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Sensory cut-off point obtained from survival analysis statistics

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ABSTRACT

In the present work we applied interval-censored survival analysis techniques to estimate sensory cut-off points based on consumer's decision to accept or reject food products taking into account the inherent variability in sensory measurements. We compared the values obtained using this survival analysis methodology with those obtained by applying a previous regression based method. Cut-off point (COP) estimations were made for acid flavor in yogurt, strawberry flavor in a strawberry flavored drink and appearance quality index in broccoli. For two of these products the regression based cut-off points were unrealistic, and would lead to much too conservative COP's, leading to unnecessary rejection of samples in quality control inspections or very short shelf-lives. For one of the products (strawberry flavored drink), the survival and regression-based COP's were comparable. The survival analysis methodology is recommended for estimating sensory cut-off points in food products.

1. Introduction

To illustrate the basics of the cut-off point methodology (Hough, 2010) suppose we are to measure the sensory shelf life (SSL) of sunflower oil. Samples are stored at 45 °C for 90 days and every 8–10 days a trained sensory panel measures oxidized flavor versus a control sample stored at 4 °C. The higher the storage time the higher the oxidized flavor. To be able to establish the SSL some decision has to be taken regarding the maximum level of oxidized flavor that will be tolerated by consumers. If, for example, the maximum level is taken = 2 on the 0–10 sensory scale, then the estimated shelf life would be, say, 25 days; if the maximum level is taken = 4 then the estimated shelf life would be 70 days. The key issue is how to establish the maximum level which we shall call the cut-off point (COP).

Hough and Garitta (2012) reviewed the cut-off-point (COP) methodology in estimating sensory shelf life of foods. They categorized this methodology in 'Arbitrary' and 'Regression-based'. An example of an 'Arbitrary' COP was the one used by Villanueva and Trindade (2010) to estimate the SSL of chocolate and carrot cup-cakes. The end of shelf life was determined as the storage time at which the quality limit decreased to the pre-established value of 5.0. In one section of their paper they mentioned that this limit was chosen due to the manufacturer's request, and in another they refer to Gacula (1975). An example of a 'Regression-based' COP was the one used by Garitta, Hough, and Sánchez (2004) for plastic flavor in dulce de leche. A consumer panel measured acceptability of samples with different levels of plastic flavor. A least significant difference was calculated from this data, and this value was subtracted from the mean liking score for the control sample to provide a minimum acceptable liking score. Next, the consumer data were related to the plastic flavor ratings given to the same samples by a trained panel. Substituting the minimum acceptable liking score in the regression equation allowed estimating the plastic flavor COP. Details of this procedure will be given in Section 3.1.

Survival analysis (Klein & Moescheberger, 1997; Meeker & Escobar, 1998) is a branch of statistics used extensively in clinical studies, epidemiology, biology, sociology, and reliability studies. Hough, Langohr, Gómez, and Curia (2003) introduced survival analysis methods to estimate sensory shelf life based on consumer's acceptance/rejection of aged samples. Consumers receive a set of samples with different storage times and for each one they state whether they accept or reject it. This raw data is analyzed using specialized interval-censored data software to estimate rejection probability as a function of storage time. Based on an adopted rejection probability (usually 50%, Hough (2010)) the sensory shelf life of the product can thus be estimated. The methodology was then extended to estimating

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concentration limits of sensory defects (Hough, Garitta, & Sánchez, 2004) and optimum concentrations of a food ingredient (Garitta, Serrat, Hough, & Curia, 2006). Survival analysis has the advantage that experimental sensory work is relatively simple: a group of consumers answer if they accept or reject samples with different storage times or different levels of a sensory defect. Another advantage is that the accept/reject decision is in line with what consumers do regularly when confronted with a food product close to the end of its SSL or close to intolerable sensory limits. Due to these advantages it would be of interest to use survival analysis methods to establish a sensory COP. As explained in the following paragraph this entails a certain degree of difficulty.

