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# Use of image analysis to determine the shelf-life of an apple compote with wine

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**Abstract**

This research aimed to understand how the storage conditions change the appearance of an apple compote added with white wine (ACWW) during storage at different temperatures (20, 30, and 40 °C) for 63 days. Microbiological quality, color parameters, and pH were monitored. The CIE L*, a*, and b* color variables were measured through image analysis. The parameters associated with the color changes during storage were the most critical quality indices of the ACWW, especially the overall color difference (ΔE), since it presented the larger velocity constants, fitting to the first-order reaction kinetic model. Therefore, ΔE was selected as a critical parameter to estimate shelf-life but fitted with the first-order fractional conversion model, which provided a shelf-life of 45.64 days at 20 °C. The shelf-life decreased with increasing storage temperature. In conclusion, the results demonstrated the applicability of the image analysis and the kinetics-based accelerated shelf-life testing approach to obtain faster insight into quality attributes changes, mainly color changes in compotes and similar products.

**Keywords:** apple compote; image analysis; color changes; kinetic modeling; shelf-life.

**Practical Application:** Image analysis to predict shelf-life of compotes and similar products.

## 1 Introduction

The elaboration of compotes is a fruit preservation method. A compote is a product prepared with fruit pulp and/or puree, mixed with sugars and/or carbohydrate sweeteners like honey, with or without water, and prepared until getting a proper gelatinous consistency (Mendoncla et al., 2001); it can also contain brandy, rum, or liquor. However, despite having alcohol and sugar, this product may be subject to important color and flavor changes that affect its shelf-life during storage. The shelf-life is the period under specific storage conditions during which the food remains acceptable for human consumption in terms of its safety, nutritional attributes, and sensory characteristics (Corradini, 2018).

It is essential for manufacturers to prevent color changes during the processing and storage of fruit-based products because this parameter is an indicator of the freshness and ripeness of fruits and vegetables that will determine product acceptability and consumer purchase behavior. Several researchers have studied the color changes of food through instrumental measurements (Ávila & Silva, 1999; Bailón-Moreno et al., 2018; Buvé et al., 2018; Haddad et al., 2017; Sokół-Łętowska et al., 2018; Udomkun et al., 2016; Wang et al., 2018).

In products such as apple compote, the reactions of enzymatic and non-enzymatic browning are the main problems associated with the processing and storage (Palazón et al., 2009). It has been reported that in addition to the anthocyanins responsible for the reddish color of the peel of many apple cultivars, chloroplast pigments (chlorophylls and carotenoids) also contribute to the external (peel) and internal (flesh) fruit coloration (Delgado-Pelayo et al., 2014).

The progressive deterioration of quality and safety limits shelf-life, distribution, and storage of foods (Corradini, 2018).

Recently, image analysis has gained interest for its simplicity, reliability, low cost, and speed of analysis to assess food quality, in addition to the fact that it does not require reagents. The combination of image analysis with multivariate statistics and machine learning has become a powerful tool for dealing with several problems in the food sector, such as classifying or making predictions. This, together with the rapid advances in hardware and software for image processing, have driven the development of computer vision systems (CVS) as analytical technology for this purpose (Barbin et al., 2016; Pereira et al., 2018). A CVS is based on the following stages: 1) image acquisition, 2) image segmentation, 3) image feature extraction and selection, and 4) image classification, object detection, or feature prediction using machine learning and/or deep learning methods (Lopes et al., 2019; Oliveira et al., 2021). Concerning the first three stages, the development of methods able to extract a set of specific descriptors from the images of a food matrix and that can be used to build calibration models for a broad set of response variables is not straightforward. Many of the reported applications are customized

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on a specific food matrix. For example, image segmentation is often based on a problem-specific criterion to isolate the sample from the background or extract the informative portion of the image (Foca et al., 2011; Oliveira et al., 2021; Pereira et al., 2018). Other times, the customization involves pretreatments like denoising, filtering, scaling, and transforming the color space (Foca et al., 2011). Recently, the convolutional neural network (CNN) has emerged as an effective and potential tool for feature extraction, which is considered the most popular architecture of deep learning and has been increasingly applied for detecting and analyzing complex food matrices (Liu et al., 2021). Many properties can be extracted from an image, for example, color, pixels values distribution, statistical greatness, and frequency domain measures (Kato et al., 2019). Color space extraction from food matrices images has been previously reported (Barbin et al., 2016; Ulrici et al., 2012; Valous et al., 2009). Later, in stage 4 of the CVS, machine learning algorithms were applied with the data obtained from the image analysis. Among these methods, the use of Random Forest (RF), Support Vector Machines (SVM), C4.5, AdaBoost (AB), k-Nearest Neighbours (KNN), Logistic Regression (LR), Stochastic Gradient Boosting Trees (GBDT), Extreme Learning Machines (ELM), Sparse Representation-based Classification (SRC), and Deep Learning (DL) (Oliveira et al., 2021).

CVS has been successfully applied in the analysis of chicken meat (Barbin et al., 2016; Geronimo et al., 2019; Kato et al., 2019), marbling meat (Campos et al., 2020), papaya (Pereira et al., 2018; Udomkun et al., 2017), barley flour (Lopes et al., 2019), pasta (noodle) (Mastelini et al., 2018), and fermented cocoa beans (Oliveira et al., 2021). One of the advantages of CVS is that it allows estimating the general color along with other characteristics on the surface of the sample (Barbin et al., 2016).

Therefore, this research aimed to understand how the storage conditions change the appearance of an apple compote added with white wine (ACWW) through the image analysis and the kinetics-based accelerated shelf-life testing (ASLT) approach to determine the shelf-life of this product.

## 2 Materials and methods

### *2.1 Processing of the apple compote added with white wine*

The raw materials used to prepare the ACWW samples were provided by local artisan food producers from Hidalgo, México. The processing and formulation parameters were adapted from other papers (Akhmetov et al., 2020; Mendoncla et al., 2001; Palazón et al., 2009). The ACWW samples were prepared with the 'Golden Delicious' apples variety using an artisanal processing line. Initially, the apples went through a manual operation of slicing, coring, and washing, followed by peel removal with 2% w/v NaOH at 100 °C for 1 min. The apples were then rewashed with water under pressure to eliminate the oxidized peel and the excess NaOH. Afterward, the apples were introduced into a 0.30% w/v citric acid solution at 25 °C for 10 min to neutralize them. Once this time had elapsed, the apples were drained. Finally, a few drops of phenolphthalein were placed on an apple sample to confirm the absence of NaOH. Apples were then processed into a puree.

For the ACWW elaboration, the final ingredients were (the amount was reported in parentheses in g kg$^{-1}$ of the product): apple puree (780), water (64), sugar (70), L-ascorbic acid (0.50), cinnamon powder (0.20), and white wine (64). All the ingredients were mixed and cooked at 56 °C for 10 min in a stainless-steel pan until a homogeneous paste was obtained. The mixture was aseptically deposited and sealed in previously sterilized glass jars. The ACWW samples were pasteurized at 85 °C for 16.02 min, then cooled at 40 °C with water. Once the compotes cooled to room temperature, they were stored at 20 °C until usage.

