaced the stuffing inside the ravioli (Fig. 2b). The methodology was previously verified to assure that the product temperature evolution measured by the thermo-button inside raviolis (Fig. 2b) was identical to that of the real raviolis with a T-type thermocouple (diameter 1 mm) at the core (Fig. 2c). The experiment consists in putting these instrumented raviolis (initial temperature 20 °C) in a control temperature chamber of 2 °C, the product temperature evolution are shown in Fig. 2a. It can be seen that the temperature profiles are very close between the measurement by button and by thermocouple.

2.3.2. On-site measurements

Experimental data were collected in the plant during one production day on June 14th' 2017. Ravioli temperature was measured along the processing line from steam pasteurization to packaging. For those experiments, Progesplus 22T type thermo-buttons (precision ± 0.5 °C, temperature range 0–125 °C), previously calibrated at 4 different temperatures (5, 20, 40 and 60 °C) were used to support high temperatures of the pasteurization process. Four raviolis were placed on the conveyor before the pasteurization steps and collected at the exit of the cooling tunnel. This procedure was repeated 3 times. To identify the instrumented raviolis on the processing line and in the pouches, they were stained in green with dry spinach powder.

Then, the temperature change in packaged ravioli placed in a box was measured using Progesplus 22L type thermo-buttons described previously (part 2.3.1) in three pouches (250 g) during storage in the cold room over 20 h. Each pouch contained three instrumented raviolis.

The electric intensity I of the three phases feeding the compressor was measured using a clamp ammeter during the nominal operating conditions. Then, the absorbed electrical power, considered as the indicator of energy consumption of the refrigeration processes, was determined from Equation (1).

$$P_a = \frac{1}{3}\sum_{n=1}^{3} I_n \times U \times \cos\phi \quad (1)$$

As compressor is three-phase fed, the value of U and cos ϕ are 400 V and 0.8, respectively. The evaporating and condensing temperatures of refrigerant fluid were also measured.

2.4. Microbiological aspects

2.4.1. Analysis of packaged raviolis stored in isothermal conditions

Two hundred ravioli pouches from a processing batch were stored at four different temperatures, 3.2 °C, 4.3 °C, 8,0 °C and 10.0 °C (±0.2 °C). At each storage temperature, a thermo-button was placed in the middle of the flushed pouches (target 50% N_2 and 50% CO_2). Six pouches were analyzed at times 0, 2, 5, 8, 12, 16, 21, 28, 35 days at 10 °C and 8 °C, at times 0, 8, 12, 16, 21, 28, 35, 42, 49 days at 4.3 °C and at times 0, 12, 16, 21, 28, 35, 42, 49 days at 3.2 °C.

At each sampling time and for the six analyzed pouches, the concentrations of CO_2 and O_2 in the pouches were measured (see section 2.4.3), the visual aspect of the raviolis was recorded, the total aerobic microflora and naturally occurring *B. cereus* were enumerated (see section 2.4.4). Oxygen was always present in pouches (Fig. S2). Therefore, strict anaerobic microorganisms were not considered in the analysis.

2.4.2. Fate of B. cereus inoculated on ravioli during storage in isothermal conditions

The psychrotrophic strain of *B. cereus sensu lato* KBAB4, belonging to the species *B. weihenstephanensis* (Lapidus et al., 2008) was used for this study because of its good ability to grow at cold temperatures (Carlin et al., 2013; Guérin, Dargaignaratz, Broussolle, Clavel, & Nguyen-the, 2016). Its growth limits and cardinal parameters for temperature and pH had previously been determined in a rich laboratory medium (Carlin et al., 2013). To determine its maximal growth rate in raviolis, the KBAB4 strains was inoculated on raviolis and its growth monitored during 250 h storage at a single temperature of 10 °C. The stock culture stored at −80 °C of the KBAB4 strain was streaked onto Luria Bertoni (LB, Biokar) agar plates incubated at 30 °C, one colony was seeded into LB broth and grown overnight at 30 °C under agitation at 200 rpm. The

Table 1
Microbial parameters of the predictive model.

Growth parameters of *B.Cereus*			
T_{min} [°C]	Minimum temperature of growth	3.9	Carlin et al. (2013)
T_{opt} [°C]	Optimal temperature of growth	31.0	Carlin et al. (2013)
T_{max} [°C]	Maximum temperature of growth	40.9	Carlin et al. (2013)
$\mu_{opt;air}$ [h^{-1}]	Optimal growth rate under air conditions	0.77	Fitted
$\mu_{opt;N2/CO2}$ [h^{-1}]	Optimal growth rate under modified atmosphere conditions	~normal (0.39,0.05)[a]	Fitted
N_0 [CFU g^{-1}]	Initial level of contamination	$10^{\sim normal(-0.09,0.087)}$	measured
y_{max} [log_{10} CFU g^{-1}]	Maximum population density	7.5	Fitted
Prevalence (%)	Percentage of contaminated products	33	measured
Growth parameters of the total microflora			
T_{ref} [°C]	Reference temperature	25	Fixed
T_{min} [°C]	Minimum temperature of growth	−3.9	Fitted
$\mu_{opt;N2/CO2}$ [h^{-1}]	Optimal growth rate under modified atmosphere conditions	~normal (0.11,0.01)	Fitted
N_0 [CFU g^{-1}]	Initial level of contamination	$10^{\sim normal(1.1,0.9)}$	measured
y_{max} [log_{10} CFU g^{-1}]	Maximum population density	6.6	Fitted
Prevalence (%)	Percentage of contaminated products	100	measured

[a] normal distribution: ~normal (μ, σ) with μ and σ, the mean and the standard deviation, respectively.

culture was diluted 100-fold in sterile buffered peptone water (EPT, Biokar) to produce the inoculum suspension containing 8.9×10^5 CFU ml^{-1} *B. cereus*. Sampling of raviolis along the processing line at two different periods revealed an absence of microorganisms able to grow on ravioli at cold temperature just after pasteurization, and a progressive increase in microbial contamination, including *B. cereus*, along the processing line (Table S1). This indicated that microbial contamination occurred mostly from the plant environment and therefore on the surface of the ravioli and not in contact of the stuffing. To reproduce and control this contamination, 10 drops of 1 µL of the inoculum suspension were deposited sterilely on the surface of each ravioli with an automatic dispenser (Multipette E3, Eppendorf) under a sterile laminar air flow (resulting in approximately 2×10^3 CFU g^{-1} *B. cereus*). Non inoculated ravioli received 10 drops of 1 µL of sterile buffered peptone water. The pH of the ravioli pasta, without the stuffing, was of 6.5. After drying of the inoculum, the ravioli were dispatched in 1.5 L glass jars (70 raviolis in each jar) hermetically closed and equipped with a septum allowing sampling of the internal gaseous atmosphere. To reproduce the gaseous atmosphere measured in the ravioli pouches, four jars were flushed with a gas mixture of 0% O_2, 40% CO_2 and 60% N_2, generated in the laboratory from pure gases with an Alphagaz RMD 280 apparatus. Two jars contained the inoculated raviolis and two the non inoculated raviolis. The four jars were stored at 10.6 °C (±0.1 °C) for 10 days (a duration sufficient to measure the maximal growth rate of psychrotrophic *B. cereus*). The storage temperature was recorded by a SPY RF N2 instrument (JRI, instrument error ≤ 0.3 °C), calibrated against a reference thermometer. One sample of raviolis from each jar was analyzed for *B. cereus* and total aerobic microflora at each of the fifteen sampling times distributed along the storage period.

