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Packaging for Food Preservation

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Packaging for Food Preservation

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Matteo Alessandro Del Nobile
Department of Agricultural Sciences
Food and Environment (SAFE)
University of Foggia
Foggia, Italy

Amalia Conte
Department of Agricultural Sciences
Food and Environment (SAFE)
University of Foggia
Foggia, Italy

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Preface

The food industry faces the task of satisfying increasing consumer demands for food that keeps as long as possible while maintaining the required quality. The development of effective scientific and commercial strategies for meeting these goals is not easy. Various technologies and ingredients are used to meet levels of product quality, but it is difficult to test them for the purpose of assessing how food quality will be maintained over the products' intended shelf life. Packaging can play a key role in food product preservation. Therefore, efforts to improve the performances of packaging solutions and preserve food freshness have been spearheaded in diverse fields. Packaging is usually a composite item meeting various needs, and its design is clearly a fundamental part of new products. Considering the importance of packaging in determining product shelf life, the correct approach entails considering, on the same level of importance, product development and its packaging system. This book addresses important issues associated with the nature of packaging and the shelf life characteristics of some important food types. Such information must be organized and made accessible to the target audience.

Three main topics of food packaging are presented and discussed. In particular, a complete overview of mass transport phenomena in polymers intended for food packaging applications is discussed in depth in the first section. With a strong emphasis on principles, this section provides a solid and comprehensive framework for students and practitioners in that it covers the basic concepts of packaging permeation and provides references commonly used to teach packaging. Students will find the first three chapters an excellent base on which to build their understanding of other, more complicated, explanations of the theory of permeation. The second section describes the most relevant approaches to developing eco-friendly active packaging, including recent fabrication methods and technical information on the advantages and limits of techniques, and the underlining systems that could find application in food. The last section surveys how packaging can help prolong shelf life. The strategies are described using different case studies of various food categories. Much of the content relates to the key issues of the microbial and chemical stability of foods and of the sensory changes that occur in foods in storage. The last four chapters of the book carefully examine issues related to how the quality of raw materials, process conditions, the internal environment created by the packaging system, and the external environment in which food is stored come together to influence the changes that occur in food during storage.

We sincerely hope that this book will help researchers and workers in the many fields related to food packaging, to understand the relevant issues and stimulate further insights.

Foggia, Italy Matteo Alessandro Del Nobile
Foggia, Italy Amalia Conte

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Part I
Shelf Life Modeling of Packaged Food

The purpose of this section is to review the basic concepts of shelf life (SL) modeling. First, the general approach will be provided. Direct and mechanistic models will be presented and discussed separately. In particular, the elements of a mechanistic model will be analyzed in detail by presenting the main information available in the literature. Models related to package mass transport properties and the process of food degradation will also be reported. The last part of this chapter will be focused on how package mass transport properties and food degradation process equations can be combined to predict food shelf life.

What is SL modeling about? It is generally recognized that a SL model is a useful tool either for predicting or simply calculating the SL of packaged foods. To do these things, first, a quantitative measure of food quality is needed, then a threshold value for it must be set, but what is needed most is a function that relates food quality to storage time. This section will be concerned with finding the relationship between food quality and storage time.

Actually, there are two possible ways to approach this problem. The fastest way to derive a SL model is to directly provide an equation that relates the packaged-food quality to storage time (i.e., direct model). Several types of direct models appear in the literature. Polynomial equation (I.1), exponential equation (I.2), and power law function equation (I.3) reported, in what follows, are a few examples:

$$\mathrm{FQ(t)} = \mathrm{a_0} + \mathrm{a_1} \cdot \mathrm{t} + \mathrm{a_2} \cdot \mathrm{t^2} + \ldots\ldots.. + \mathrm{a_n} \cdot \mathrm{t^n}, \tag{I.1}$$

$$\mathrm{FQ(t)} = \mathrm{a_0} \cdot \exp(-\mathrm{a_1} \cdot \mathrm{t}), \tag{I.2}$$

$$\mathrm{FQ(t)} = \mathrm{a_0} \cdot \mathrm{t^{a_1}} \tag{I.3}$$

where FQ(t) is the packaged-food quality, $\mathrm{a_i}$ are the fitting constants, and t is the storage time. Generally, the direct model's parameters (i.e., $\mathrm{a_i}$) do not have any particular physical meaning since these models are not based on a specific picture of the phenomena involved in food degradation.