### *2.2 Shelf-life estimation*

Samples containing 100 g of the ACWW were stored in clear glass jars at 20, 30, and 40 °C. Temperature conditions were controlled in recirculating air stoves. Finally, the microbiological quality, pH, and color parameters were monitored every 7 days for 63 days. The pH was measured using a calibrated potentiometer. Determinations were made in triplicate.

*Microbiological quality*

The analysis of the microbiological quality of the sample was performed according to the Mexican legislation through the determination of mesophilic aerobic bacteria (NOM-092-SSA1-1994), total coliforms (NOM-113-SSA1-1994), and molds and yeasts (NOM-111-SSA1-1994). Sample preparation was made following the NOM-110-SSA1-1994.

*Color measurement by image analysis*

The CVS used consisted of an illumination chamber, a charge-coupled device (CCD) digital camera, and a computer (laptop), all were constructed and calibrated according to previous research, with some modifications (León et al., 2006; Pereira et al., 2012; Udomkun et al., 2017).

Image acquisition system

A lightproof cardboard box was equipped with a parabolic aluminized reflector bulb 38/8 inches frontal diameter (PAR38) (Sunlite PAR38/LED/18W/FL40/D/E/65K IP65 UL, Sunlite, USA) with a color temperature of 6500 K ($D_{65}$) and a color rendering index up to 80%.

A digital 10.1-megapixel camera with 4× optical zoom (Panasonic Lumix DMC-FS42, Japan) was installed with the distance between the camera and sample fixed at 50 cm. The angle between the camera lens and the light source axis was set to 45° to capture the diffuse reflection. The angle between the camera lens axis and the sample was 90° to reduce specular reflectance. The camera setting was the following: shutter speed 1/30 s, manual operation mode, aperture value F2.8, ISO velocity 80, flash off, focal distance 33 mm, and F2.8-5.9 zoom lens. The acquired images were saved in JPG format.

Image analysis

Three areas were randomly examined on the ACWW surface using Adobe® Photoshop® CS3 Extended software

(Adobe Systems Incorporated, San Jose, California, USA). The color images of the ACWW were digitized into pixels (24 bits/pixel) containing levels of the three primary colors: red, green, and blue (RGB). Subsequently, the RGB color space obtained from digital image analysis was transformed to CIE L*, a*, and b* color space (Wu & Sun, 2013).

Color parameters were expressed as L* describing lightness (L* = 0 for black, L* = 100 for white), a* or redness for intensity in green-red (a* < 0 for green, a* > 0 for red), and b* or yellowness describing intensity in blue-yellow (b* < 0 for blue, b* > 0 for yellow) representing the rectangular chromaticity coordinates. Subsequently, the overall color difference (ΔE), hue angle (h*) or color angle, and chroma (C*) or color saturation were calculated using the following equations (Equations 1-3):

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (1)$$

$$h^* = arctan\frac{b^*}{a^*} \quad (2)$$

and

$$C^* = \sqrt{a^* + b^*} \quad (3)$$

Where ΔL*, Δa*, and Δb* represent changes in lightness, redness, and yellowness, respectively (Udomkun et al., 2017; Wu & Sun, 2013).

*Sensory analysis*

The samples' color, odor, and flavor were evaluated by 20 semi-trained judges. All of them were students (male and female, mean age 23.5) from Universidad Autónoma del Estado de Hidalgo (Mexico). Each week, the judges tested each sample stored at different temperatures (20, 30, and 40 °C) for two months and compared it with a freshly prepared ACWW.

The panelists evaluated the sensory parameters of samples through a questionnaire. They were asked to find differences between samples and rate the intensity of such differences (light, moderate or intense).

### 2.3 Kinetic considerations

Different models were applied to fit the experimental data to obtain information about the changes produced in the quality attributes of the ACWW during storage. Initially, they were fitted with the zero- and first-order kinetic models (Dermesonlouoglou et al., 2016; Jaimez-Ordaz et al., 2019; Park et al., 2018).

Subsequently, the first-order fractional conversion (FOFC) model (Rizvi & Tong, 1997) was used to study the changes in the color of the ACWW. This model has been applied in fruit purees presenting non-enzymatic color changes associated with heat treatment, which happen through a two-stage mechanism (Ibarz et al., 1999, 2000). When the fractional conversion model is used, the quality index, *f*, is defined as shown in Equation 4 (Ling et al., 2015; Rizvi & Tong, 1997).

$$f = \frac{Q_0 - Q_t}{Q_0 - Q_\infty} \quad (4)$$

Where $Q_0$ is the initial quality property of the food, $Q_t$ is the quality property after a specific time *t*, and $Q_\infty$ is the final quality property at the non-zero equilibrium value. For a first-order reaction, substituting the index *f* into Equation 5 and taking natural logarithm yields as follows (Ling et al., 2015):

$$\ln(1-f) = \ln\left(\frac{Q_t - Q_\infty}{Q_0 - Q_\infty}\right) = -kt \quad (5)$$

Where *k* is the reaction rate constant (days$^{-1}$), and *t* is the storage time (days).

The influence of the reaction temperature on *k* was analyzed with an Arrhenius plot of *ln (k)* against *1/T*. The activation energy ($E_a$, kJ mol$^{-1}$) and pre-exponential factor (*A*, days$^{-1}$) were determined from the slope and y-intercept, respectively, of the lines generated by regression. Finally, the acceleration factor $Q_{10}$ was calculated from the slope of the line (Jafari et al., 2017; Jaimez-Ordaz et al., 2019).

### 2.4 Thermodynamic analysis

Activation enthalpy ($\Delta H^‡$), the free energy of activation ($\Delta G^‡$), and activation entropy ($\Delta S^‡$) were determined. First, $\Delta H^‡$ and $\Delta S^‡$ values were determined by regression of *ln k/T* as a function of the inverse of temperature (*T*, K) through the equation derived from the theory of activated complex. The values of $\Delta H^‡$ and $\Delta S^‡$ were calculated from the slope and y-intercept (Jaimez-Ordaz et al., 2019). Finally, for a reaction at a given temperature (*T*), $\Delta G^‡$ value can be calculated in terms of $\Delta H^‡$ and $\Delta S^‡$ (Hashemi et al., 2016).

### 2.5 Statistical analysis

Two-way analysis of variance (ANOVA) and a post-hoc Tukey's HSD test (*p*-value < 0.05) for comparison of sample means were performed to assess the effect of storage time and temperature on the physicochemical quality attributes of the ACWW. Subsequently, one-way ANOVA with a post-hoc Tukey's test (*p*-value < 0.05) was used to identify significant differences in storage temperature and time. All tests were performed using the R software package (v3.4.4) (R Core Team, 2018) and RStudio (v1.4.1106) (RStudio Team, 2021).

