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Shelf Life Prediction for Non-accelerated Studies (*SheNon*) Applied to Minimally Processed Eggplant

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Abstract This study aimed to propose a multivariate method for determining the shelf life of food in non-accelerated studies. The method allows incorporating different kinds of variables such as sensorial, physical, chemical and microbiological. The idea is to maintain two components most (co)related to(with) time (not necessarily the first two) and regress the score of a sample adjacent against these components, predicting the shelf live. It was applied in minimally processed eggplant data, resulting in a prediction of 9.6 days of life. Results suggest that the proposed method is promising and can be used in non-accelerated studies considering attributes of different types.

Keywords: *shelflife estimation, food safety, multivariate analysis, regression analysis*

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1. Introduction

The shelf life is the guarantee that the food is suitable for consumption within the stipulated period. According to the Brazilian National Health Surveillance Agency [1], determining the shelf life is responsibility the food manufacturers, processors or packers who should conduct stability studies required to determine how long the product keeps its safety, sensorial, physical, nutritional and functional features. Such features are usually assessed through microbiological, physicochemical and sensory properties.

Shelf life tests measure the time from production to packaging of the product to the point where it becomes unsuitable for consumption. Therefore, it is related to the overall quality of food and directly linked to production planning, ingredient specifications, handling processes and storage procedures. Assessments of microbiological and physicochemical properties express the concern with food safety.

The most widely used method to determine food shelf life is the direct monitoring [2]. This method requires food samples to be taken at each stage of development, placing them in an environment with controlled temperature and humidity and performing, at short intervals, microbiological, physical, chemical and sensory analyses to ensure that the food remains suitable for consumption.

When the target food deteriorates quickly, direct monitoring is widely used to determine its shelf life. However, when the food has slow deterioration, this method becomes unsuitable since it requires a large period for monitoring [3]. An alternative for such cases is the acceleration process.

In accordance to [4], this acceleration consists of reducing the period by increasing the deterioration rate, usually by increasing the storage temperature. The results of the accelerated procedure allow to predict the product shelf life under normal storage conditions.

For short-term food spoilage, the direct monitoring method of Rancimat [5] is used. On the other hand, for long-term food spoilage, we can use the Accelerated Shelf Life Test (ALST) [6] and its generalization, Multivariate Accelerated Shelf Life Test (MASLT) [7].

According to the studies of ANVISA [1], MAPA [8] and CODEX [9] it is evident that food shelf life is closely related to food safety. It is defined by Pinstrup-Andersen [10] as a set of standards regarding production, transport and storage aiming to ensure some characteristics under which the food would be suitable for consumption. Microbiological, physicochemical, sensorial and functional properties can be assessed for that purpose.

Microbiological attributes are essential since they indicate not only possible intoxication, but also future sensory changes in food [11]. Physicochemical analyses allow checking the nutrition labeling, identifying frauds and detecting changes in food physical, chemical and organoleptic properties. Moreover, evaluating sensory and functional attributes can be seen as a differential in the food market.

Therefore, many kinds of variables should be taken into account to predict food shelf life. For that reason, this study proposed a multivariate method that incorporates all information about data as well as supplementary borderline data.

2. Proposed Method

SheNon (Shelf life prediction for Non-accelerated studies) is a multivariate method designed to predict food shelf life based on the principal component and multiple regression analyses.

The idea is to retain a couple of components highly correlated with time (not necessarily the first ones) and regress the scores of a borderline sample into those components, predicting the shelf life (Figure 1).

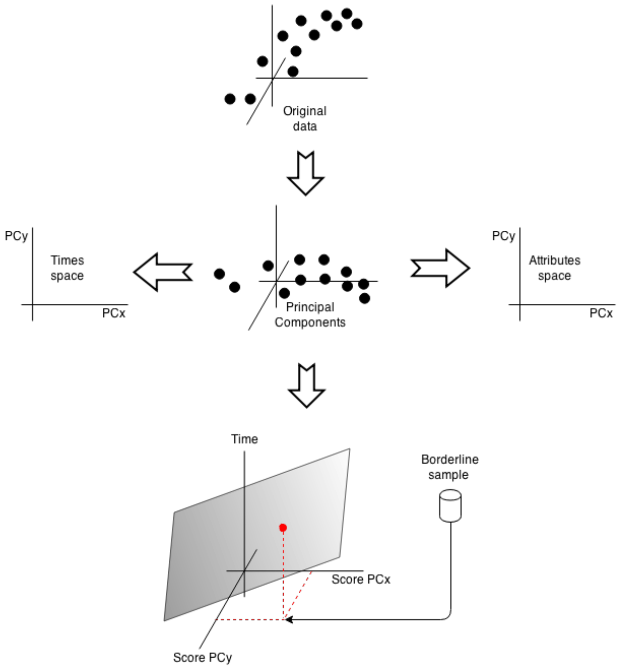

Figure 1. Schematic Algorithm to carry out the *SheNon* method

The proposed method follows the algorithm:

(i) Use the data matrix $\mathbf{X}_{nxp}$, where we have n times and p attributes, compute the eigenvalues (λ_i) and their respective eigenvectors (e_i), $i=1,...,p$, by the spectral decomposition of the sample correlation/covariance matrix $\mathbf{R}_{pxp}$;

(ii) Compute the p principal componentes $\mathbf{PC}_i=\mathbf{e}'_i\mathbf{Z}$, where $\mathbf{Z}$ is the standardized data matrix, and sets the scores matrix $\mathbf{S}_{nxp}=\{PC_i\}$;

(iii) From the p principal components select those k dimensions more correlated with time[1] ($k\leq p$);

(iv) Compute the loadings matrix $L_{p\times p}=\sqrt{\lambda_i}e_i$

(v) Fit a regression model for the scores of the chosen dimensions against time;

(vi) Arbitrate a vector $x_{bl(1\times p)}$ containing the scores given for a borderline sample [12];

(vii) Compute the cut-off criteria, that is, scores for each time related dimension, $s'_{bl}=x'_{bl}L_{p\times k}$

(viii) Predict shelflife using s_{bl} in the fitted regression model;

(ix) Plot scores and loadings for the k selected dimensions to infer food degradation along time.

At the third step, be careful with close-to-null eigenvalues. Too small eigenvalues lead to estimation problems in the regression stage. We advise to choose dimensions more correlated with time, since the associated eigenvalue is larger than 0.01, for instance. Correlations between the principal components and time can be verified by the Pearson's correlation coefficient, a regression model or even a scatter plot.

At the sixth step, the scores for a possible borderline (at the edge of the desired characteristics) sample should be obtained from an expert in that specific food, according to Gacula [12].

[1] $k=2$ shall be enough, since the time will be probably correlated with the first dimension in longitudinal studies.

3. Eggplant Experiment

The proposed method was applied in data from an experiment with raw minimally processed eggplant, performed at the Federal University of Alfenas, Minas Gerais State, Brazil, and stored at 5°C for 0, 3, 6, 9, 12 and 15 days.

We assessed the attributes of appearance (Ap), color (Cl), aroma (Ar), overall impression (OI), purchase intention (PI), color components L, a*, b*, Hue (H), soluble solids (SS), acidity (Ac), pH, browning index (BI) and chromaticity (Ch). The physicochemical variables (L, a*, b*, H, SS, Ac, pH, BI and Ch) were measured in three replicates and the sensory attributes (Ap, Cl, Ar, OI, PI) were evaluated by 50 consumers of eggplant.

Thus, the data matrix of this study consists of $n=6$ times (rows) and $p=14$ variables (columns). The entries of such matrix were the averages of the replicates.

Routines to determine the shelf life using the method SheNon were implemented into R (version 3.2.3) [13] available under request.

4. Results and Discussion

As well as the authors Pilon, Oetterer, Gallo and Spoto [14] predicted the shelf life of carrots and green peppers, Antoniolli, Benedetti, Souza Filho, Garruti, and Borges, [15] predicted the shelflife of minimally processed pineapple and Allende, Luo, Mcevoy, Artes and Wang [16] did it for spinach, this paper predicted the shelflife for minimally processed eggplant.

Regarding the anlysis per se, after finding the principal components, their correlation with time was also computed (Table 1) in order to choose the most representatives. The highest absolute correlations were found in PC1 and PC5. On the other hand, obviously, the first two principal components account for the highest variation. However, here we are looking for components that better explain food shelf life. Therefore, we chose to retain PC1 and PC5 although they do not account for the highest variability (76.1\% of variance).