2.4.3. Measure of O_2 and CO_2 concentrations

Atmosphere into the jars or the pouches was analyzed by gas chromatography using a µGC (Agilent 3000 A) with two capillary columns (MS-5A and Poraplot) under argon and helium respectively and a TCD detector. The gas chromatograph was calibrated before each group of analysis with a reference mixture of 10% O_2, 10% CO_2 and 80% N_2 (Linde gas). Analysis were performed after each gas flushing and before opening the jars or the pouches to sample raviolis.

2.4.4. Total aerobic microflora and B. cereus enumeration in ravioli

To enumerate the total aerobic microflora and *B. cereus* in raviolis, between 25 and 30 g of raviolis were homogenized in 50 ml of sterile buffered peptone water. One hundred microliters of the appropriate dilution in sterile buffered peptone water homogenate were spread onto Plate Count Agar (PCA, Biokar) for total aerobic microflora and Bacara medium (Biomerieux) for *B. cereus*. PCA plates were incubated at room temperature (20–22 °C) while Bacara plates were incubated at 30 °C for 24 h and 48 h, respectively. Colonies on Bacara medium with the morphology characteristic of *B. cereus* were isolated for confirmation following the ISO-7932 standard.

2.4.5. Determination of microbial growth parameters

The value of the maximal growth rate (μ_{max}) is necessary to predict the microbial load change with time. μ_{max} can be related to temperature following the cardinal value model of Rosso, Lobry, and Flandrois (1993) (Equation (5)) for *B. cereus*, or the square root model (Mc Meekin, Olley, Ross, & Ratkowsky, 1993) for the total aerobic microflora (Equation (6)). The parameters T_{min}, T_{max}, T_{opt}, μ_{opt} and μ_{ref}, needed to calculate μ_{max} at any temperatures, were obtained from published studies or estimated in the present study (Results in section 3.1 and in Table 1). To estimate these values, data of the total aerobic microflora and *B. cereus* enumeration in ravioli stored in isothermal conditions were fitted using the model proposed by Baranyi and Roberts (1994) (Equations (2)–(4)) and the cardinal value model (Equation (5)) for *B. cereus* (the square root model for total aerobic microflora, Equation (6)). The Baranyi and Roberts' model allows the estimation of μ_{max} but also of the initial physiological state (Q_0) and the maximum population (y_{max}). Equations are described below.

$$\frac{dy(t)}{dt} = \frac{1}{1+e^{-Q(t)}} \times \mu_{max} \times (1 - e^{y - y_{max}}) \quad (2)$$

$$\frac{dQ(t)}{dt} = \mu_{max}(T) \quad (3)$$

$$y(0) = y_0 \text{ and } Q(0) = Q_0 \quad (4)$$

where y is the microbiological load (log_{10} CFU g^{-1}).

For *B.cereus*, the cardinal values were used (Rosso et al., 1993)

$$\mu_{max} = \frac{\mu_{opt}(T - T_{max})(T - T_{min})^2}{(T_{opt} - T_{min})\left[(T_{opt} - T_{min})(T - T_{opt}) - (T_{opt} - T_{max})(T_{opt} + T_{min} - 2T)\right]} \quad (5)$$

with μ_{opt} the optimal growth rate (in raviolis) and T_{min}, T_{opt} and T_{max}, the minimal, optimal, and maximal temperatures of growth (Carlin et al., 2013), respectively. For the total aerobic microflora, μ_{max} was calculated using.

$$\mu_{max} = \mu_{ref} \times \left(\frac{T - T_{min}}{T_{ref} - T_{min}}\right)^2 \quad (6)$$

with μ_{ref} and T_{ref} the reference growth rate and the reference temperature (25 °C), respectively.

2.4.6. Validation of the optimal growth rate of B. cereus

The growth parameters calculated for *B. cereus* KBAB4 on raviolis, with the isothermal growth experiments described in section 2.4.2, were validated in two replicate experiments under dynamic temperature profiles. For each of these experiments, raviolis were inoculated, placed under modified atmosphere in the same way as for the isothermal experiments and incubated successively 180 h at 10 °C, 60 h at 6 °C and 80 h at 10 °C. To evaluate the performance of the model in dynamic temperature, the percent relative errors (%RE) were used to minimized the discrepancy between the observed and predicted growth (Equation (7)). Results of the validation are presented in section 3.1.

$$\%\ relative\ error(RE) = \frac{\left(y_{observed} - y_{predicted}\right)}{y_{observed}} \times 100 \quad (7)$$

2.5. Modelling methodology

Modelling considered only the three steps involving refrigeration after the drying step (i.e. steam pasteurization, pre-drying and drying not included; Fig. 1). The model was developed as a discrete event framework to describe the consecutive steps of the processing line (i.e. cooling tunnel, pending during palletization, storage cold room). This framework was chosen because of its ability to modify the operating conditions of the process and to include the different study modules: a predictive microbiology module, a thermal module, and an energy consumption module. To account for the variability of the initial temperature of the product, cooling rates, initial level and growth of microorganisms, stochastic and deterministic models were coupled using the Monte Carlo method. 20,000 iterations were simulated; the percentage of products above the microbiological criteria was used to verify the model convergence. The model was implemented in the Matlab software R2016b (MathWorks Inc., Natick, MA, USA) and is available on request to the corresponding author.

2.5.1. Product temperature in the plant

The initial temperature was measured for 12 raviolis at the entrance of the air forced tunnel before cooling. Based on the plant data, a normal distribution was assumed to describe the initial temperature T_0 in Equation (8):

$$T_0 \sim norm(60.7; 1.7)\ [°C] \quad (8)$$

In the cooling tunnel and in the cold room steps, the temperature was predicted using Equation (9):

$$T_k(t) = T_{air,k} + \left(T_{0,k} - T_{air,k}\right) \times e^{-t/\tau_k}\ [°C] \quad (9)$$

with $k = 1$ in cooling tunnel, $k = 2$ in cold room, $T_{0,k}$ the product initial temperature at step k, t the time and τ_k the characteristic time of the product at step k. This characteristic time depends on the product properties, mass and form (heat capacity C, mass m, exchange surface with the ambient air A) and on the air velocity during the process through the convective heat transfer coefficient h. τ was determined from the slope of the curve (Fig. 4a) of the temperature expressed in dimensionless form $T^*\left(\frac{T(t)-T_a}{T_0-T_a}\right)$ in function of time (Fig. 4b). The variability of τ values, mainly due to the product position in a pallet, can be described by a uniform distribution. Based on the plant data, $\tau \sim unif(230; 300)$ sec for the cooling in the air forced tunnel and $\tau \sim unif(8670; 11280)$ sec in the cold room. τ in the packaging area was assumed to be equal to the one in the storage cold room since products are in similar environment conditions (packaged in boxes stacked on pallets).