## 3 Results and discussion

### 3.1 Microbiological quality

No growth of mesophilic bacteria, total coliforms or molds and yeasts were observed during the storage of the sample at 20, 30, and 40 °C. These results indicate that the ACWW was prepared under good manufacturing practices, that cleaning and disinfection were compelling, and, that the constant temperature during the thermal treatment processes and storage was correctly applied. Another factor contributing to avoiding the growth of microorganisms was the pH of the sample. It has been reported that an acid pH and a thermal treatment help extend the shelf-life of purees (Aaby et al., 2018). In food products showing a stable behavior from a microbiological point of view, evaluating quality physicochemical attributes is the critical factor for their shelf-life determination.

### *3.2 Estimation of shelf-life*

*Influence of time and storage temperature*

Time and temperature and their interaction significantly influenced the evolution of the physicochemical quality attributes of the ACWW during storage ($p < 0.001$). Figure 1 shows the storage time dependence at 20, 30, and 40 °C.

*pH*

Figure 1a shows the results of the pH of the ACWW stored at 20, 30, and 40 °C. An increase in these values was observed during the storage period, mainly at higher temperatures, from 3.35 at 20 °C on day 0, to 3.51 at 40 °C on day 63. This behavior can be attributed to the oxidation of organic acids during storage, as reported in a similar study. Before storage, heat treatment was applied to some apples ('Anna' and 'Granny Smith' varieties) to extend their shelf-life. The increased $CO_2$ production in apples that rose during heat treatment was related to the malic acid decarboxylase that was present and enhanced its activity at high temperatures (Klein & Lurie, 1990). Therefore, the increase in the pH values indicates that the concentration of organic acids in the ACWW decreased with the rise in storage temperature and time (Anthon et al., 2011).

The pH of the medium can be one of the parameters that influence carotenoid stability. For example, it has been reported that during orange juice processing, the acidic pH of the medium and heating cause rearrangements of 5,6-epoxide groups of violaxanthin to 5,8-epoxide groups (Dhuique-Mayer et al., 2007). It is possible that the acidic pH of the ACWW and the storage temperature promote the isomerization reactions of the carotenoids present in the sample, thus influencing the color changes of the product (Zepka et al., 2009).

*Color parameters*

Figure 1b shows the decrease in the values of L* by increasing the storage time and temperature. The final reduction in the value of L* ranged from 80.67 at 20 °C to 32 at 30 °C. Previous research showed that this behavior is related in the first stage to the degradation of thermolabile pigments that generate dark compounds, which reduce luminosity and degrade more stable compounds in a later stage (Dehghannya et al., 2017; Fuente & Lopes, 2018). Decreasing L* values have also been associated with dehydration of the sample (Onwude et al., 2017).

The variation of the redness values during storage is shown in Figure 1c. An increase from 1.667 at 20 °C to 15.667 at 40 °C in the values of a* was observed. It was detected that by increasing the temperature (40 °C), the ACWW changes its original color to dark red/brownish nuances compared to the sample stored at 20 °C. The same trend was observed in puree (Ibarz et al., 2000) and apple juice (Damasceno et al., 2008), both subjected to a heat treatment. A decrease in the L* value and an increase in a* value simultaneously indicate the sample's browning (Rocha & Morais, 2003).

On the other hand, the ACWW quickly lost its yellow shades; this was attributed to decreased values of b* with increasing storage time and temperature (Figure 1d) and also agrees with the decrease in the values of C* (Figure 1e). C* is the measure that goes from the center of the CIELAB system (C* = 0 = gray) to the direction of pure colors (C* = 100); higher values of C* indicates higher purity or color intensity (Dini et al., 2019). The reduction observed in the b* value varied from 77.67 at 20 °C to 31.67 at 30 °C. This change can be associated with the oxidation of pigments, especially carotenes (Oliveira et al., 2016; Onwude et al., 2017; Prakash et al., 2004) since chloroplastic pigments (chlorophylls and carotenoids) contribute to the coloring of the pulp in apples (Delgado-Pelayo et al., 2014). In fact, in a study where the thermal degradation of carotenoids present in cashew apple was evaluated, it was determined that the decrease in b* values was related to the degradation of β-carotene and β-cryptoxanthin (Zepka et al., 2009). Furthermore, the partial formation of brown pigments (quinones and melanins) could also be responsible for reducing b* values at higher temperatures (Onwude et al., 2017) and also from the decrease in the values of C*. This loss of yellow color due to the decrease in the values of b* and C*, and the change to dark red/brownish nuances due to the increase in the values of a* and the simultaneous decrease in the values of L*, agrees with the decline in the values of h* (Figure 1f). The final reduction in the value of h* ranged from 88.77° at 20 °C to 63.43 at 40 °C. The sample of ACWW changed its color from yellow (< 90°) to orange-yellow (< 67.50) (Dini et al., 2019).

According to the results, the browning of the ACWW was more evident in the samples stored at 30 and 40 °C. The color evolution observed is similar to that reported for a heat-treated apple juice which the color variation showed a clear tendency to shift from light yellow to a dark brown hue. This change was more noticeable with increasing treatment temperature (Damasceno et al., 2008). High temperatures have been shown to favor several non-enzymatic reactions related to discoloration and browning. These include Maillard condensation between reducing sugars and amino acids, caramelization, ascorbic acid browning processes (Ávila & Silva, 1999; Cortellino & Rizzolo, 2018), and destruction of pigments (Ibarz et al., 2000).

Finally, ΔE showed a total increase in color, especially at 20 °C. At higher temperatures (30 and 40 °C), the change in ΔE is faster around the first 20 days. In general, small increases in color are desirable because they indicate that the pigment maintains its properties during storage (Silva et al., 2013). However, the ΔE values obtained for the ACWW at different storage temperatures (Figure 1g) showed values of ΔE in the rank of 1.50 to 50, which indicates that the color difference can be visually perceived. This difference becomes more evident when the ΔE value is greater than 5 (Obón et al., 2009), as for the ACWW analyzed. This variation of ΔE can be primarily associated with transforming the main all-*trans* carotenoids in *cis* isomers, oxidation compounds, volatiles, and other non-detectable low molecular weight compounds (Zepka et al., 2009).

*Kinetics analysis and shelf-life prediction*

Zero- and first-order kinetic models described the changes in quality attributes of the ACWW. Table 1 shows the kinetic parameters obtained for these fittings. Several authors have also