The mechanistic approach is the other way to find the relationship between food quality and storage time (i.e., to derive a SL model). It consists in first identifying all the phenomena involved in the deterioration process that affect the packaged food during storage, then in providing a quantitative description for each of them, and finally in combining all this information into a single set of equations, which are generally differential equations. The phenomena involved in packaged food degradation can be clustered into two main groups: mass transport properties of the package and food deterioration mechanisms. As an example, the equation used to determine the amount of low molecular weight compound exchanged between the inside and outside of a flexible package under steady-state conditions has the following form:

$$J_{SS} = P \cdot \frac{\Delta p}{\ell}, \tag{I.4}$$

where J_{SS} is the steady-state permeant mass flux, P is the permeability coefficient of the packaging film, Δp is the permeant partial pressure across the packaging film, and ℓ is the packaging film thickness. As an example of a packaged-food deterioration mechanism, the extent of the oxidation reaction rate, Ext(t), of dry foods is reported as a function of the extent of oxidation reaction, water vapor partial pressure, $p_W^{in}(t)$, and oxygen partial pressure, $p_{O_2}^{in}(t)$, in the package headspace (Labuza 1971):

$$\frac{dExt(t)}{dt} = mp \cdot \left(Ext + \frac{M_1 + M_2 \times Ext(t)}{\sqrt{\frac{p_W^{in}(t)}{p_W^*} \times 100}} \right) \cdot \left(\frac{p_{O_2}^{in}(t)}{M_3 + M_4 \times p_{O_2}^{in}(t)} \right) \tag{I.5}$$

where mp is the mass of packaged food, p_W^* is the equilibrium water vapor pressure, and M_i are the model's parameters.

Generally, the aforementioned elements are integrated by means of balance equations, usually mass balance equations, which combine the package mass transport properties with the packaged-food deterioration mechanisms. Actually, the SL model is a set of equations, usually differential equations, composed of relationships describing the package mass transport properties, the food deterioration mechanisms, and the balance equations, where the food quality indices are unknown functions. Continuing with the example of dry foods, the oxygen and water mass balance equation in the package headspace is as follows:

$$\frac{dn_{O_2}^{ins}(t)}{dt} = A \times J_{O_2} - R_{O_2} \tag{I.6}$$

$$\frac{dn_{H_2O}^{ins}(t)}{dt} = A \times J_{H_2O}, \tag{I.7}$$

where $n_{O_2}^{ins}(t)$ and $n_{H_2O}^{ins}(t)$ are the number of oxygen and water moles inside the package, respectively; J_{O_2} and J_{H_2O} are the oxygen and water mass flux through the package, respectively; A is the surface area of the package; and R_{O_2} is the oxidation rate given by Eq. I.5. In this specific case, the SL model is composed of Eqs. I.5, I.6, and I.7 and has unknown functions such as Ext(t), $p_{H_2O}^{in}(t)$, and $p_{O_2}^{in}(t)$. The former two functions are the packaged-food quality indices. Solving the aforementioned set of differential equations it is possible to find the relationship between food quality [i.e., Ext(t), $p_{H_2O}^{in}(t)$] and storage time.

As expected, advantages and disadvantages are associated with these two approaches. Normally direct models are simple and empirical and are usually used to calculate SL by means of either data interpolation or small-scale extrapolation. The model's parameters are usually obtained through an experimental data fitting procedure. The other approach is generally more complex since mechanistic models are difficult both to derive and to handle. The most important feature of these types of model is that they are generally predictive and can be used for design purposes. It is worth noting that these models are generally derived by giving a quantitative description of each involved phenomenon. Therefore, they also provide insight into each event occurring during storage.

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Chapter 1
Direct Models for Shelf Life Prediction

1.1 Introduction

It is often necessary to study various packaging strategies to preserve a specific commodity. To this aim, shelf life (SL) tests are run to determine the effectiveness of certain packaging solutions. In these cases, a model that either extrapolates or interpolates the experimental data (e.g., by a simple data fitting) is generally used to calculate the SL and, consequently, the effectiveness of a given packaging strategy. To get an idea of what these types of models are about, two cases will be presented: one where the quality of the packaged food can be described by means of a single quality index, as is the case with many kinds of fresh-cut produce, and another where the quality depends on more than just one quality index, such as dairy products.