2.5.2. Energy consumption in the plant

Due to the few available data from the food plant, it was not possible to develop an energy consumption model from the estimated or measurements heat load as in the previous studies (Brito et al., 2014; Duret et al., 2020; Evans et al., 2014). A simplified approach, considering only the absorbed electrical power of the cooling tunnel (CT) and the storage cold room (CR), was chosen to overcome this lack of information; the energy modelling methodology was developed from the measurements described in section 2.3.2. The conditions observed during the on-site measurements were defined as the baseline of this study. The relationship between the absorbed electrical power P_a and the refrigeration power $P_{r;ref}$ can be defined as follows in the nominal conditions:

$$P_{r;ref} = P_a \times \eta \times COP \quad (10)$$

With η the global performance coefficient of the cooling unit ($\eta = 0.5$, taking into account the irreversibility in the refrigerating machine) and the Carnot COP (Coefficient Of Performance of Carnot) representing the ratio of the useful cooling provided to the work required (not including thermodynamic irreversibility in the refrigerating machine). The Carnot COP can be calculated by:

$$COP = \frac{T_{cold}}{T_{hot} - T_{cold}} \quad (11)$$

with T_{cold} and T_{hot} the temperatures of the cold and hot sources, respectively. For the cooling tunnel, T_{cold} and T_{hot} were measured at 251 K (−22 °C) and 309 K (36 °C), respectively. For the cold room, T_{cold} and T_{hot} were measured at 266 K (−7 °C) and 315 K (42 °C), respectively. Given the operating temperatures during the on-sit measurements (external temperature of 304 K (31 °C), air temperature of 271 K (−2 °C) in the cooling tunnel and 278 K (5 °C) in the cold room), temperature pinches were determined (temperature difference between the air and the refrigerant in the heat exchanger). For the cooling tunnel pinches of 20 °C and 5 °C were found for the evaporator and the condenser, respectively. Pinches of 10 °C were found for both the evaporator and condenser in the cold room. It was assumed that temperature pinch is constant at all operating temperatures.

In order to take into account the modification of the thermostat setting temperature in the studied scenarios (cf. 2.6), the refrigeration power was adjusted assuming a negligible effect of radiation and hence a linearity in the thermal transfer according to temperature ratios. The estimated refrigerating power was considered as a ratio of the refrigerating power in the reference scenario. Different ratios were considered for the cooling tunnel and the cold room. Indeed, it is expected that most

Table 2
Studied scenarios on the ravioli processing line. Residence times of the product in the cooling tunnel and cold room are presented in Fig. 1.

Scenario	Simplified description	Cooling tunnel temperature, T_{CT} [°C]	Storage cold room temperature, T_{CR} [°C]
#1	Baseline – nominal running condition of the plant	−2	4
#2	Temperature increase of the cooling tunnel, $T_{CT} = 2$ °C	2	4
#3	Temperature increase of the cooling tunnel, $T_{CT} = 6$ °C	6	4
#4	Temperature increase of the cooling tunnel, $T_{CT} = 8$ °C	8	4
#5	Temperature increase of the cold room, $T_{CR} = 6$ °C	−2	6
#6	Temperature increase of both the cooling tunnel and the cold room, $T_{CT} = 8$ °C, $T_{CR} = 6$ °C	8	6

Table 3
Scenario for the post-processing cold chain, based on data from (Derens et al., 2006).

Temperatures (°C)		Residence time (days)	
Professional[a]	Domestic	Professional	Domestic
~normal[b](3.36; 1.26)	~normal (5.9; 2.9)	~normal (17.5; 3.4)	~exponential (4.32)

[a] Refrigerated transport, distribution and retail.
[b] normal distribution: ~normal (μ, σ); exponential distribution: ~exponential(μ), with μ and σ, the mean and the standard deviation, respectively.

of the heat load in the cooling tunnel is due to the products while in the cold room, the main heat load is due to the heat load from through the walls (Duret et al., 2020). Hence, the refrigerating powers for the cooling tunnel and the cold room were calculated from Eqs. (12) and (13), respectively.

$$P_r = P_{r,ref} \times \frac{mean(T_0) - mean(T_1)}{mean(T_0) - mean(T_{1,ref})} \quad (12)$$

With T_0 the initial product temperatures (Equation (8)), T_1 and $T_{1,ref}$, the products' temperature at the exit of the cooling tunnel in the tested scenario and the baseline scenario, respectively.

$$P_r = P_{r,ref} \times \frac{T_{ext} - T_{CR,th}}{T_{ext} - T_{CR,th,ref}} \quad (13)$$

With T_{ext}, the external temperature, $T_{CR,th}$ and $T_{CR,th,ref}$ the cold room setting temperatures in the tested and reference scenarios, respectively.

Finally, the absorbed electrical power P_a in the various scenarios can be deduced from Equation (12) or (13), based on the following equation (similar to Equation (10) by replacing $P_{r,ref}$ by P_r):

$$P_a = \frac{P_r}{\eta \times COP} \quad (14)$$

2.6. Description of studied scenarios

Six scenarios presented in Table 2 were simulated to evaluate the impact of the processing line conditions on the product temperature, quality, and energy consumption. The baseline scenario (#1) represents the nominal operating conditions of the plant with an air temperature of −2 °C in the cooling tunnel and a thermostat setting temperature of 4 °C in the cold room. In the other scenarios, the setting of thermostat temperatures of the cooling tunnel or the cold room were modified.

These six scenarios on the processing line were combined with a scenario representing the cold chain conditions in France (Table 3). This cold chain scenario was based on previously acquired field data from food plant to the consumer (Derens, Palagos, & Guilpart, 2006). In this cold chain scenario, the variability of the temperature and residence times for both the professional and domestic parts were described. Temperature distributions (°C) for the professional part (transport, distribution, retail) and the domestic part were modeled using normal distributions ~ normal (μ = 3.36; σ = 1.26) and ~normal (μ = 5.9; σ = 2.9), respectively. These distributions were fitted from the 314 curves available from the previous study, assuming that the temperature in the different parts of the cold chain were independent of the type of products (several types of processed foods were studied). However, for the residence time, data from a product with a shelf life similar to that of the raviolis were used to fit the distributions because the durations of the different steps of the cold chain depends on the shelf life. Hence, the distributions of the residence times (days) were modeled from 20 curves. The professional part was described by a normal distribution (~normal (μ = 17.5; σ = 3.4)) while the domestic part was represented by an exponential distribution (~exponential (μ = 4.32); Table 3).