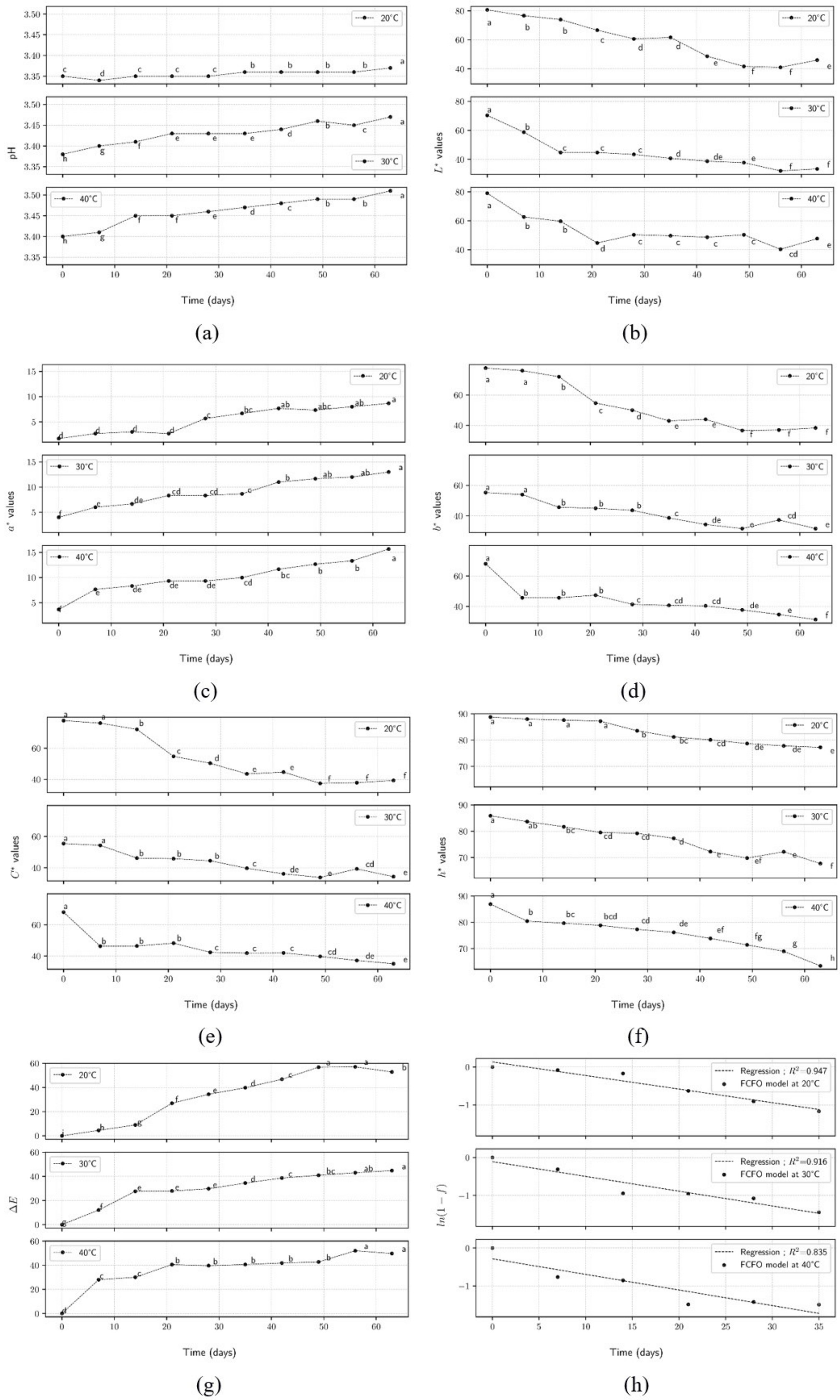


**Figure 1**. Evolution of pH (a), L* values (b), a* values (c), b* values (d), overall color difference (e), chroma or color saturation (f), hue angle (g), and FOFC model (h) as a function of storage time, in the ACWW stored at 20, 30, and 40 °C for 63 days. Different lower case letters indicate differences within storage times ($p < 0.05$).

**Table 1**. $Q_0$, $k$, and $R^2$ for the kinetic models of zero- and first-order for the ACWW.

| T (°C) | Q | Order zero | | | First-order | | |
|---|---|---|---|---|---|---|---|
| | | $Q_0$ | $k$ (days) | $R^2$ | ln $Q_0$ | $k$ (days$^{-1}$) | $R^2$ |
| 20 | pH | 3.344 ± 0.000 | 0.0003 ± 0.000 | 0.784 ± 0.000 | 1.207 ± 0.000 | 0.0001 ± 0.000 | 0.784 ± 0.000 |
| | L* values | 80.939 ± 0.691 | −0.672 ± 0.010 | 0.973 ± 0.032 | 4.423 ± 0.009 | −0.011 ± 0.000 | 0.991 ± 0.001 |
| | a* values | 1.636 ± 0.329 | 0.119 ± 0.005 | 0.886 ± 0.054 | 0.692 ± 0.134 | 0.027 ± 0.003 | 0.880 ± 0.114 |
| | b* values | 75.915 ± 0.907 | −0.730 ± 0.012 | 0.961 ± 0.056 | 4.352 ± 0.012 | −0.013 ± 0.000 | 0.989 ± 0.004 |
| | ΔE | 1.520 ± 0.826 | 0.995 ± 0.011 | 0.977 ± 0.033 | 1.896 ± 0.208 | 0.041 ± 0.004 | 0.967 ± 0.050 |
| 30 | pH | 3.391 ± 0.000 | 0.001 ± 0.000 | 0.924 ± 0.000 | 1.221 ± 0.000 | 0.0004 ± 0.000 | 0.923 ± 0.000 |
| | L* values | 60.091 ± 0.756 | −0.498 ± 0.013 | 0.921 ± 0.121 | 4.101 ± 0.015 | −0.011 ± 0.000 | 0.986 ± 0.006 |
| | a* values | 4.703 ± 0.800 | 0.135 ± 0.014 | 0.947 ± 0.033 | 1.604 ± 0.158 | 0.017 ± 0.003 | 0.909 ± 0.050 |
| | b* values | 53.642 ± 0.499 | −0.378 ± 0.011 | 0.941 ± 0.062 | 3.995 ± 0.011 | −0.009 ± 0.000 | 0.958 ± 0.024 |
| | ΔE | 10.210 ± 0.961 | 0.626 ± 0.014 | 0.946 ± 0.082 | 2.809 ± 0.090 | 0.018 ± 0.002 | 0.972 ± 0.036 |
| 40 | pH | 3.411 ± 0.000 | 0.002 ± 0.000 | 0.935 ± 0.000 | 1.227 ± 0.000 | 0.0005 ± 0.000 | 0.934 ± 0.000 |
| | L* values | 66.218 ± 0.777 | −0.410 ± 0.022 | 0.852 ± 0.221 | 4.183 ± 0.011 | −0.007 ± 0.000 | 0.977 ± 0.004 |
| | a* values | 5.339 ± 0.361 | 0.153 ± 0.007 | 0.931 ± 0.046 | 1.712 ± 0.066 | 0.017 ± 0.001 | 0.931 ± 0.021 |
| | b* values | 56.048 ± 1.003 | −0.406 ± 0.013 | 0.895 ± 0.154 | 4.029 ± 0.020 | −0.009 ± 0.000 | 0.979 ± 0.003 |
| | ΔE | 17.855 ± 0.564 | 0.592 ± 0.025 | 0.891 ± 0.165 | 3.342 ± 0.026 | 0.010 ± 0.001 | 0.959 ± 0.022 |

observed the reaction orders mentioned above by studying the non-enzymatic browning in the dissolutions model and fruit juices (Burdurlu & Karadeniz, 2003; Shi & Jiang, 2002).