1.2 Single Quality Index Models

Predictive microbiology is a useful tool for determining the SL of food products whenever the microbial cell load is the sole packaged-food quality index. Several attempts have been made to develop a predictive model of spoilage growth inside or on the surface of foods as a function of time. These models may be analytical expressions (direct models), such as the Gompertz or the logistic curve (Zwietering et al. 1991) that exhibit the typical sigmoidal trend of a bacterial growth curve, or are sets of ordinary differential equations (mechanistic models) (Baranyi and Roberts 1995).

The empirical sigmoidlike analytical expressions used in predictive food microbiology are very appealing mainly due to their simplicity. The accuracy in predicting growth depends on the number of parameters used in the sigmoidal model. Modified versions of the Gompertz equation can include three or more parameters to describe the behavior of the bacterial growth curve. For example,

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a modified version of the Gompertz model to describe a bacterial population was proposed by Zwietering et al. (1990). The kinetic parameters derived by the Gompertz equation have often been used to calculate the SL of numerous minimally processed vegetables (Corbo et al. 2004; Lanciotti et al. 1999; Riva et al. 2001; Sinigaglia et al. 2003). In fact, the SL of these products was calculated by setting the maximum acceptable contamination level to $5 \cdot 10^7$ CFU/g, as determined by French regulations (Ministere de l'Economie des Finances et du Budget 1988). The method adopted by Zwietering et al. (1990) consists in estimating the Gompertz parameters by fitting the following expression to the experimental data:

$$\log[N(t)] = K + A \cdot \exp\left\{-\exp\left\{\left[(\mu_{\max} \cdot 2.7182) \cdot \frac{\lambda - t}{A}\right] + 1\right\}\right\}, \tag{1.1}$$

where *N(t)* is the viable cell concentration (CFU/g) at time t, K is related to the initial level of the viable cell concentration (log CFU/g), A is related to the difference between the decimal logarithm of maximum bacteria growth attained at the stationary phase and the decimal logarithm of the initial value of viable cell concentration, μ_{max} is the maximal specific growth rate, and λ is the lag time. Once the modified Gompertz function parameters are estimated, the SL of the packaged produce is calculated through the following expression:

$$SL = \lambda - \frac{A \cdot \left\{\ln\left[-\ln\left(\frac{Log(N_{\max}) - K}{A}\right)\right] - 1\right\}}{\mu_{\max} \cdot 2.7182}, \tag{1.2}$$

where $N_{\max}$ is the microbial threshold (CFU/g), which, as reported previously, is equal to $5 \cdot 10^7$ CFU/g for minimally processed vegetables. It is worth noting that, even when it is possible to use Eq. 1.1 for estimating the confidence interval of each Gompertz parameter, it is not possible to directly estimate the confidence interval of the SL because it does not appear explicitly as an equation parameter. The difficulty of estimating the SL confidence interval is the main drawback of using the foregoing approach to estimating the SL of fresh produce.

An alternative method for estimating the SL of fresh-cut products was proposed by Corbo et al. (2006). It consists in rearranging Eq. 1.1 in such a way that the SL parameter appears in the equation, relating the log (CFU/g) to the storage time:

$$\begin{aligned}\log[N(t)] = \log(N_{\max}) - A \cdot \exp\left\{-\exp\left\{\left[(\mu_{\max} \cdot 2.71) \cdot \frac{\lambda - SL}{A}\right] + 1\right\}\right\} \\ + A \cdot \exp\left\{-\exp\left\{\left[(\mu_{\max} \cdot 2.71) \cdot \frac{\lambda - t}{A}\right] + 1\right\}\right\}.\end{aligned} \tag{1.3}$$

It is worth noting that SL is the time at which the microbiological threshold is reached [i.e., the time at which $N(t)$ is equal to $N_{\max}$].