3. Results and discussion

3.1. Characterization of the microbial contamination, growth, quality and safety parameters

3.1.1. Initial contamination

Initial prevalence and initial numbers (N_0) of total aerobic microflora and of *B. cereus* were determined from the analysis of the packaged raviolis stored in isothermal conditions (section 2.4.1). For total aerobic microflora the parameters were based on the analysis at time 0 of six packages of raviolis. The prevalence was 100% and the contamination

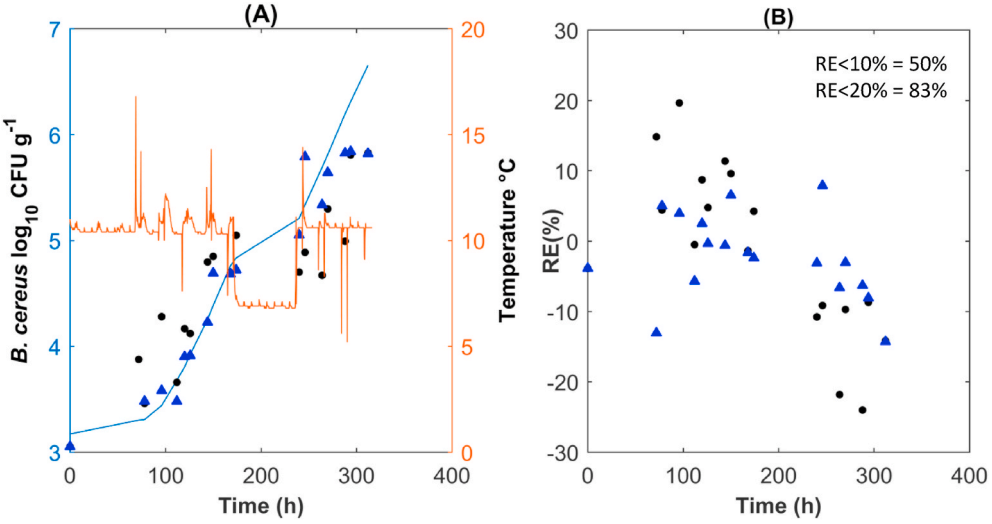

Fig. 3. (A) Comparison between the two observed repetitions (black points and blue triangles) and predicted (blue line) growth of *B. cereus* in raviolis under dynamic temperature profiles (orange line). (B) Corresponding percent relative error (%RE). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

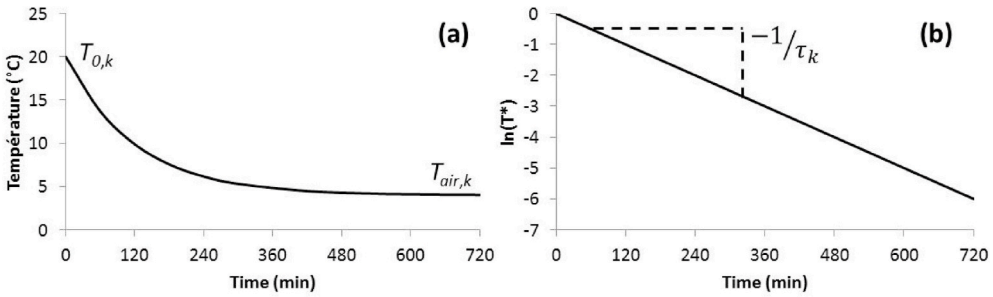

Fig. 4. Illustration of the method to calculate the characteristic time τ at the step k in the processing line. (a) Temporal evolution of product temperature. (b) The characteristic time τk can be calculated from the slope of the curve (H. M. Hoang, Flick, Derens, Alvarez, & Laguerre, 2012).

described by the distribution $10^{\sim normal(1.1,0.9)}$. For *B. cereus*, packages were analyzed at time 0 and after 35 days storage at the different refrigeration temperatures. No *B. cereus* were detected (i.e. numbers below the limit of detection of 39 CFU g^{-1}) in twelve packages analyzed at time 0, whereas *B. cereus* was counted in four packages out of the twelve analyzed after storage at 8–9 °C. We assumed that these four packages contained at least one *B. cereus* in the 250 g of ravioli at time 0 and that it multiplied during storage, whereas the eight others contained less than one *B. cereus* per 250 g ravioli at time 0. With this approach, prevalence and initial contamination (N_0) estimation was restricted to those *B. cereus* able to grow at the refrigeration temperatures tested, consistently with the temperatures considered in the scenarios (Table 2). The prevalence of *B.cereus* was hence of 33% and the initial contamination was represented by the distribution $10^{\sim normal(-0.09,0.087)}$ (Table 1).

3.1.2. Microbial growth on ravioli

The total aerobic microflora increased on raviolis at all storage temperatures (Fig. S1). Spoilage, small white patches on raviolis without any swelling of the pouches nor off-odours, appeared on raviolis containing at least 10^6 CFU g^{-1} total aerobic microflora per g. Gas flushing at packaging in the plant created an atmosphere of ~3% O_2 and ~35% CO_2 inside the ravioli packages (Fig. S2). Gas flushing of the glass jars in the laboratory to measure growth of *B. cereus* on raviolis, reproduced this atmosphere composition, albeit with less variations (Fig. S3). It represented the best in plant flushing conditions. Growth of the psychrotrophic strain of *B. cereus* on raviolis under this gaseous atmosphere is shown in Fig. S4.

Microbial growth parameters for the total aerobic microflora and *B. cereus* (Table 1) were calculated as described in section 2.4.5, from the experimental results presented in this section and literature data.

3.1.3. Microbial growth model validation

Validation experiments of the microbial growth model are described in section 2.4.6. Observed and predicted microbial growth of the three validation experiments as well as the relative errors are presented in Fig. 3. 50% of the points fall in the ±10% error zone and 89% of the points fall in the ±20% zone. Overall, at least 50% and 83% of the points fall into the 10% and 20% zone for all conditions. It can be noted that most of the points at the end of the growth (>250 h) are above and close to the 20%. This may be explained by the values of the maximum population which is impacted by the total microflora (through Jameson effect). However, in our case, the impact of the model results is limited as the value of 5 $\log_{10}$ CFU g^{-1} has been chosen as the threshold quality criteria for *B. cereus* (see section 3.1.4). Finally, due to the high variability of the population type of the total microflora, the growth model of the total microflora could not be validated on another batch of ravioli. Characterization of the extent of this variability would have required important experimental resources.

This predictive microbial model used is function of the temperature only, other parameters such as water activity could have been considered. However, as the steam pasteurization, pre-drying and drying processes were controlled; the initial variability of the water activity was neglected in this study. Moreover, no water exchange through the packaging was expected. Hence, it was assumed that the water activity of the product did not vary over time through the cold chain. Finally, as the growth rates (μ_{opt}, *B.cereus* and μ_{ref}, *total flora*) were determined from experiments conducted on the products, the effect of the water activity (and its variability) is indirectly taken into account in their distributions.

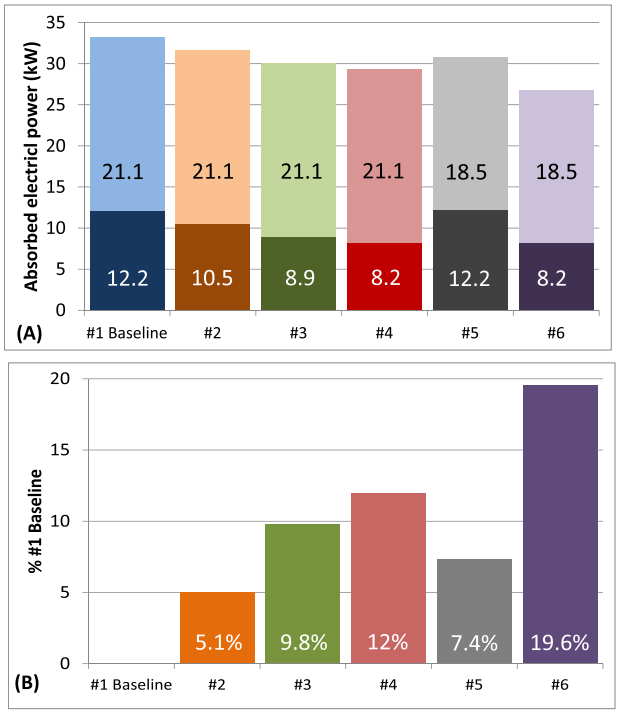

Fig. 5. (A) Absorbed electrical consumption (kW) of the cooling tunnel (dark color) and the cold room (faded color) for the six scenarios. (B) Percentage of total energy reduction (tunnel and cold room) in comparison with the baseline scenario #1. Scenarios #1 corresponds to the baseline of this study with a temperature of the cooling tunnel (T_{CT}) and of the cold room (T_{CR}) of −2 °C and 4 °C, respectively. In scenarios #2, #3 and #4 temperature of the cooling tunnel was modified to 2 °C, 6 °C and 8 °C, respectively. In scenarios #5 cold room temperature was modified to 6 °C. In scenario #6 T_{CT} = 8 °C and T_{CR} = 6 °C. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