The complexity of fruit-based products gives rise to a wide range of non-enzymatic browning reactions during their thermal treatment. Consequently, it is difficult to establish a reaction mechanism and obtain a kinetic model that adequately describes the whole process (Ibarz et al., 2000). For this reason, ΔE was chosen as the critical quality variable to estimate shelf-life (Θ) of the ACWW since it encompasses a general change in the color of the product during storage. In addition, the reaction rate constants ($k$) of ΔE presented the most significant values compared to the $k$ of the other quality attributes: 0.995, 0.626, and 0.592 days$^{-1}$ at 20, 30 y 40 °C, respectively. The above indicates that color change reactions occur faster than the rest during storage at different temperatures. The evolution of ΔE presented the best linear adjustments when modeled with the first-order reaction equation, according to the values of the coefficient of determination ($R^2$), that is, 0.967, 0.972, and 0.959 at 20, 30, and 40 °C, respectively.

A graphical representation of ΔE expressed as FOFC model is shown in Figure 1h. The equations: $ln(1-f) = -0.0358t + 0.1347$ ($R^2 = 0.947$), $ln(1-f) = -0.0390t - 0.1091$ ($R^2 = 0.916$), and $ln(1-f) = -0.0412t - 0.2847$ ($R^2 = 0.835$) were obtained by linear regression to calculate $ln(1-f)$ as a function of time ($t$, days) at 20, 30, and 40 °C of storage, respectively.

These equations provided the following shelf-life estimation: 45.640 ± 0.770 days at 20 °C, 35.822 ± 2.369 days at 30 °C, and 29.561 ± 0.955 days at 40 °C using as a "critical" point the value $ln(1-f) = -1.496$ that was determined by sensory analysis, at 35 days of storage at 40 °C. In this regard, according to sensory evaluation results, the judges perceived that the color, flavor, and odor of the ACWW suffered intense changes associated with deterioration during the storage of the sample, mainly at 40 °C. These results are in agreement with those obtained from the physicochemical attributes. After 35 days of storage at 40 °C, the sample's color, odor, and flavor were not typical for the product and limited the willingness to consume it. It was observed that the higher the temperature, the shorter the shelf-life of the sample.

Subsequently, to establish the equation that allows predicting the shelf-life (Θ, days) of the ACWW, the values of Log Θ vs. temperature (T, °C) were plotted. Data presented a linear adjustment ($R^2 = 0.996$) leading to Equation 6.

$$\Theta = 10^{-0.0094T+1.8444} \tag{6}$$

The changes in the $k$ due to storage temperature are usually characterized using a measure called acceleration factor $Q_{10}$ (Giarratana et al., 2020; Hemanth et al., 2020; Mancebo-Campos et al., 2008). So, in this work, $Q_{10}$ was 1.070; that is, for every 10 °C that the temperature increases, the $k$ value of the FOFC model (ΔE), will increase 1.070 times.

Additionally, the FOFC model velocity constants dependence on the temperature had a linear adjustment with the Arrhenius equation ($R^2 = 0.990$), so that an $E_a$ of 5.307 kJ mol$^{-1}$ and a pre-exponential factor ($A$) of 0.317 days$^{-1}$ were calculated. The higher values of $E_a$ are related to greater heat sensitiveness of color degradation during storage (Chutintrasri & Noomhorm, 2007). Similar results were observed for seedless guava (*Psidium guajava* L.) stored at higher temperatures (of 80 to 95 °C) which leads to the obtention of higher $E_a$ of the ΔE (112.65 ± 5 kJ mol$^{-1}$) (Ganjloo et al., 2011).

### *3.3 Thermodynamic analysis of color degradation*

Foods are thermodynamically unstable, and they are gradually tending to a state with higher entropy and lower enthalpy (Van Boekel, 2008). In this work, the thermodynamic parameters were calculated using ΔE expressed as the FOFC model. The $\Delta S^{\ddagger}$ is related to the number of molecules with appropriate energy that can react (Vikram et al., 2005). In this work, a value of −262.916 J K$^{-1}$ mol$^{-1}$ indicates that the transition state has less structural freedom than the reactants. Consequently, more energy is required to form an activated complex (Martynenko & Chen, 2016). This benefits the ACWW because the ΔE requires more energy, and the color will remain stable longer at room temperature or lower, which is supported by the $\Delta G^{\ddagger}$ value.

The $\Delta G^{\ddagger}$ value is defined as the difference between energies of reactants and activated state and generally is used as a measure of process spontaneity (Chouaibi et al., 2021; Liu et al., 2019; Martynenko & Chen, 2016). Positive $\Delta G^{\ddagger}$ value obtained (79.86 kJ $mol^{-1}$) indicated that for the ACWW, color thermal degradation is a non-spontaneous reaction at 20 °C, and it needs a contribution of energy to be carried out (Martynenko & Chen, 2016; Mercali et al., 2013).

Finally, the value of $\Delta H^{\ddagger}$ (2.789 kJ $mol^{-1}$) was close to the value of $E_a$, which was consistent with the result reported in a previous study (Zhang et al., 2021). This is because $\Delta H^{\ddagger}$ represents the minimum energy required for the reactant to make the reaction occur and is related to the strength of the chemical bonds which are broken and made during the reaction. The positive value of $\Delta H^{\ddagger}$ determined for the ACWW indicated that the reaction of color degradation is endothermic, therefore the degradation rate increased with temperature (Martynenko & Chen, 2016; Vikram et al., 2005). Indeed, the higher value of $E_a$ or $\Delta H^{\ddagger}$ from ΔE implied that a higher temperature change was needed to degrade color in the ACWW compared to the other quality indices. Therefore, the thermodynamic analysis provides a reliable criterion for predicting fruit-based products' storage stability and shelf-life, such as compotes.

## 4 Conclusion

The implementation of CVS for image analysis and the kinetics-based ASLT can be used to predict the shelf-life of apple compotes and similar products. Color was the critical parameter determining the shelf-life of the ACWW, and the shelf-life predicted was shorter than expected for this type of product. Different strategies as, including anti-browning additives in the formulation as well as the use of dark glass jars, could be adequate to prevent or slow down the non-enzymatic reactions occurring during storage. This will allow preserving the product's properties for extended periods avoiding economic losses for producers.

A study with a longer storage time and with the proposed modifications in the formulation and packaging of the product should be carried out to determine if the color continues to be the physicochemical quality attribute with the most significant impact on its shelf life, with the purpose to assess the relevance of the proposed method. However, the developed method can be useful in other applications where color is the determining attribute of food quality during storage, distribution, and sale.

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## References

Aaby, K., Grimsbo, I. H., Hovda, M. B., & Rode, T. M. (2018). Effect of high pressure and thermal processing on shelf life and quality of strawberry purée and juice. *Food Chemistry*, 260, 115-123. http://dx.doi.org/10.1016/j.foodchem.2018.03.100. PMid:29699651.

Akhmetov, M., Demirova, A., Abdulkhalikov, Z., Daudova, T., & Daudova, L. (2020). An enhanced technology of pear compote production through direct blanching with sugar syrup in glass jars and a device for its implementation. *E3S Web of Conferences*, 161, 01049. http://dx.doi.org/10.1051/e3sconf/202016101049.