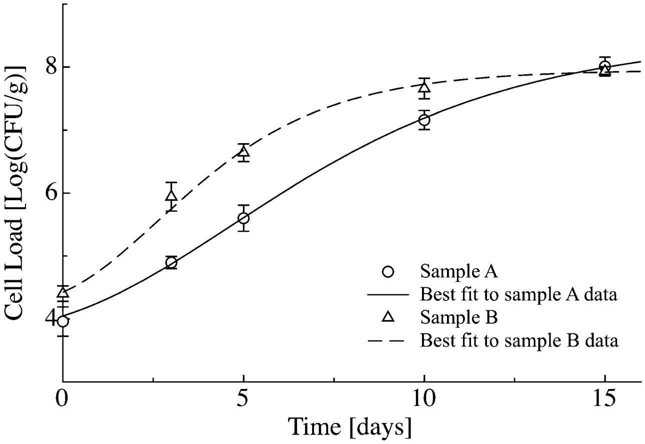

Fig. 1.1 Evolution of mesophilic bacteria as a function of storage time for fresh-cut lettuce. The curves are the best fit of Eq. 1.3 to the experimental data. *Sample A*: treated lettuce with a solution containing 150 ppm of free chlorine; *sample B*: treated lettuce with a solution containing 100 ppm of free chlorine and washed after cutting

By fitting Eq. 1.3 to the experimental data it is possible to estimate the equation's parameters and their confidence interval. Therefore, Eq. 1.3 can be used in place of Eqs. 1.1 and 1.2 to determine both the SL and the confidence interval. The model proposed by Corbo et al. (2006) was used for the mesophilic bacteria cell load of different packaged minimally processed vegetables (fresh-cut lettuce, fennel, and shredded carrots). As an example, Fig. 1.1 shows the evolution during storage of the microbial population in samples of packed fresh-cut lettuce, as reported by Corbo et al. (2006). The curves shown in the figure were obtained by the authors by fitting Eq. 1.3 to the experimental data. Table 1.1 reports some examples of SL values for ready-to-eat produce, obtained according to the approach proposed by Corbo et al. (2006). As pointed out earlier, using Eq. 1.3 it is possible to estimate the SL confidence interval, which in turn makes it possible to establish whether or not there is a significant difference in the SL among the packaged products.

1.3 Multiple Quality Index Models

Whenever the quality of a given packaged food depends on various quality indices, its SL is, by definition, the time at which one of the food quality indices reaches its threshold. Packaged fresh dairy products can serve an example of food whose quality has been reported to depend on more than one single quality index. In fact, the numerous works reported in the literature dealing with fresh dairy product SL have determined that food quality is related to both microbial and sensory quality (Conte et al. 2009a; Del Nobile et al. 2009b; Gammariello et al. 2008b;

Table 1.1 Shelf life values obtained according to mathematical model proposed by Corbo et al. (2006). The 95 % confidence intervals of the calculated shelf life values, calculated on the basis of 200 converging interactions, are shown in square brackets

Product[a]		Shelf life (days)
Shredded carrots	C1	6.42 [4.65, 7.15]
	C2	6.92 [6.34, 7.69]
	C3	6.30 [5.65, 7.00]
	C4	4.56 [4.27, 4.86]
Fresh-cut lettuce	L1	12.63 [11.5, 14.7]
	L2	–[b]
	L3	9.69 [8.47, 11.7]
	L4	4.51 [3.62, 5.41]

[a] C1, C2, C3, C4: shredded carrots produced according to processing lines I, II, III, and IV, respectively; L1, L2, L3, and L4: fresh-cut lettuce produced according to processing lines I, II, III and IV

I: treatment with solution containing 150 ppm of free chlorine

II: treatment with solution containing 100 ppm of free chlorine

III: treatment with a solution containing 100 ppm of free chlorine and washing after cutting for lettuce or shredding for carrots to reduce the residual chlorine concentration

IV: pause of 12 h at room temperature (15–18 °C) before treatment with a chlorine solution (100 ppm of free chlorine) and washing

[b] Mesophilic bacterial count that did not attain $5 \cdot 10^7$ CFU/g

Papaioannou et al. 2007; Pintado et al. 2001). Generally, for assessing dairy microbial quality *Pseudomonas* spp. and coliforms are used as target microbial groups (Conte et al. 2009a; Del Nobile et al. 2009b; Gammariello et al. 2008b). In several cases, the quality of fresh-cut produce has also been described by means of more than one quality index (Mastromatteo et al. 2009; Watada and Qi 1999). Various studies dealing with ready-to-use vegetables (lampascioni, artichokes, and zucchini) also took into account microbial and sensory quality for the purpose of assessing SL (Conte et al. 2009b; Del Nobile et al. 2009a; Lucera et al. 2010).