3.1.4. Quality and safety parameters

The threshold of total aerobic microflora associated with spoilage of ravioli (see section 3.1.2), *i.e.* 10^6 CFU g^{-1} was fixed as quality parameter with products lower considered acceptable and product higher considered non acceptable. Moreover, a maximum limit of 10^6 CFU g^{-1}

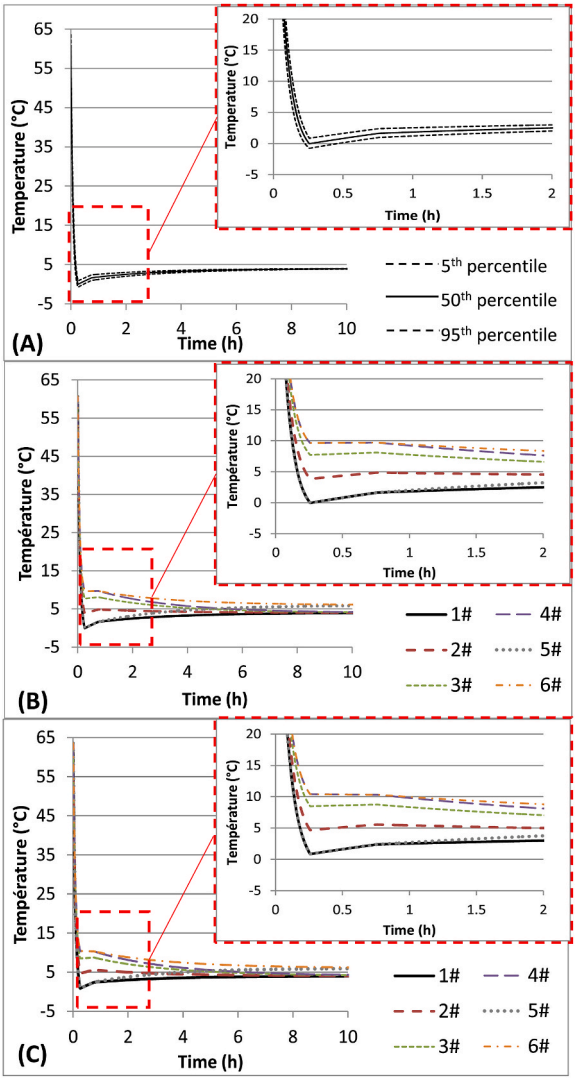

Fig. 6. (A) Temperature evolution of the raviolis during cooling and storage in the cold room for the baseline scenario (#1) with the mean temperature (black line) and 95th percentile (dashed lines). (B) Products median temperature of the 6 scenarios. (C) Products 95th percentile of the temperature for the 6 scenarios. Scenarios #1 corresponds to the baseline of this study with a temperature of the cooling tunnel (T_{CT}) and of the cold room (T_{CR}) of −2 °C and 4 °C, respectively. In scenarios #2, #3 and #4 temperature of the cooling tunnel was modified to 2 °C, 6 °C and 8 °C, respectively. In scenarios #5 cold room temperature was modified to 6 °C. In scenario #6 T_{CT} = 8 °C and T_{CR} = 6 °C.

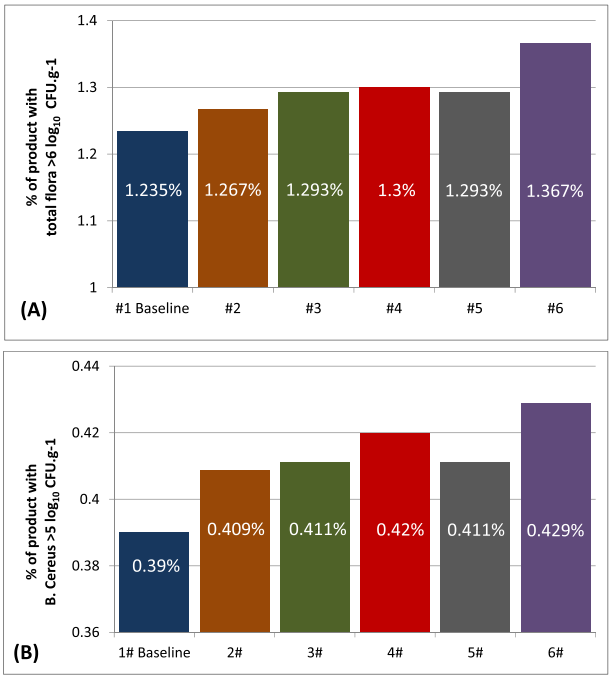

Fig. 7. Percentage of products with the total flora >6 $\log_{10}$ $CFUg^{-1}$ (A) and *B. cereus* > 5 $\log_{10}$ $CFUg^{-1}$ (B) in the 6 processing scenarios combined with the realistic post-processing cold chain scenario. Scenarios #1 corresponds to the baseline of this study with a temperature of the cooling tunnel (T_{CT}) and of the cold room (T_{CR}) of −2 °C and 4 °C, respectively. In scenarios #2, #3 and #4 temperature of the cooling tunnel was modified to 2 °C, 6 °C and 8 °C, respectively. In scenarios #5 cold room temperature was modified to 6 °C. In scenario #6 T_{CT} = 8 °C and T_{CR} = 6 °C.

total aerobic microflora at the end of shelf life is also applied as a specification by French retailers for fresh pasta packaged after heat treatment (FCD, 2019). For *B. cereus,* it is considered as non acceptable products containing more *B. cereus* than the "alert limit" of 10^5 CFU g^{-1} fixed by the French government (DGAL, 2009).

3.2. Scenarios analysis

3.2.1. Energy

The absorbed electrical consumption of the refrigeration process of the different scenarios is shown on Fig. 5A. In the baseline scenario, the absorbed electrical power of the refrigeration processes of the cooling tunnel and the cold room are 12.2 kW and 21.1 kW, respectively. The absorbed electrical power of the cooling tunnel can be reduced to 8.9 kW if the thermostat is increased to 8 °C (−2 °C in the baseline scenario). It corresponds to a reduction of 12% of the total absorbed electrical power (cooling tunnel and the cold room) (scenario #4; Fig. 5B). Changing the thermostat temperature of the cold room from 4 °C to 6 °C reduces the absorbed electrical power from 21.1 kW to 18.5 kW (scenario #5), this corresponds to a 12% reduction for the cold room alone and 7% for the total absorbed power. Changing both thermostat temperature of the cooling tunnel and the cold room to 8 °C and 6 °C respectively would reduce the total absorbed power by 19.7%. As expected, the minimum energy consumption was found for scenario #6, however, the product temperature may be too high and the food microbiological quality cannot be assured. This will be presented in the following sub-sections.

