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# Estimation of failure criteria in multivariate sensory shelf life testing using survival analysis

Ana Giménez*, Andrés Gagliardi, Gastón Ares

*Sensometrics & Consumer Science, Instituto Polo Tecnológico de Pando, Facultad de Química, Universidad de la República, By Pass de Rutas 8 y 101 s/n, C.P. 91000 Pando, Canelones, Uruguay*

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ABSTRACT

For most food products, shelf life is determined by changes in their sensory characteristics. A predetermined increase or decrease in the intensity of a sensory characteristic has frequently been used to signal that a product has reached the end of its shelf life. Considering all attributes change simultaneously, the concept of multivariate shelf life allows a single measurement of deterioration that takes into account all these sensory changes at a certain storage time. The aim of the present work was to apply survival analysis to estimate failure criteria in multivariate sensory shelf life testing using two case studies, hamburger buns and orange juice, by modelling the relationship between consumers' rejection of the product and the deterioration index estimated using PCA. In both studies, a panel of 13 trained assessors evaluated the samples using descriptive analysis whereas a panel of 100 consumers answered a "yes" or "no" question regarding intention to buy or consume the product. PC1 explained the great majority of the variance, indicating all sensory characteristics evolved similarly with storage time. Thus, PC1 could be regarded as index of sensory deterioration and a single failure criterion could be estimated through survival analysis for 25 and 50% consumers' rejection. The proposed approach based on multivariate shelf life testing may increase the accuracy of shelf life estimations.

## 1. Introduction

Shelf life dating has several economic, environmental and moral consequences, as it determines products' maximum commercialization time. It has been identified as one of the causes of food waste at both retail and household levels, particularly in developed countries (European Commission, 2010). Shelf life is usually defined as the storage time during which a food product remains safe and retains its physical, chemical and sensory characteristics (IFST, 1993). However, the shelf life of most food products is determined by changes in their sensory characteristics, as they occur before their safety is compromised (Lawless & Heyman, 2010).

Several physical, chemical and microbiological changes occur simultaneously during storage, causing a decrease in the sensory quality of the product (Derossi, Mastrandrea, Amodio, de Chiara, & Colelli, 2016). Therefore, sensory shelf life studies usually involve measuring the intensity of different sensory characteristics throughout storage, until they reach a failure criteria or cut-off point, which corresponds to the maximum tolerable deterioration (Giménez, Ares, & Ares, 2012). Shelf life can be limited by an increase in the intensity of a sensory defect or a decrease in the intensity of a desirable characteristic (Garitta, Hough, & Sánchez, 2004). Therefore, failure criteria for each of the evaluated sensory attributes are needed.

This approach has several disadvantages. First of all, the consideration of a different failure criterion for each sensory attribute can lead to different shelf life estimations. Besides, the estimation of a failure criterion for each sensory attribute is tedious and time-consuming. Finally, it should be taken into account that all the sensory characteristics of the product change simultaneously. Consumers' reaction towards a product with high intensity of a single defect can be different from their reaction towards a product with several sensory defects. Thus, selecting the most relevant sensory attribute to establish the end of a product's shelf life might be cumbersome. For this reason, it is necessary to obtain a single measurement of the sensory deterioration of products.

In this context, Pedro and Ferreira (2006) introduced the concept of multivariate shelf life. In this approach, Principal Component Analysis (PCA) is applied on the dataset containing the average value of a set of product characteristics at different moments of storage to identify the main sources of variability in the dataset. The first component of the PCA usually summarizes the evolution of all product characteristics with storage time and can be regarded as a deterioration index. This

* Corresponding author.
*E-mail address:* agimenez@fq.edu.uy (A. Giménez).

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approach has been applied to a limited number of situations (Derossi et al., 2016; Pedro & Ferreira, 2006, 2009; Richards, De Kock, & Buys, 2014).

The main challenge of multivariate shelf life testing is how to determine the failure criterion of the deterioration index in order to estimate the product's shelf life. Derossi et al. (2016) determined a failure criterion by setting maximum values for specific attributes based on previous studies. However, consumer perception has been recognized as a key input for the selection of failure criteria for shelf life estimation (Giménez et al., 2012). In this sense, Hough, Langohr, Gómez, and Curia (2003) stressed that sensory shelf life does not only depend on changes in the sensory characteristics of the product, but rather on how consumers react to these changes, as they decide to consume a product after a certain storage time or not.

Survival analysis has become one of the most popular methodologies for shelf life estimation based on consumers' perception (Giménez et al., 2012). This methodology focuses on the risk of consumers rejecting a product that has been stored for a certain time (Hough, 2010). Survival analysis can also be used for estimating the maximum tolerable intensity of a sensory defect (Hough, Garrita, & Sánchez, 2004). Therefore, survival analysis could be used to estimate failure criteria for multivariate sensory shelf life testing by modelling the relationship between consumers' rejection of the product and the deterioration index estimated using PCA. The application of survival analysis in the context of multivariate shelf life estimation would allow the estimation of failure criteria based on consumers' perception instead of the arbitrary criteria commonly used. Accurate estimations of failure criteria for multivariate shelf life estimation are particularly relevant when shelf life estimations should be obtained under different storage conditions, as they allow working with trained assessor panels, which is usually simpler and cheaper than conducting several consumer studies.