The way the aforementioned quality indices are described through mathematical models depends on the trend of the experimental data. In fact, it must be recalled that direct models are empirical in nature, and usually their parameters have no particular physical meaning; they are only used to interpolate data by means of a fitting procedure. Therefore, the choice of model should be based solely on its simplicity and its ability to fit the experimental data. Several empirical models can be found in the literature to describe packaged-food quality. For instance, Gammariello et al. (2008a) proposed a first-order kinetic type of equation to quantitatively determine the influence of chitosan on the sensory quality decay of Apulia spreadable cheese during storage. To derive the model, the authors started from a first-order equation:

$$\frac{d\xi(x)}{dx} = -k \cdot x, \tag{1.4}$$

where ξ is the normalized dependent variable, x is the generic independent variable, and k is the kinetic parameter; ξ is defined as follows:

$$\xi(x) = \frac{y(x) - y^{\infty}}{y^{0} - y^{\infty}}, \tag{1.5}$$

where $y(x)$ is the generic dependent variable, y^0 is the initial value of $y(x)$, and y^{∞} is the asymptotic value of $y(x)$. The solution of Eq. 1.4 is as follows:

$$\xi(x) = \xi^{0} \cdot \exp(-k \cdot x). \tag{1.6}$$

Substituting Eq. 1.5 into Eq. 1.6 one obtains

$$y(x) = y^{\infty} + (y^{0} - y^{\infty}) \cdot \exp(-k \cdot x). \tag{1.7}$$

Equation 1.7 can be further rearranged to incorporate as a parameter the threshold value of the dependent value y:

$$\begin{aligned} y(x) = {} & \frac{y^{T} - y^{0} \cdot \exp(-k \cdot x^{T})}{1 - \exp(-k \cdot x^{T})} \\ & + \left[y^{0} - \frac{y^{T} - y^{0} \cdot \exp(-k \cdot x^{T})}{1 - \exp(-k \cdot x^{T})} \right] \cdot \exp(-k \cdot x), \end{aligned} \tag{1.8}$$

where y^T is the threshold value of $y(x)$, and x^T is the value of the independent variable at which $y(x)$ reaches y^T.

Equation 1.8 was used by the authors to interpolate the sensory data of Apulia spreadable cheese. The authors introduced the concept of sensory acceptability limit, rewriting the preceding equation in the following form:

$$\begin{aligned} OSQ(t) = {} & \frac{OSQ_{\min} - OSQ_{0} \cdot \exp(-k \cdot SAL)}{1 - \exp(-k \cdot SAL)} \\ & + \left(OSQ_{0} - \frac{OSQ_{\min} - OSQ_{0} \cdot \exp(-k \cdot SAL)}{1 - \exp(-k \cdot SAL)} \right) \cdot \exp(-k \cdot t), \end{aligned} \tag{1.9}$$

where $OSQ(t)$ is the packaged-food overall sensory quality at time t, OSQ_0 is the initial value of the packaged-food overall sensory quality, $OSQ_{\min}$ is the packaged-food overall sensory quality threshold, SAL is the sensorial acceptability limit [i.e., the time at which $SA(t)$ is equal to $SA_{\min}$]. It is worth noting that in all cases where the food quality depends on several indices, the time at which one of its quality indices reaches the threshold does not necessarily coincide with food SL. Consequently, Gammariello et al. (2008a) used the term *sensory acceptability*

Table 1.2 Appearance, texture, flavor, and overall acceptability of spreadable cheese samples studied by Gammariello et al. (2008a)

Samples	Appearance	Texture	Flavor	Overall acceptability
CTRL	13.58 ± 1.79^a	1.67 ± 0.32^c	12.06 ± 1.48^a	10.56 ± 0.65^a
C12	8.55 ± 0.88^b	3.64 ± 1.25^b	9.81 ± 1.64^b	8.10 ± 0.52^b
C24	>18	10.18 ± 1.29^a	>18	>18
C36	7.33 ± 0.81^b	4.46 ± 1.32^b	7.63 ± 0.8^b	3.71 ± 0.86^c

Data are presented ± standard deviation

$^{a\text{-}c}$Data in each column with different superscript letter are statistically different ($p < 0.05$)