3.2.2. Temperature

The product temperature evolution in the processing line for the baseline scenario (#1) is presented in Fig. 6A. The cooling step, the pending for packing and the storage in the cold room can clearly be identified in the figure. Low variability of the temperature during cooling is observed (±0.5 °C) meaning that the airflow is homogeneous during this step. A slight temperature increase is observed in the pending zone during palletization and then in the cold room. In other word, the cooling decreases product temperature to a level lower than that of the cold room, and might be optimized through an increase of the thermostat temperature of the tunnel. In Fig. 6B and C, the median and the 95th percentile of product temperatures of the different scenarios are shown, respectively. Setting the temperature of the cooling tunnel at 2 °C in scenario #2 (instead of −2 °C in the baseline) would cool down the product to a temperature close to that in the cold room. For a cold room temperature of 6 °C (scenarios #5 and #6), product temperature reaches 6 °C in around 6 h, for scenario #5, and 8 h for scenario #6 after the cooling. It can be noted that the air temperature of the cooling tunnel can be increased up to 8 °C (scenarios #4 and #6) in order to decrease product temperature below 10 °C within 2 h (Fig. 6B and C). Indeed, product temperature has to decrease below 10 °C in less than 2 h in order to comply with the French Guide of Good Manufacturing Processes for

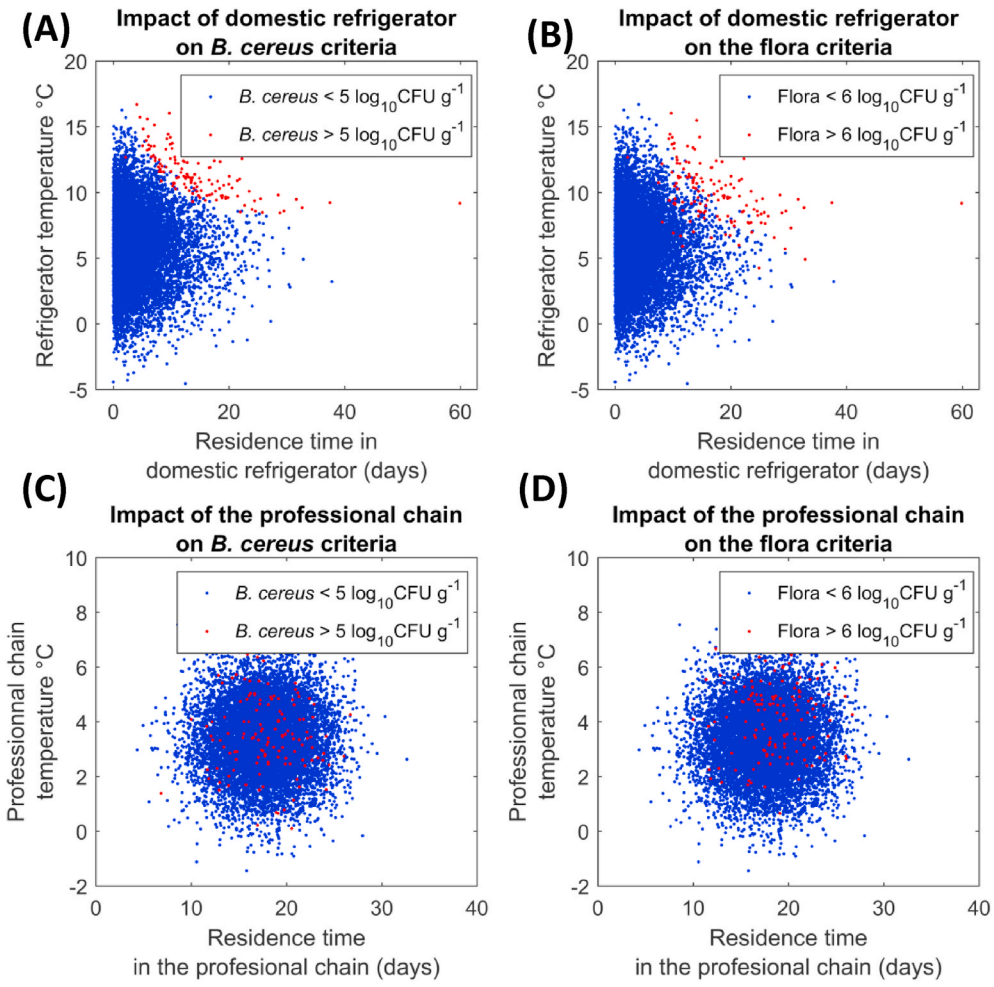

Fig. 8. Distribution of the products in the realistic post-processing cold chain, with the baseline processing scenario (#1). Impact of the residence time and temperature conditions in the domestic chain on products exceeding safety criteria (*B. cereus* >5 $\log_{10}$ CFU g^{-1} - A) and quality criteria (Total flora >6 $\log_{10}$ CFU.g^{-1}- B). Impact of the residence time and temperature conditions in the professional chain on products exceeding safety criteria (*B. cereus* >5 $\log_{10}$ CFU g^{-1} - C) and quality criteria (Total flora >6 $\log_{10}$ CFU g^{-1} - D).

cooked/pasteurized chilled foods (Synafap, 2011). In scenarios with the cooling tunnel temperature set at 6 °C (#3) and 8 °C (#4 and #6), the end of the cooling was reached in the cold room. However, as products were packed in boxes and placed in pallet, the thermal inertia was important and temperature decreases were slow. For this reason, the choice of the setting temperature has to take into account the impact on the microbiological quality of the products.

3.2.3. *Microbiological quality*

In order to evaluate the microbial quality of the food product, the % of products above a threshold was considered. This threshold was fixed as the French food safety alert limit of 5 $\log_{10}$ CFU g^{-1} for *B.cereus* (DGAL, 2009) and 6 $\log_{10}$ CFU g^{-1} for the total flora corresponding to the maximum population without noticeable spoilage (section 3.1.4).

The baseline cold chain processing scenario (#1 in Table 2) resulted in 1.24% of products at consumption with aerobic microflora >6 $\log_{10}$ CFU.g^{-1} and 0.39% with *B. cereus* > 5$\log_{10}$ CFU.g^{-1} (Fig. 7). The products exceeding the quality and safety criteria are presented in red in Fig. 8. They correspond to a combination of higher storage temperature and longer residence times in the domestic cold chain (upper panels) whereas they are evenly distributed over the range of conditions of the professional cold chain (lower panel), indicating that exceeding the limits is due to conditions in the domestic and not the professional part of the post processing cold chain.