Anthon, G. E., Lestrange, M., & Barrett, D. M. (2011). Changes in pH, acids, sugars and other quality parameters during extended vine holding of ripe processing tomatoes. *Journal of the Science of Food and Agriculture*, 91(7), 1175-1181. http://dx.doi.org/10.1002/jsfa.4312. PMid:21384370.

Ávila, I. M. L. B., & Silva, C. L. M. (1999). Modelling kinetics of thermal degradation of colour in peach puree. *Journal of Food Engineering*, 39(2), 161-166. http://dx.doi.org/10.1016/S0260-8774(98)00157-5.

Bailón-Moreno, R., Olivares-Arias, V., Vicaria, J. M., & Chiadmi-García, L. (2018). Shelf-life kinetic model for freeze-dried oranges using sensory analysis and luminance determination. *Journal of Food Science and Technology*, 55(10), 4013-4019. http://dx.doi.org/10.1007/s13197-018-3326-4. PMid:30228399.

Barbin, D. F., Mastelini, S. M., Barbon, S. Jr., Campos, G. F. C., Barbon, A. P. A. C., & Shimokomaki, M. (2016). Digital image analyses as an alternative tool for chicken quality assessment. *Biosystems Engineering*, 144, 85-93. http://dx.doi.org/10.1016/j.biosystemseng.2016.01.015.

Burdurlu, H. S., & Karadeniz, F. (2003). Effect of storage on nonenzymatic browning of apple juice concentrates. *Food Chemistry*, 80(1), 91-97. http://dx.doi.org/10.1016/S0308-8146(02)00245-5.

Buvé, C., Kebede, B. T., Batselier, C., Carrillo, C., Pham, H. T. T., Hendrickx, M., Grauwet, T., & Van Loey, A. (2018). Kinetics of colour changes in pasteurised strawberry juice during storage. *Journal of Food Engineering*, 216, 42-51. http://dx.doi.org/10.1016/j.jfoodeng.2017.08.002.

Campos, G. F. C., Seixas, J. L. Jr., Barbon, A. P. A. C., Felinto, A. S., Bridi, A. M., & Barbon, S. Jr. (2020). Robust computer vision system for marbling meat segmentation. *ELCVIA*, 19(1), 15-27. http://dx.doi.org/10.5565/rev/elcvia.777.

Chouaibi, M., Snoussi, A., Attouchi, S., & Ferrari, G. (2021). Influence of drying processes on bioactive compounds profiles, hydroxymethylfurfural, color parameters, and antioxidant activities of Tunisian eggplant (*Solanum melongena* L.). *Journal of Food Processing and Preservation*, 45(6), e15460. http://dx.doi.org/10.1111/jfpp.15460.

Chutintrasri, B., & Noomhorm, A. (2007). Color degradation kinetics of pineapple puree during thermal processing. *Lebensmittel-Wissenschaft + Technologie*, 40(2), 300-306. http://dx.doi.org/10.1016/j.lwt.2005.11.003.

Corradini, M. G. (2018). Shelf life of food products: from open labeling to real-time measurements. *Annual Review of Food Science and Technology*, 9(1), 251-269. http://dx.doi.org/10.1146/annurev-food-030117-012433. PMid:29328810.

Cortellino, G., & Rizzolo, A. (2018). Storage stability of novel functional drinks based on ricotta cheese whey and fruit juices. *Beverages*, 4(3), 67. http://dx.doi.org/10.3390/beverages4030067.

Damasceno, L. F., Fernandes, F. A. N., Magalhães, M. M. A., & Brito, E. S. (2008). Non-enzymatic browning in clarified cashew apple juice during thermal treatment: kinetics and process control. *Food Chemistry*, 106(1), 172-179. http://dx.doi.org/10.1016/j.foodchem.2007.05.063.

Dehghannya, J., Gorbani, R., & Ghanbarzadeh, B. (2017). Influence of combined pretreatments on color parameters during convective drying of Mirabelle plum (*Prunus domestica* subsp. *syriaca*). *Heat and Mass Transfer*, 53(7), 2425-2433. http://dx.doi.org/10.1007/s00231-017-1995-6.

Delgado-Pelayo, R., Gallardo-Guerrero, L., & Hornero-Méndez, D. (2014). Chlorophyll and carotenoid pigments in the peel and flesh of commercial apple fruit varieties. *Food Research International*, 65(Pt B), 272-281. http://dx.doi.org/10.1016/j.foodres.2014.03.025.

Dermesonlouoglou, E. K., Giannakourou, M., & Taoukis, P. S. (2016). Kinetic study of the effect of the osmotic dehydration pre-treatment with alternative osmotic solutes to the shelf life of frozen strawberry. *Food and Bioproducts Processing*, 99, 212-221. http://dx.doi.org/10.1016/j.fbp.2016.05.006.

Dhuique-Mayer, C., Tbatou, M., Carail, M., Caris-Veyrat, C., Dornier, M., & Amiot, M. J. (2007). Thermal degradation of antioxidant micronutrients in Citrus juice: kinetics and newly formed compounds. *Journal of Agricultural and Food Chemistry*, 55(10), 4209-4216. http://dx.doi.org/10.1021/jf0700529. PMid:17451252.

Dini, M., Raseira, M. C. B., Scariotto, S., Carra, B., Abreu, E. S., Mello-Farias, P., & Cantillano, R. F. F. (2019). Color shade heritability of peach flesh. *The Journal of Agricultural Science*, 11(8), 236-247. http://dx.doi.org/10.5539/jas.v11n8p236.

Foca, G., Masino, F., Antonelli, A., & Ulrici, A. (2011). Prediction of compositional and sensory characteristics using RGB digital images and multivariate calibration techniques. *Analytica Chimica Acta*, 706(2), 238-245. http://dx.doi.org/10.1016/j.aca.2011.08.046. PMid:22023857.

Fuente, C. I. A., & Lopes, C. C. (2018). HTST puffing in order to produce crispy banana - the effect of the step-down treatment prior to air-drying. *Lebensmittel-Wissenschaft + Technologie*, 92, 324-329. http://dx.doi.org/10.1016/j.lwt.2018.02.049.

Ganjloo, A., Rahman, R. A., Osman, A., Bakar, J., & Bimakr, M. (2011). Kinetics of crude peroxidase inactivation and color changes of thermally treated seedless guava (*Psidium guajava* L.). *Food and Bioprocess Technology*, 4(8), 1442-1449. http://dx.doi.org/10.1007/s11947-009-0245-4.

Geronimo, B. C., Mastelini, S. M., Carvalho, R. H., Barbon, S. Jr., Barbin, D. F., Shimokomaki, M., & Ida, E. I. (2019). Computer vision system and near-infrared spectroscopy for identification and classification of chicken with wooden breast, and physicochemical and technological characterization. *Infrared Physics & Technology*, 96, 303-310. http://dx.doi.org/10.1016/j.infrared.2018.11.036.

Giarratana, F., Nalbone, L., Ziino, G., Giuffrida, A., & Panebianco, F. (2020). Characterization of the temperature fluctuation effect on shelf life of an octopus semi-preserved product. *Italian Journal of Food Safety*, 9(1), 8590. http://dx.doi.org/10.4081/ijfs.2020.8590. PMid:32300571.