Table 1. Principal components, correlation with time and variance accounted for

Principal Components	Correlation with time	Variance accounted for
PC1	0.924	0.757
PC2	-0.043	0.128
PC3	0.126	0.069
PC4	-0.086	0.043
PC5	0.348	0.004
PC6	0.102	0.000

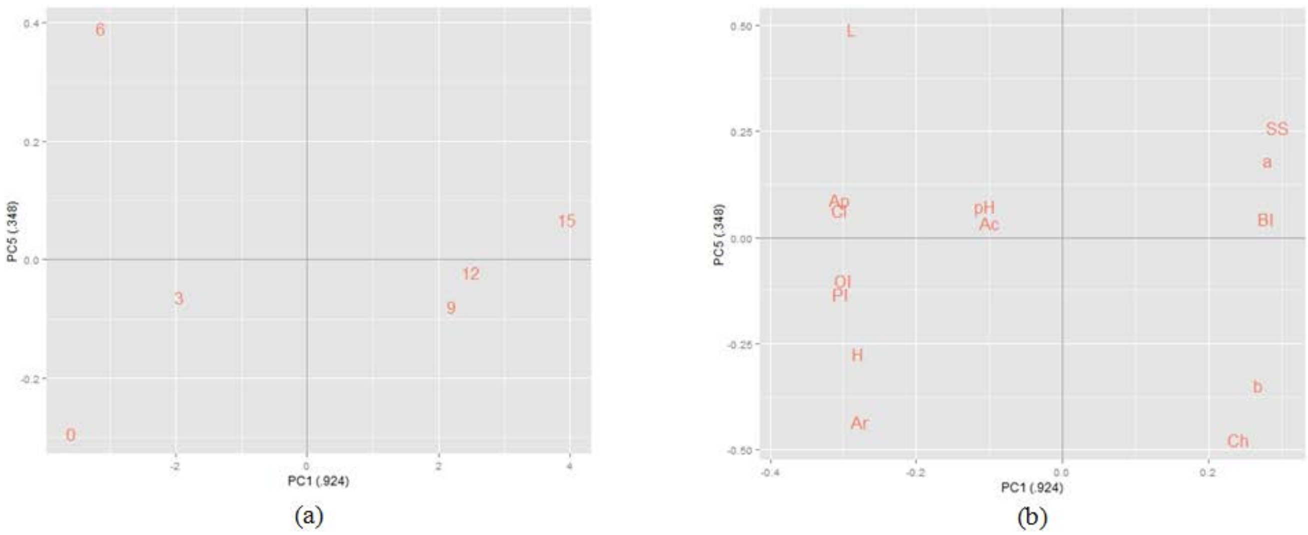

Figure 2. First two principal components of the product space (scores) (a); and variable space (loadings) (b) along with their correlation with time

Analyzing the scores and loadings of these two principal components, we observe that the minimally processed eggplant ages mainly along PC1 (Figure 2a). In Figure 2b we observe that the sensory attributes, L and H, are associated with fresh vegetables.

As the eggplants age, the browning index, SS, a*, b* and Ch tend to increase. Extra information about the association between variables and time can be observed in Table 2. Information about how several variables relate with time is an advantage of multivariate studies, what is missing when the shelf life is based in a single variable [12,14,15,17,18,19].

Figure 3 shows the relationship between scores and time for the selected components, PC1 (Figure 3a) and PC5 (Figure 3b). The relation between time and these components is linear, even though the association is stronger with PC1. The next step is to search for a good regression model to explain time, using such components.

Table 2. Correlation coefficient of the attributes with the principal components

Atributes	PC1	PC5
L	-0.506	0.862
a*	0.837	0.548
b*	0.612	-0.791
SS	0.749	0.662
PI	-0.916	-0.402
Ac	-0.945	0.326
pH	-0.819	0.573
H	-0.717	-0.697
BI	0.988	0.157
Oi	-0.949	-0.316
Ch	0.452	-0.892
Ap	-0.96	0.28
Cl	-0.978	0.209
Ar	-0.538	-0.843