In this context, the aim of the present work was to exemplify the application of survival analysis to estimate failure criteria in multivariate sensory shelf life testing using two case studies with different product categories, hamburger buns and orange juice, in which shelf life has been reported to be mainly determined by changes in their sensory characteristics (Gray & Bemiller, 2003; Moshonas & Shaw, 1989).

## 2. Materials and methods

### 2.1. Study 1 - hamburger buns

#### 2.1.1. Samples and storage conditions

Hamburger buns were obtained from a local bread industry which elaborates different kinds of breads and keeps them frozen until commercialization. Samples from one batch were packaged in polypropylene (PP) bags containing 4 buns each, and stored at − 18 °C. In order to have samples with different degree of deterioration from one batch, hamburger buns were defrosted at given times prior to evaluation day (Gacula & Kubala, 1975). Hamburger buns were defrosted at 20 °C for 6 h, at different times before evaluation (0, 2, 4, 7, 9, and 11 days), and kept at ambient temperature (20 °C) inside polypropylene packages, simulating commercial storage conditions.

#### 2.1.2. Trained assessors panel

The sensory panel consisted of thirteen assessors, ages ranging from 25 to 47 years old. Assessors had been selected according to the guidelines of the ISO 8586:2012 standard (ISO, 2012) and had prior experience in discriminative and descriptive analysis of different food products.

In a first session, assessors were presented with 4 samples of hamburger buns with different storage times (0, 3, 6 and 10 days) to identify the changes in the sensory characteristics of the products most likely to appear due to prolonged storage. They were asked to generate their individual descriptors using a modified grid method (Damasio & Costell, 1991). By open discussion with the panel leader, assessors agreed on the best descriptors to describe differences among samples, their definitions and how to evaluate them. The selected descriptors were firmness (texture), softness (texture), cohesiveness (texture), off-odour (odour), dryness (texture), and off-flavour (flavour).

Assessors were trained in the quantification of the selected descriptors using unstructured scales 10-cm scales. Assessors were presented with samples with different intensity of each of the sensory attributes. In the first sessions, they used paired comparisons and ranking for sample evaluation, whereas in the following sessions they used unstructured scales for attribute rating. A total of eight 20 min sessions, performed on separate days, were considered to train the panel. Once the training phase ended, samples were evaluated using 10-cm unstructured line scales anchored from 'low' to 'high'.

A whole hamburger bun was presented to each assessor on a white plastic plate, coded with a 3-digit random number. The six samples were presented following a Williams' Latin square design. Two replications of each sample were evaluated by each assessor in two sessions, conducted on the same day with a waiting time of 4 h between sessions. Assessors rinsed their mouths with mineral water two times during a 15 s interval between samples. The testing was carried out in a sensory laboratory designed in compliance with ISO 8589 (ISO, 2007), under artificial daylight and temperature control (22 °C). Data collection was performed using paper ballots.

#### 2.1.3. Consumer panel

Consumers were recruited from the consumer database of the Sensometrics & Consumer Science group of Universidad de la República (Uruguay) based on their interest to participate in the study and their consumption frequency of hamburger buns (at least once a month). One-hundred consumers, ages ranging between 18 and 60 years, 60% female and 40% male, participated in the study.

Each consumer received the six samples of bread, one for each storage time (0, 2, 4, 7, 9, and 11 days). The samples were presented in odorless open plastic containers labeled with three digit random numbers. Consumers had to try each of the samples and to answer "yes" or "no" to the following question: "Imagine you have just bought this hamburger bun at the supermarket and when you arrive home you try it. Would you purchase it again?".

The test was conducted in a sensory laboratory that was designed in accordance with ISO 8589 (ISO, 2007) with individual booths with artificial daylight type illumination, temperature control (between 22 and 24 °C) and air circulation.

### 2.2. Study 2 – orange juice

#### 2.2.1. Samples and storage conditions

Samples of a commercial orange juice (13.6 °Brix) made by reconstitution of a Uruguayan concentrate (65 °Brix) of the orange variety 'Salustiana' were used. The juice was aseptically packaged in 1 litre TetraBrik® packages (all filled from the same batch). Three storage temperatures were considered: 25 °C, 35 °C, and 55 °C.

A reversed design was used for the shelf life study conducted at 25 °C because it was not feasible to gather consumers repeatedly over the period of time that the study required. Six industrial batches were stored at 25 °C immediately after produced to obtain samples with different storage time at the time of the study. Samples were stored at 25 °C at the following 0, 100, 183, 267, 338, and 433 days before the study. Previous studies proved that the industrial process variation or this product was minimal in terms of the juices' physicochemical and sensory characteristics. Furthermore, no significant differences in acidity (0.76–0.79% citric acid, $p > 0.25$) and total soluble solids (13.8–14.3 °Brix, $p > 0.08$) existed between the batches considered in the present study.

Samples from a single batch were stored at 35 °C and 55 °C, following a basic experimental design (Giménez et al., 2012). Seven