Haddad, A. M. L., Margalef, M. I., Armada, M., & Goldner, M. C. (2017). Physico-chemical and sensory properties of marmalades made from mixtures of fruits and under-exploited Andean tubers. *Journal of the Science of Food and Agriculture*, 97(12), 4124-4134. http://dx.doi.org/10.1002/jsfa.8280. PMid:28220503.

Hashemi, S. M. B., Brewer, M. S., Safari, J., Nowroozi, M., Sherahi, M. H. A., Sadeghi, B., & Ghafoori, M. (2016). Antioxidant activity, reaction mechanisms, and kinetics of *Matricaria recutita* extract in commercial blended oil oxidation. *International Journal of Food Properties*, 19(2), 257-271. http://dx.doi.org/10.1080/10942912.2015.1020438.

Hemanth, K. J., Hema, M. S., Sinija, V. R., & Hema, V. (2020). Accelerated shelf-life study on protein-enriched carbonated fruit drink. *Journal of Food Process Engineering*, 43(3), e13311. http://dx.doi.org/10.1111/jfpe.13311.

Ibarz, A., Pagán, J., & Garza, S. (1999). Kinetic models for colour changes in pear puree during heating at relatively high temperatures. *Journal of Food Engineering*, 39(4), 415-422. http://dx.doi.org/10.1016/S0260-8774(99)00032-1.

Ibarz, A., Pagán, J., & Garza, S. (2000). Kinetic models of non-enzymatic browning in apple puree. *Journal of the Science of Food and Agriculture*, 80(8), 1162-1168. http://dx.doi.org/10.1002/1097-0010(200006)80:8<1162::AID-JSFA613>3.0.CO;2-Z.

Jafari, S. M., Ganje, M., Dehnad, D., Ghanbari, V., & Hajitabar, J. (2017). Arrhenius equation modeling for the shelf life prediction of tomato paste containing a natural preservative. *Journal of the Science of Food and Agriculture*, 97(15), 5216-5222. http://dx.doi.org/10.1002/jsfa.8404. PMid:28452059.

Jaimez-Ordaz, J., Pérez-Flores, J. G., Castañeda-Ovando, A., González-Olivares, L. G., Añorve-Morga, J., & Contreras-López, E. (2019). Kinetic parameters of lipid oxidation in third generation (3G) snacks and its influence on shelf-life. *Food Science and Technology*, 39(Suppl. 1), 136-140. http://dx.doi.org/10.1590/fst.38917.

Kato, T., Mastelini, S. M., Campos, G. F. C., Barbon, A. P. A. C., Prudencio, S. H., Shimokomaki, M., Soares, A. L., & Barbon, S. Jr. (2019). White striping degree assessment using computer vision system and consumer acceptance test. *Asian-Australasian Journal of Animal Sciences*, 32(7), 1015-1026. http://dx.doi.org/10.5713/ajas.18.0504. PMid:30744375.

Klein, J. D., & Lurie, S. (1990). Prestorage heat treatment as a means of improving poststorage quality of apples. *Journal of the American Society for Horticultural Science*, 115(2), 265-269. http://dx.doi.org/10.21273/JASHS.115.2.265.

León, K., Mery, D., Pedreschi, F., & León, J. (2006). Color measurement in L*a*b* units from RGB digital images. *Food Research International*, 39(10), 1084-1091. http://dx.doi.org/10.1016/j.foodres.2006.03.006.

Ling, B., Tang, J., Kong, F., Mitcham, E. J., & Wang, S. (2015). Kinetics of food quality changes during thermal processing: a review. *Food and Bioprocess Technology*, 8(2), 343-358. http://dx.doi.org/10.1007/s11947-014-1398-3.

Liu, Y., Pu, H., & Sun, D.-W. (2021). Efficient extraction of deep image features using convolutional neural network (CNN) for applications in detecting and analysing complex food matrices. *Trends in Food Science & Technology*, 113, 193-204. http://dx.doi.org/10.1016/j.tifs.2021.04.042.

Liu, Y., Zhang, X.-K., Shi, Y., Duan, C.-Q., & He, F. (2019). Reaction kinetics of the acetaldehyde-mediated condensation between (−)-epicatechin and anthocyanins and their effects on the color in model wine solutions. *Food Chemistry*, 283, 315-323. http://dx.doi.org/10.1016/j.foodchem.2018.12.135. PMid:30722877.

Lopes, J. F., Ludwig, L., Barbin, D. F., Grossmann, M. V. E., & Barbon, S. Jr. (2019). Computer vision classification of barley flour based on spatial pyramid partition ensemble. *Sensors*, 19(13), 2953. http://dx.doi.org/10.3390/s19132953. PMid:31277468.

Mancebo-Campos, V., Fregapane, G., & Salvador, M. D. (2008). Kinetic study for the development of an accelerated oxidative stability test to estimate virgin olive oil potential shelf life. *European Journal of Lipid Science and Technology*, 110(10), 969-976. http://dx.doi.org/10.1002/ejlt.200800022.

Martynenko, A., & Chen, Y. (2016). Degradation kinetics of total anthocyanins and formation of polymeric color in blueberry hydrothermodynamic (HTD) processing. *Journal of Food Engineering*, 171, 44-51. http://dx.doi.org/10.1016/j.jfoodeng.2015.10.008.

Mastelini, S. M., Sasso, M. G. A., Campos, G. F. C., Schmiele, M., Clerici, M. T. P. S., Barbin, D. F., & Barbon, S. (2018). Computer vision system for characterization of pasta (noodle) composition. *Journal of Electronic Imaging*, 27(5), 1. http://dx.doi.org/10.1117/1.JEI.27.5.053021.

Mendoncla, C. R., Zambiazi, R., & Granada, G. G. (2001). Partial substitution of sugars by the low-calorie sweetener sucralose in peach compote. *Journal of Food Science*, 66(8), 1195-1200. http://dx.doi.org/10.1111/j.1365-2621.2001.tb16104.x.

Mercali, G. D., Jaeschke, D. P., Tessaro, I. C., & Marczak, L. D. F. (2013). Degradation kinetics of anthocyanins in acerola pulp: comparison between ohmic and conventional heat treatment. *Food Chemistry*, 136(2), 853-857. http://dx.doi.org/10.1016/j.foodchem.2012.08.024. PMid:23122136.

Obón, J. M., Castellar, M. R., Alacid, M., & Fernández-López, J. A. (2009). Production of a red-purple food colorant from *Opuntia stricta* fruits by spray drying and its application in food model systems. *Journal of Food Engineering*, 90(4), 471-479. http://dx.doi.org/10.1016/j.jfoodeng.2008.07.013.

Oliveira, M. M., Cerqueira, B. V., Barbon, S. Jr., & Barbin, D. F. (2021). Classification of fermented cocoa beans (cut test) using computer vision. *Journal of Food Composition and Analysis*, 97, 103771. http://dx.doi.org/10.1016/j.jfca.2020.103771.