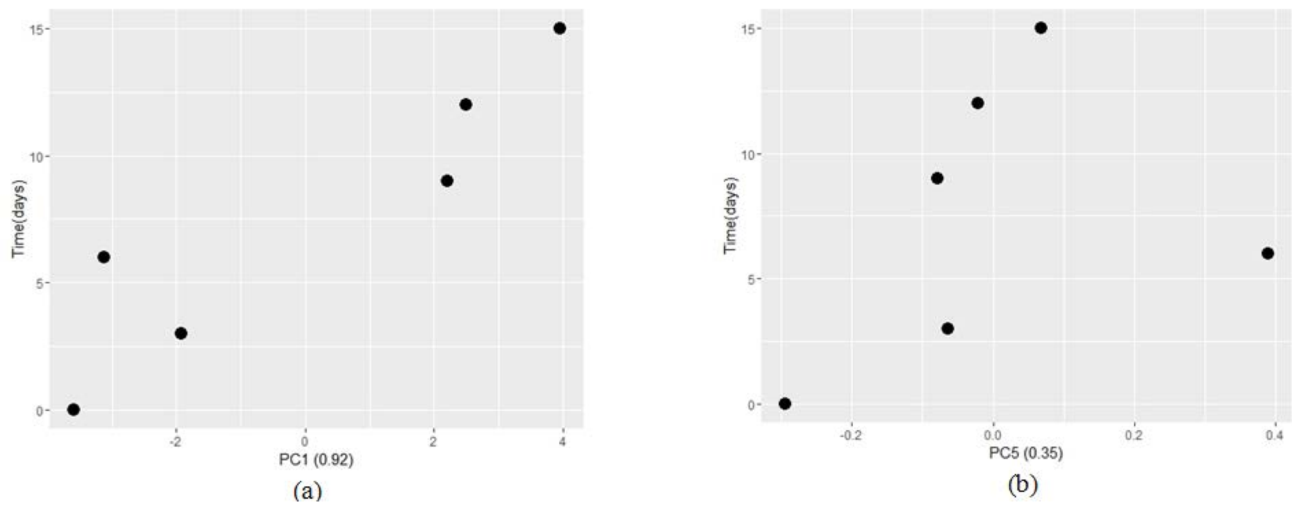

Figure 3. Behavior of the first principal component as a function of time (a). Behavior of the fifth principal component as a function of time (b)

A regression model was then fitted considering scores of PC1 and PC5 simultaneously:

$$Y = \beta_0 + \beta_1 S_{PC_1} + \beta_2 S_{PC_5} + \varepsilon$$

The estimated coefficients showed significance at 5%, according to the t test: $\hat{\beta}_0 = 7.5(0.47)$, $\hat{\beta}_1 = 1.59(0.16)$, $\hat{\beta}_2 = 8.68(2.29)$. The standard error is shown in brackets. Such model had a good fit ($R^2 = 0.97$) and a good analysis of residuals. The model is presented in Figure 4.

Afterward, the vector of scores for a borderline sample, given by an expert, was multiplied by the matrix of loadings in order to compute the borderline scores $s_{bl} = (-0.062, 0.258)$, which were used in the fitted model to predict shelf life.

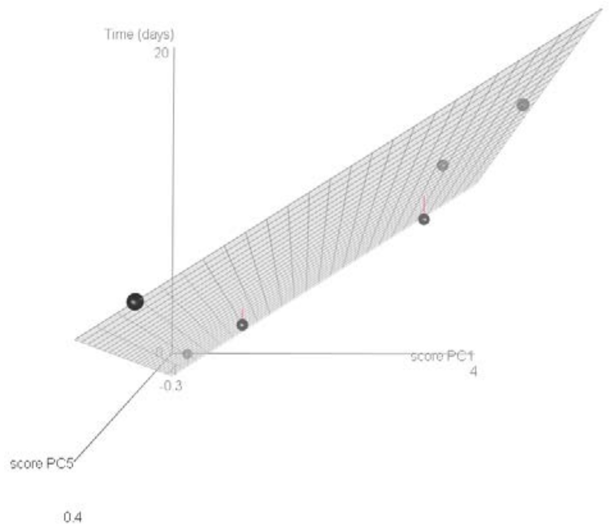

Figure 4. Linear regression of the adjusted model

It was found 9.6 days (±4) for the shelf life of raw minimally processed eggplant. One can argue about the length of that prediction interval. The point is that food shelf life is highly variable. Some foods allow long monitoring, while others do not. Longer experiments would generate more observed times and therefore more accurate prediction intervals.

5. Conclusion

The results showed that the proposed method is useful and auspicious to predict shelf life in non-accelerated studies involving variables of many different types, such as sensorial, physicochemical, microbiological, etc.

Particularly for raw minimally processed eggplant, a shelf life between 6 and 13 days was predicted. Future studies can use the proposed methodology for predicting the shelf life for other products. Besides, on a statistical point of view, the method can be evaluated regarding its stability and sensibility.

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