In shelf-life studies the researcher decides at what storage times he/she will extract the samples from their storage conditions. For example, for a yogurt study (Curia, Aguerrido, Langohr, & Hough, 2005), samples were stored for 0, 14, 28, 42, 56, 70, and 84 days. These values are exact, that is there is no doubt that the experimenter extracted samples with 70 days storage, and not 70 ± 2 days. Another example of survival analysis is found in Sosa et al. (2008) who estimated the optimum concentration of salt in French-type bread from a consumer's perspective. They prepared samples of bread with 0.6, 1.2, 1.8, 2.4, 3.0, 3.6, and 4.2 g sodium chloride per 100 g of flour. Since the weighing error of these salt quantities was negligible, the values could be taken as exact as is the case of storage time in a shelf-life study. However, the values of the independent variable may not always be free of error. Consider the case of a yogurt manufacturer interested in estimating shelf lives of present and future formulations. If the critical descriptor has been established as acid flavor, he/she would find it practical to have an acid flavor COP. For any given formulation a correlation would be established between acid flavor and storage time, and with the COP a SSL value could be estimated. To obtain this COP using survival analysis 6–8 samples of yogurt with different levels of acid flavor (prepared, for example, by mixing a highly acid yogurt with different levels of a control sample) would be submitted to a consumer panel and to a trained sensory panel. The consumers would respond if they accept or reject each sample, and the trained panel would measure acid flavor. Nevertheless, trained panel measurements are subject to measurement error. In particular, the mean acid flavor given by the trained panel for one of the samples could be 4.8 on a 1–10 acid flavor scale. However, the acid value assigned to a sample cannot be summarized solely by its mean, its variability has to be incorporated. In the case of the above storage times or grams or salt, variability is null. When a consumer accepts a sample with mean acid value = 4.8 and rejects a sample with mean = 6.2, his/her data is interval-censored (Hough et al., 2003) between 4.8 and 6.2, where these limits are not exact values and their variability has to be taken into account.

Langohr, Gómez, and Hough (2013) presented a model to fit parametric distributions to interval-censored data when the interval limits have been measured with certain error. They provided details of the likelihood function corresponding to this data taking into account the variability. The required estimators are obtained maximizing the likelihood function. Finally, they applied their model to data from a yogurt experiment and estimated the acid taste COP corresponding to various rejection probabilities between 0.1 and 0.9.

The objectives of the present work were: (a) use the recently published survival analysis model (Langohr et al., 2013) to estimate the COP's corresponding to different data sets, and (b) compare the survival analysis COP's with the regression-based COP's (Garitta et al., 2004).

2. Data sets

Three data sets were chosen based on the following criteria:

- Yogurt: a taste descriptor measured by a trained panel was the critical descriptor. The relationship between %Rejection and acid taste was positive.
- Strawberry flavored drink: a flavor descriptor measured by a trained panel was the critical descriptor. The relationship between %Rejection and artificial strawberry was negative.
- Broccoli: the trained panel used a quality index for the appearance of the product. The relationship between %Rejection and quality index was negative.

2.1. Yogurt

Fat-free strawberry yogurts were obtained from a dairy company in Argentina and stored at 10 °C for 0, 14, 28, 42, 56, 70, and 84 days.

Sensory evaluation was conducted using the DESA-ISETA's sensory trained panel (14 women); the resulting critical descriptor was acid flavor which increased over storage time and was measured on a 100-cm structured scale. Consumer testing was performed by 80 regular consumers of the product recruited in the town of 9 de Julio-Argentina. For each sample they were asked "Would you normally consume this product? Yes or no?". They were also asked to evaluate overall acceptability using a 9-pt scale. Details of the experimental procedures can be found in Curia et al. (2005).

2.2. Strawberry flavored drink

Samples of a commercially available strawberry flavored non-carbonated drink were collected from local supermarkets in the UK with different best-before dates. The manufacturer recommended a maximum storage time of 26 weeks; with this information the resulting storage times of the collected samples were: 8, 12, 16, 20 and 28 weeks. It was not possible to have a sample with storage time = 0 as it was not found in the supermarkets.

Sensory evaluation was conducted using the Leatherhead Food Research's sensory trained panel (15 women); the resulting critical descriptor was artificial strawberry flavor which decreased over storage time and was measured on a 10-cm unstructured scale. Consumer testing was performed by 79 non-rejectors recruited from a local data base. They were asked to taste each of the samples and measure their acceptability for: overall liking, appearance and flavor on a 9 pt scale (1 = dislike extremely, 9 = like extremely). In addition to rating acceptability, consumers were asked if they would accept or reject each sample by indicating 'yes' or 'no' on their ballot form. Details of the experimental procedures can be found in Hough, Subramaniam, Narain, and Beeren (2013).

2.3. Broccoli

Trays with 300 g of minimally processed broccoli florets were stored at 0 °C for 0, 11, 18, 26, 63, 89, 152 and 169 days. A reversed storage design was used (Hough, 2010) freezing the broccoli trays after each storage time. This allowed the trained panel and consumers to evaluate all samples in a single session at the end of the total storage time.

Sensory evaluation was conducted using the DESA-ISETA's sensory trained panel (10 women); the quality index (QI) method was used to measure the appearance of the product on a 1–6 quality scale. The 1 represented a completely brown broccoli and the 6 a