Oliveira, S. M., Brandão, T. R. S., & Silva, C. L. M. (2016). Influence of drying processes and pretreatments on nutritional and bioactive characteristics of dried vegetables: a review. *Food Engineering Reviews*, 8(2), 134-163. http://dx.doi.org/10.1007/s12393-015-9124-0.

Onwude, D. I., Hashim, N., Janius, R., Nawi, N. M., & Abdan, K. (2017). Color change kinetics and total carotenoid content of pumpkin as affected by drying temperature. *Italian Journal of Food Science*, 29(1), 1-18.

Palazón, M. A., Pérez-Conesa, D., Abellán, P., Ros, G., Romero, F., & Vidal, M. L. (2009). Determination of shelf-life of homogenized apple-based beikost storage at different temperatures using Weibull hazard model. *Lebensmittel-Wissenschaft + Technologie*, 42(1), 319-326. http://dx.doi.org/10.1016/j.lwt.2008.03.011.

Park, J.-M., Koh, J.-H., & Kim, J.-M. (2018). Predicting shelf-life of ice cream by accelerated conditions. *Korean Journal for Food Science of Animal Resources*, 38(6), 1216-1225. http://dx.doi.org/10.5851/kosfa.2018.e55. PMid:30675114.

Pereira, C. A. P., León, G. M. L., Hernández, A. I. M., & González, R. A. O. (2012). Determinación del color en epicarpio de tomates (*Lycopersicum esculentum* Mill.) con sistema de visión computarizada durante la maduración. *Agronomia Costarricense*, 36(1), 97-111.

Pereira, L. F. S., Barbon, S. Jr., Valous, N. A., & Barbin, D. F. (2018). Predicting the ripening of papaya fruit with digital imaging and random forests. *Computers and Electronics in Agriculture*, 145, 76-82. http://dx.doi.org/10.1016/j.compag.2017.12.029.

Prakash, S., Jha, S. K., & Datta, N. (2004). Performance evaluation of blanched carrots dried by three different driers. *Journal of Food Engineering*, 62(3), 305-313. http://dx.doi.org/10.1016/S0260-8774(03)00244-9.

R Core Team. (2018). *R: a language and environment for statistical computing*. Vienna: R Core Team. Retrieved from https://www.r-project.org/

Rizvi, A. F., & Tong, C. H. (1997). Fractional conversion for determining texture degradation kinetics of vegetables. *Journal of Food Science*, 62(1), 1-7. http://dx.doi.org/10.1111/j.1365-2621.1997.tb04356.x.

Rocha, A. M. C. N., & Morais, A. M. M. B. (2003). Shelf life of minimally processed apple (cv. Jonagored) determined by colour changes. *Food Control*, 14(1), 13-20. http://dx.doi.org/10.1016/S0956-7135(02)00046-4.

RStudio Team. (2021). *RStudio: integrated development environment for R*. Vienna: RStudio Team. Retrieved from http://www.rstudio.com/

Shi, D., & Jiang, B. H. (2002). Antioxidant properties of apple juice and its protection against Cr(VI)-induced cellular injury. *Journal of Environmental Pathology, Toxicology and Oncology*, 21(3), 233-242. http://dx.doi.org/10.1615/JEnvironPatholToxicolOncol.v21.i3.40. PMid:12435076.

Silva, P. I., Stringheta, P. C., Teófilo, R. F., & Oliveira, I. R. N. (2013). Parameter optimization for spray-drying microencapsulation of jaboticaba (*Myrciaria jaboticaba*) peel extracts using simultaneous analysis of responses. *Journal of Food Engineering*, 117(4), 538-544. http://dx.doi.org/10.1016/j.jfoodeng.2012.08.039.

Sokół-Łętowska, A., Kucharska, A. Z., Szumny, A., Wińska, K., & Nawirska-Olszańska, A. (2018). Phenolic composition stability and antioxidant activity of sour cherry liqueurs. *Molecules*, 23(9), 2156. http://dx.doi.org/10.3390/molecules23092156. PMid:30150590.

Udomkun, P., Nagle, M., Argyropoulos, D., Mahayothee, B., Latif, S., & Müller, J. (2016). Compositional and functional dynamics of dried papaya as affected by storage time and packaging material. *Food Chemistry*, 196, 712-719. http://dx.doi.org/10.1016/j.foodchem.2015.09.103. PMid:26593545.

Udomkun, P., Nagle, M., Argyropoulos, D., Wiredu, A. N., Mahayothee, B., & Müller, J. (2017). Computer vision coupled with laser backscattering for non-destructive colour evaluation of papaya during drying. *Journal of Food Measurement and Characterization*, 11(4), 2142-2150. http://dx.doi.org/10.1007/s11694-017-9598-y.

Ulrici, A., Foca, G., Ielo, M. C., Volpelli, L. A., & Fiego, D. P. (2012). Automated identification and visualization of food defects using RGB imaging: application to the detection of red skin defect of raw hams. *Innovative Food Science & Emerging Technologies*, 16, 417-426. http://dx.doi.org/10.1016/j.ifset.2012.09.008.

Valous, N. A., Mendoza, F., Sun, D. W., & Allen, P. (2009). Colour calibration of a laboratory computer vision system for quality evaluation of pre-sliced hams. *Meat Science*, 81(1), 132-141. http://dx.doi.org/10.1016/j.meatsci.2008.07.009. PMid:22063973.

Van Boekel, M. A. J. S. (2008). Kinetic modeling of food quality: a critical review. *Comprehensive Reviews in Food Science and Food Safety*, 7(1), 144-158. http://dx.doi.org/10.1111/j.1541-4337.2007.00036.x.

Vikram, V. B., Ramesh, M. N., & Prapulla, S. G. (2005). Thermal degradation kinetics of nutrients in orange juice heated by electromagnetic and conventional methods. *Journal of Food Engineering*, 69(1), 31-40. http://dx.doi.org/10.1016/j.jfoodeng.2004.07.013.

Wang, S., Zhang, H., Liu, X., Tamura, T., Kyouno, N., & Chen, J. Y. (2018). Relationship between chemical characteristics and sensory evaluation of Koikuchi soy sauce. *Analytical Letters*, 51(14), 2192-2204. http://dx.doi.org/10.1080/00032719.2017.1419252.

Wu, D., & Sun, D. W. (2013). Colour measurements by computer vision for food quality control - a review. *Trends in Food Science & Technology*, 29(1), 5-20. http://dx.doi.org/10.1016/j.tifs.2012.08.004.

Zepka, L. Q., Borsarelli, C. D., Silva, M. A. A. P., & Mercadante, A. Z. (2009). Thermal degradation kinetics of carotenoids in a cashew apple juice model and its impact on the system color. *Journal of Agricultural and Food Chemistry*, 57(17), 7841-7845. http://dx.doi.org/10.1021/jf900558a. PMid:19663479.

Zhang, W., Luo, Z., Wang, A., Gu, X., & Lv, Z. (2021). Kinetic models applied to quality change and shelf life prediction of kiwifruits. *LWT*, 138, 110610. http://dx.doi.org/10.1016/j.lwt.2020.110610.