CTRL Apulia spreadable cheese without chitosan, *C12* Apulia spreadable cheese with chitosan – final concentration in working milk 0.012 % (wt/vol), *C24* Apulia spreadable cheese with chitosan – final concentration in working milk 0.024 % (wt/vol), *C36* Apulia spreadable cheese with chitosan – final concentration in the working milk 0.036 % (wt/vol)

limit (SAL) to indicate the time at which the sensory quality reaches its threshold. If this attribute is the sole packaged-food quality index, the *SAL* value would coincide with the product SL. The calculated values of each sensory attribute are reported in Table 1.2. As can be inferred, the *SAL* of the most studied Apulia spreadable cheese samples is mainly affected by texture characteristics. Gammariello et al. (2008a) took into account two quality indices, microbial and sensory ones, to evaluate the SL of dairy products. Considering that the monitored viable cell counts of target spoilage microorganisms were found to be below the threshold for the entire observation period, the authors assessed that the *SAL* values coincided with the SL of the Apulia spreadable cheese.

A Weibull type equation can also be used to interpolate the experimental data and calculate the quality acceptability limit of a packaged food. The Weibull equation was originally used to describe the cumulative density function (Park 1979), which has the following form:

$$y = 1 - \exp\left[-\left(\frac{x}{\beta}\right)^{\alpha}\right], \tag{1.10}$$

where α and β are shape and scale parameters, respectively. Equation 1.10 is an increasing sigmoid function ranging between 0 and 1. To use Eq. 1.10 to interpolate a packaged-food quality index, such as the sensory one, it must be modified to a decreasing function ranging between two arbitrary limits:

$$y = K_1 + K_2 \cdot \exp\left[-\left(\frac{x}{\beta}\right)^{\alpha}\right], \tag{1.11}$$

where K_1 and K_2 are fitting parameters. Equation 1.11 is now a decreasing function ranging between (K_1 + K_2) and K_1. Equation 1.11 can be further rearranged to make the quality index acceptability limit (i.e., the time at which the quality index reaches its threshold value) appear directly as a parameter of the equation relating the

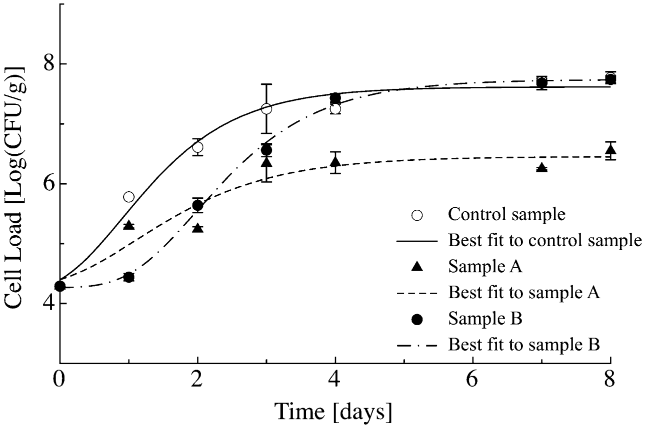

Fig. 1.2 Evolution of *Pseudomonas* spp. as a function of storage time for fior di latte cheese. The curves are the best fit of Eq. 1.13 to the experimental data. *Sample A*: coated cheese sample with sodium alginate (8 %) and 0.25 mg/ml of lysozyme/EDTA; *sample B*: coated cheese sample with sodium alginate (5 %) and 0.25 mg/ml of lysozyme/EDTA

quality index to the storage time. In the specific case where the sensory quality must be interpolated, Eq. 1.11 can be rearranged as follows:

$$OSQ(t) = OSQ_{\min} - K_2 \cdot \exp\left[-\left(\frac{SAL}{\beta}\right)^{\alpha}\right] + K_2 \cdot \exp\left[-\left(\frac{t}{\beta}\right)^{\alpha}\right]. \tag{1.12}$$

A different equation was used by Del Nobile et al. (2010) to quantitatively determine the efficiency of alginate gel loaded with lysozyme and ethylenediaminetetraacetic acid (EDTA) in controlling microbial growth in fior di latte cheese. The authors used the Gompertz equation as reparameterized by Corbo et al. (2006) to interpolate the microbial growth curve:

$$\begin{aligned}\log[N(t)] = \log(N_{\max}) - A \cdot \exp\left\{-\exp\left\{\left[(\mu_{\max} \cdot 2.71) \cdot \frac{\lambda - MAL}{A}\right] + 1\right\}\right\}\\ + A \cdot \exp\left\{-\exp\left\{\left[(\mu_{\max} \cdot 2.71) \cdot \frac{\lambda - t}{A}\right] + 1\right\}\right\},\end{aligned} \tag{1.13}$$

where MAL is the microbial acceptability limit, i.e., the time at which the microbiological threshold is reached [i.e., the time at which $N(t)$ is equal to $N_{\max}$]. It is worth noting that the term *microbial acceptability limit* (MAL) has been used in place of *shelf life*, which was used in Eq. 1.3. Figure 1.2 presents an example of the fitting ability of Eq. 1.13. The figure shows the evolution during storage of *Pseudomonas* spp. viable cell concentration in some fior di latte cheese samples along with the best fit of Eq. 1.13 to the experimental data. The authors set