Increasing the thermostat setting temperature of the cooling tunnel, although a short process (15min), impacts the final microbiological quality of the products, with % defective products increasing for total flora/*B. cereus* from 1.24/0.39 to 1.30/0.42 when shifting cooling temperature from −2 °C (#1) to 2 °C (#2), 6 °C (#3) and 8 °C (#4) (Fig. 7). Indeed, after product packing and filling in boxes, the product temperature decrease is low particularly at certain positions in a pallet, due to low air circulation in the box and the product thermal inertia. Increasing cold room temperature to 6 °C without changing cooling temperature (#5) resulted in percentage of defective products similar to increasing cooling temperature to 6 °C without changing cold room temperature (#3). In scenario #5, products packaged in boxes stacked on pallets warmed up slowly to 6 °C by the end of cold room storage (Fig. 6) and cooled down slowly in the professional post processing chain, resulting in several hours over the temperature of the baseline scenario (#1). However, scenario #5 saved less energy than scenario #3 (Fig. 5), which support the option of acting on the cooling tunnel rather than on the cold room. Increasing both cooling tunnel and cold room temperatures (#8, T_{CP} = 8 °C and T_{CR} = 6 °C) caused the highest percentage of defective product, 1.37 and 0.43 for respectively total flora and *B. cereus* (Fig. 7), a ~10% increase from baseline scenario #1.

4. General discussion

The energy consumption of the refrigeration processes can represent 30% of the electricity consumption of the food industry (Monforti-Ferrario et al., 2015). One simple way to reduce the energy consumption of the refrigeration processes is to increase the thermostat setting temperatures. However, this practice is difficult to apply as it can lead to the product temperature increase and thus, the microbial growth. For this reason, in order to optimize the thermostat temperature of the refrigerating equipment such as the cooling tunnel and storage cold

rooms, the quantification of the different impacts of such actions is needed. In this context, numerical tool can assist decision making as experiments in field conditions are difficult to conduct because of the high number of situations encountered (e.g. external temperatures, outages, thermostat setting temperature) and the cost to harvest the relevant data.

Modelling studies have to account for the available data. In Duret et al. (2020), it was possible to develop a model using plant design (wall surfaces, composition), number of product manufactured, operating conditions such as external temperature and thermostat setting temperatures, as well as weekly energy consumption over one year. However, from our experience, few food plants have such available data. Thus, although desirable, the applicability of such methodology is limited. In the present study, a thermal and energy models based on measurement conducted during one day were developed, with no additional data provided by the food stakeholder. The objective was to develop a methodology that can be broadcast and applied to most of food plants. Regarding the evaluation of the microbiological quality, a specific microbial model was developed in this study for the food product, to evaluate the growth of *B. cereus* and the total microflora. Such model development can limit the broadcasting of the methodology, however, database such as Combase (https://www.combase.cc) or Sym'previus (http://symprevius.eu/fr/) provides growth rates and cardinal values of microbial pathogens and libraries continue to be developed with more microbial/matrix couples.

The present study shows that an optimized temperature management in the processing plant can reduce the absorbed electrical power to ~20% with a ~10% increase of defective products, on the microbiological quality at the 'use by' date. This microbiological impact depends on the post-processing cold chain conditions, which can differ markedly from the processor recommendation, stressing the need for cold chain data in real situation for a wide range of products. To maintain microbial quality, an improvement of domestic storage conditions, as they account for the defective products would be necessary. However, this is presumably out of reach of the product manufacturer alone. To decide which of the scenarios is preferable, food business operators can simply benchmark the two outputs of the global model. They could also establish their decision more objectively by applying multi-criteria decision analysis. In this situation, weights would have to be attributed to the importance of energy saving and the importance of defective products, the different scenarios could then be ranked according to these weights (Duret et al., 2018). Finally, food business operator could also decide to apply one of the scenario to save energy and to shorten the 'use by' date to maintain the percentage of detective product.

The solutions to reduce energy consumption based on the modification of the thermostat temperature can have other applications. It can be used to manage unexpected events such as process outages or heatwave that may induce cooling tunnel frosting or higher temperature during cooling and storage due to limited refrigeration power.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodcont.2021.108076.

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References

Baranyi, J., & Roberts, T. A. (1994). A dynamic approach to predicting bacterial growth in food. *International Journal of Food Microbiology, 23*(3), 277–294. https://doi.org/10.1016/0168-1605(94)90157-0

Ben-abdallah, R., Leducq, D., Hoang, H. M., Pateau, O., Ballot-Miguet, B., Delahaye, A., et al. (2018). Modeling and experimental investigation for load temperature prediction at transient conditions of open refrigerated display cabinet using Modelica environment. *International Journal of Refrigeration, 94*, 102–110. https://doi.org/10.1016/j.ijrefrig.2018.02.017

Brito, P., Lopes, P., Reis, P., & Alves, O. (2014). Simulation and optimization of energy consumption in cold storage chambers from the horticultural industry. *International Journal of Energy and Environmental Engineering, 5*(2), 88. https://doi.org/10.1007/s40095-014-0088-2

Carlin, F., Albagnac, C., Rida, A., Guinebretière, M.-H., Couvert, O., & Nguyen-the, C. (2013). Variation of cardinal growth parameters and growth limits according to phylogenetic affiliation in the *Bacillus cereus* Group. Consequences for risk assessment. *Food Microbiology, 33*(1), 69–76. https://doi.org/10.1016/j.fm.2012.08.014

Chaomuang, N., Flick, D., & Laguerre, O. (2017). Experimental and numerical investigation of the performance of retail refrigerated display cabinets. *Trends in Food Science & Technology, 70*, 95–104. https://doi.org/10.1016/j.tifs.2017.10.007

Coldrey, P., Moureh, J., Alvarez, G., Leducq, D., Foster, A., Youbi-Idrissi, M., … Evans, J. (2018). *Numerical study of airflow and temperature distribution in a loaded cold store.* Paper presented at the Foodsim' 2018, Ghent, Belgium.

Del Torre, M., Della Corte, M., & Stecchini, M. L. (2001). Prevalence and behaviour of *Bacillus cereus* in a REPFED of Italian origin. *International Journal of Food Microbiology, 63*(3), 199–207. https://doi.org/10.1016/S0168-1605(00)00421-9

Derens, E., Palagos, B., & Guilpart, J. (2006). *The cold chain of chilled products under supervision in France*. Paper presented at the IUFOST, 13th world congress of food science & technology "Food is life", Nantes, 17-21 septembre 2006 https://hal.inrae.fr/hal-02588805.

DGAL. (2009). *Révision et publication du Guide de gestion des alertes d'origine alimentaire.* NOTE DE SERVICE DGAL/MUS/N2009-8188, Date: 07 juillet 2009. Paris.

Duret, S., Hamon, E., Hoang, H.-M., Stahl, V., Derens-Bertheau, E., Delahaye, A., et al. (2020). Modelling methodology of temperature and energy consumption in food plant: Application to puff pastry. *International Journal of Refrigeration, 115*, 28–38. https://doi.org/10.1016/j.ijrefrig.2020.03.009

Duret, S., Hoang, H.-M., Derens-Bertheau, E., Delahaye, A., Laguerre, O., & Guillier, L. (2018). Combining quantitative risk assessment of human health, food waste and energy consumption: The next step in the development of the food cold chain? *Risk Analysis, 39*(4), 906–925. https://doi.org/10.1111/risa.13199

Duret, S., Hoang, H.-M., Flick, D., & Laguerre, O. (2014). Experimental characterization of airflow, heat and mass transfer in a cold room filled with food products. *International Journal of Refrigeration, 46*, 17–25. https://doi.org/10.1016/j.ijrefrig.2014.07.008

EFSA. (2005). Opinion of the scientific panel on biological hazards on *Bacillus cereus* and other *Bacillus* spp in foodstuffs. *The EFSA Journal, 175*, 1–48.