Table 1.3 Shelf life of fior di latte cheese samples evaluated as lowest value between MAL and SAL, calculated as fitting parameters

Sample	Shelf life (days)
Control sample	1.33 ± 0.12^{a}
0.25 mg ml^{-1} lysozyme and 50 mM Na_2–EDTA in brine	3.37 ± 0.14^{b}
0.50 mg ml^{-1} lysozyme and 50 mM Na_2–EDTA in brine	3.16 ± 0.15^{b}
1.00 mg ml^{-1} lysozyme and 50 mM Na_2–EDTA in brine	2.71 ± 0.29^{e}
0.25 mg ml^{-1} lysozyme and 50 mM Na_2–EDTA in alginate (8%) coating	2.74 ± 0.52^{e}
0.50 mg ml^{-1} lysozyme and 50 mM Na_2–EDTA in alginate (8%) coating	2.72 ± 0.00^{e}
1.00 mg ml^{-1} lysozyme and 50 mM Na_2–EDTA in alginate (8%) coating	$2.51 \pm 0.05^{d,e}$
0.25 mg ml^{-1} lysozyme and 50 mM Na_2–EDTA in alginate (5%) coating	$2.35 \pm 0.07^{d,e}$
0.50 mg ml^{-1} lysozyme and 50 mM Na_2–EDTA in alginate (5%) coating	$2.16 \pm 0.24^{c,d}$
1.00 mg ml^{-1} Lysozyme and 50 mM Na_2–EDTA in alginate (8 %) coating	1.91 ± 0.09^{c}

Data are presented ± standard deviation

[a-e]Data in column with different superscript letters are significantly different ($p < 0.05$)

the value of $N_{\max}$ for *Pseudomonas* spp. at 10^6 CFU/g because at this contamination level alterations of the product start to appear (Bishop and White 1986). The authors used the Gompertz equation as reparameterized by Corbo et al. (2006) also to quantitatively determine the efficiency of the packaging system in slowing down the quality loss of fior di latte cheese in terms of sensory quality preservation:

$$
\begin{aligned}
OSQ(t) = OSQ_{\min} - A^{Q} \cdot \exp\left\{-\exp\left\{\left[\left(\mu_{\max}^{Q} \cdot 2.71\right) \cdot \frac{\lambda^{Q} - SAL}{A^{Q}}\right] + 1\right\}\right\} \\
+ \ A^{Q} \cdot \exp\left\{-\exp\left\{\left[\left(\mu_{\max}^{Q} \cdot 2.71\right) \cdot \frac{\lambda^{Q} - t}{A^{Q}}\right] + 1\right\}\right\},
\end{aligned}
\tag{1.14}
$$

where A^Q is related to the difference between the packaged-food overall sensory quality attained at the stationary phase and the initial value of packaged-food overall sensory quality, $\mu^{Q}{}_{\max}$ is the maximal rate at which $OSQ(t)$ changes, and λ^Q is the lag time. Values of SL were calculated as the lowest value between the MAL and the SAL values (Table 1.3).

A further example of the use of empirical equations to calculate the SL of packaged food is provided by Gammariello et al. (2011), who conducted a study on the effects of the addition of chitosan during cheese making, combined with modified atmosphere packaging (MAP) to prolong the SL of stracciatella cheese stored at 4 °C. The authors calculated the stracciatella cheese SL using three quality parameters, two related to the growth of two spoilage microbial groups, *Pseudomonas* spp. and total coliforms, and the third related to the sensory quality of packaged food. Equations 1.13 and 1.14, used by Gammariello et al. (2011), interpolate the experimental data in a quite acceptable way. The SAL and MAL values calculated by the authors were compared to determine stracciatella cheese SL (Table 1.4).