Evans, J. A., Foster, A. M., Huet, J. M., Reinholdt, L., Fikiin, K., Zilio, C., . ., van Sambeeck, T. W. M. (2014). Specific energy consumption values for various

refrigerated food cold stores. *Energy and Buildings, 74*, 141–151. https://doi.org/10.1016/j.enbuild.2013.11.075

FCD. (2019). *Critères microbiologiques applicables à partir de 2020 aux marques de distributeurs, marques premiers prix et matières premières dans leur conditionnement initial industriel*. Fédération du Commerce et de la Distribution, Version du 15/11/2019 applicable à partir de Janvier 2020.

Gruyters, W., Verboven, P., Delele, M., Gwanpua, S. G., Schenk, A., & Nicolaï, B. (2018). A numerical evaluation of adaptive on-off cooling strategies for energy savings during long-term storage of apples. *International Journal of Refrigeration, 85*, 431–440. https://doi.org/10.1016/j.ijrefrig.2017.10.018

Guérin, A., Dargaignaratz, C., Broussolle, V., Clavel, T., & Nguyen-the, C. (2016). Combined effect of anaerobiosis, low pH and cold temperatures on the growth capacities of psychrotrophic *Bacillus cereus*. *Food Microbiology, 59*, 119–123. https://doi.org/10.1016/j.fm.2016.05.015

Guillier, L., Duret, S., Hoang, H.-M., Flick, D., & Laguerre, O. (2016). Is food safety compatible with food waste prevention and sustainability of the food chain? *Procedia Food Science, 7*, 125–128. https://doi.org/10.1016/j.profoo.2016.05.001

Guinebretiere, M. H., Thompson, F. L., Sorokin, A., Normand, P., Dawyndt, P., Ehling-Schulz, M., … De Vos, P. (2008). Ecological diversification in the *Bacillus cereus* group. *Environmental Microbiology, 10*(4), 851–865. https://doi.org/10.1111/j.1462-2920.2007.01495.x

Hoang, H.-M., Duret, S., Flick, D., & Laguerre, O. (2015). Preliminary study of airflow and heat transfer in a cold room filled with apple pallets: Comparison between two modelling approaches and experimental results. *Applied Thermal Engineering, 76*, 367–381. https://doi.org/10.1016/j.applthermaleng.2014.11.012

Hoang, H. M., Flick, D., Derens, E., Alvarez, G., & Laguerre, O. (2012). Combined deterministic and stochastic approaches for modelling the evolution of food products along the cold chain. Part II: A case study. *International Journal of Refrigeration, 35*(4), 915–926. https://doi.org/10.1016/j.ijrefrig.2011.12.009

James, S. (1996). The chill chain "from carcass to consumer". *Meat Science, 43*, 203–216. https://doi.org/10.1016/0309-1740(96)00066-6

Jouhara, H., Nannou, T., Ghazal, H., Kayyali, R., Tassou, S. A., & Lester, S. (2017). Temperature and energy performance of open refrigerated display cabinets using heat pipe shelves. *Energy Procedia, 123*, 273–280. https://doi.org/10.1016/j.egypro.2017.07.240

Laguerre, O., Chaomuang, N., Dinis Gaspar, P., & Dinho da Silva, P. (2019). Closed refrigerated display cabinets: Is it worth it for food quality? *Novel Technologies and Systems for Food Preservation*, 1–23. IGI Global http://doi:10.4018/978-1-5225-7894-9.ch001.

Laguerre, O., & Flick, D. (2010). Temperature prediction in domestic refrigerators: Deterministic and stochastic approaches. *International Journal of Refrigeration, 33*(1), 41–51. https://doi.org/10.1016/j.ijrefrig.2009.09.014

Lapidus, A., Goltsman, E., Auger, S., Galleron, N., Segurens, B., Dossat, C., … Sorokin, A. (2008). Extending the *Bacillus cereus* group genomics to putative food-borne pathogens of different toxicity. *Chemico-Biological Interactions, 171*(2), 236–249. https://doi.org/10.1016/j.cbi.2007.03.003

Logan, N. A., & De Vos, P. (2009). Genus I. Bacillus. In P. De Vos, G. M. Garrity, D. Jones, N. R. Krieg, W. Ludwig, F. A. Rainey, et al. (Eds.), *BERGEY'S MANUAL OF systematic bacteriology second edition volume three the firmicutes* (pp. 21–128). Dordrecht: Springer.

Mc Meekin, T. A., Olley, J. N., Ross, T., & Ratkowsky, D. A. (1993). *Predictive microbiology - theory and application*. New York: Wiley.

Monforti-Ferrario, F., Dallemand, J.-F., Pinedo Pascua, I., Motola, V., Banja, M., Scarlat, N., … Renzulli, P. A. (2015). *Energy use in the EU food sector: State of play and opportunities for improvement EUR - Scientific and Technical Research Reports*.

Moureh, J., Tapsoba, M. S., & Flick, D. (2009). Airflow in a slot-ventilated enclosure partially filled with porous boxes: Part I measurements and simulations in the clear region. *Computers & Fluids, 38*(2), 194–205. https://doi.org/10.1016/j.compfluid.2008.02.006

Rosso, L., Lobry, J. R., & Flandrois, J. P. (1993). An unexpected correlation between cardinal temperatures of microbial growth highlighted by a new model. *Journal of Theoretical Biology, 162*(4), 447–463. https://doi.org/10.1006/jtbi.1993.1099

Santé-Publique-France. (2019). *Surveillance des toxi-infections alimentaires collectives. Données de la déclaration obligatoire*. Santé Publique France, 2018. Point de Janvier 2019 https://www.santepubliquefrance.fr/maladies-et-traumatismes/maladies-infectieuses-d-origine-alimentaire/toxi-infections-alimentaires-collectives/documents/bulletin-national/surveillance-des-toxi-infections-alimentaires-collectives.-donnees-de-la-declaration-obligatoire-2018, 2019. (Accessed 23 November 2020).

Synafap. (2011). *Guide de bonnes pratiques d'hygiène et d'application des principes HACCP des entreprises fabricantes de produits traiteurs frais et réfrigérés*. La Documentation française. https://agriculture.gouv.fr/sites/minagri/files/documents/pdf/Partie_1_de_Produits_traiteurs_frais_refrigeres_5951_sept2011_cle4bea21.pdf. Les éditions des Journaux officiels. (Accessed 23 November 2020).

Tassou, S. A., Lewis, J. S., Ge, Y. T., Hadawey, A., & Chaer, I. (2010). A review of emerging technologies for food refrigeration applications. *Applied Thermal Engineering, 30*(4), 263–276. https://doi.org/10.1016/j.applthermaleng.2009.09.001

Webb, M. D., Barker, G. C., Goodburn, K. E., & Peck, M. W. (2019). Risk presented to minimally processed chilled foods by psychrotrophic *Bacillus cereus*. *Trends in Food Science & Technology, 93*, 94–105. https://doi.org/10.1016/j.tifs.2019.08.024

Zanoni, S., & Zavanella, L. (2012). Chilled or frozen? Decision strategies for sustainable food supply chains. *International Journal of Production Economics, 140*(2), 731–736. https://doi.org/10.1016/j.ijpe.2011.04.028