Utilization of physicochemical variables developed from changes in sensory attributes and consumer acceptability to predict the shelf life of fresh-cut mango fruit

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Abstract Sensory evaluation is the ideal tool for shelf-life determination. With the objective to develop an easy shelf-life indicator, color (L^* , a^* , b^* , chroma and hue angle), total soluble solids (TSS), firmness (F), pH, acidity, and the sensory attributes of appearance, brightness, browning, odor, flavor, texture, color, acidity and sweetness were evaluated in fresh cut mangoes (FCM) stored at 5, 10, 15 and 20 °C. Overall acceptability was evaluated by consumers. Correlation analysis between sensory attributes and physicochemical variables was carried out. Physicochemical cut-off points based on sensory attributes and consumer acceptability was obtained by regression analysis and utilized to estimate FCM shelf-life by kinetic models fitted to each variable. The validation of the model was done by comparing the shelf life estimated by kinetic models and consumers. It was recorded large correlations between appearance, brightness, and color with L^* ; appearance and color with chroma and hue angle; sweetness and flavor with TSS, and between F and texture. The shelf life estimated based on consumer using a 9 point hedonic scale was in the range of 10–12, 2.3–2.6, 1.3–1.5 and 1.0–1.1 days for 5, 10, 15 and 20 °C. It was recorded large correlation coefficients between the shelf life estimated by consumer acceptability scores and physicochemical variables. Kinetic models based on physicochemical variables showed a tendency to

overestimate the shelf life as compared with the models bases on the sensory attributes. It was concluded that physicochemical variables can be used as a tool to estimate the FCM shelf life.

Keywords Fresh-cut fruits · Sensory quality · Consumer acceptability · Mathematical models · Shelf life prediction

Introduction

The shelf-life is the time period in which a produce maintain its sensory, functional, and nutritional characteristics in optimal conditions in such a way that it is acceptable for consumer (Hough and Fiszman 2005). Several studies indicate that sensory changes are the most important factors affecting the quality of products, suggesting the importance of utilizing sensory evaluations to determine the shelf-life of fresh cuts products (Kader 2001; Fiszman 2005).

Sensory shelf-life can be estimated based in a significant change in one or several critical attributes evaluated by a trained panel, but only consumer evaluation can ensure commercial acceptance of product (Hampson et al. 2000). However, the protocols involved in sensory evaluation can be time consuming and expensive. In this context, it is important to identify physicochemical variables related with sensory changes that can be used as indicators of quality, due to the fact that they are easy to measure, objective, and relatively inexpensive.

According to Kokini (1985), the accuracy of an objective method to measure the sensory quality of a food is determined by its correlation to the sensory evaluation of that attribute. Therefore, physicochemical variables with a high correlation with the sensory attributes can be used as indicators of the sensory changes. This is true only if there is an effective dependence or causal interaction between the

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two variables. In agreement, Stone and Sidel (1993) mentioned that several sensory characteristics can be correlated with physicochemical and biochemical changes of the food-stuff. Correlation between sensory attributes and physicochemical changes had been analyzed in several products (Hough et al. 2002; Wittig de Penna et al. 2005). In fruits, the correlation between texture and color has been analyzed in plum, apple, tomato, and pineapple (Plochanski and Konopacka 2003; Mehinagic et al. 2004; Chaïb et al. 2007; Schulbach et al. 2007).

A study was done comparing the tomato mutants deficient in carotenoid biosynthesis: tangerine, old-gold and yellow-flesh with their nearly isogenic tomato line 'Ailsa Craig'. Large Pearson correlation coefficients were found between samples with high levels of citric acid and total soluble solids with overall acceptability, sweetness acceptability and flavor acceptability. The high concentrations of β -ionone and β -cyclocitral was found related with large scores of flavor acceptability and overall acceptability, whereas guaiacol y methylsalicylate showed an opposite trend. Moreover, the higher amount of 2-isobutylthiazole, phenylacetaldehyde and the stereoisomer (E)-pseudoionone were correlated with low scores in sweetness acceptability. The authors concluded that the profile of volatiles can influence the tomato flavor and acceptability (Vogel et al. 2010). Furthermore, the sensorial and analytical evaluation of peaches and nectarines showed a significant correlation between either malic acid, citric acid and pH and sourness (Esti et al. 1997).

Lin et al. (2006) found in fresh cut pears a good correlation between color and appearance evaluated by a consumer panel with lightness (L^*). Moreover, regression analysis showed a concomitant increase of L^* with consumer acceptability of fresh-cut pear slices color. Also, it was found for eggplant, the surface gloss measured using a spectroradiometer, showed a linear correlation with weight which suggest that it is possible to use this instrument to do a non destructive quality evaluation for this vegetable (Jha and Matsuoka 2002). By other side, in apples, Péneau et al. (2007) observed the correlation between freshness (sensory evaluated) and texture instrumentally evaluated. In the case of mango, critical properties for acceptability related with taste were identified by Malundo et al. (2001).

Besides of correlation analysis, the identification of physicochemical variables related with sensory changes had been also carried out by regression analysis. This has been used to obtain cut-off points of sensory attributes based on the limit of consumer acceptability (Ramírez et al. 2001; Hough et al. 2002; Gámbaro et al. 2004; Wittig de Penna et al. 2005). In the case of mango, two experiments were carried out analyzing the texture and sensory attributes. In one of the experiments, it was evaluated the changes during 10 days of the textural properties in seven cultivars of mango fruit

harvested at three different sampling times (Jha et al. 2011a). The changes in texture during mango fruit ripening allowed the development of an equation to predict appearance, taste, flavor and overall acceptability from firmness of fruit, peel and pulp as well as from peel and pulp toughness for the mango cultivars during 10 days of ripening time. It was found that flavor showed a negative and large correlation with peel firmness whereas overall acceptability showed a large positive correlation. Moreover, polynomial equations with determination coefficients higher than 0.9 were developed to predict the sensory quality of mango fruit from textural changes for all cultivars with the exception of one (Jha et al. 2011b). However, a methodology to obtain cut-off points for the physicochemical variables based on sensorial analysis has not been reported for fresh cuts. Instead, subjective analysis of the organoleptic quality changes had been used in several studies to know the shelf life of these products (Beaulieu and Lea 2003; Sothornvit and Rodsamran 2010; Sgroppo et al. 2010; Chiumarelli et al. 2010).

In this sense, this is the first effort to obtain cut-off points using physicochemical variables, taking into account sensory cut-off points and consumer acceptability. These values can be used as simple and fast indicators to monitor sensory changes or to estimate shelf-life.

Based on the above mentioned, the aim of this study was to establish physicochemical cut-off points to estimate the shelf-life of fresh cut mango fruits.

Materials and methods

Mango fruit

Mangoes cultivar 'Haden' were obtained from a commercial supplier and stored at 10 °C prior to carry out the experimentation.

Sample preparation and treatments

Mango fruits were processed once they had reached a percentage of total soluble solids (TSS) of 16–17 %. The whole mangoes were washed in chlorinated water (150 ppm), peeled and cut into cubes of approximately 2.5 cm of side length. The cubes were sanitized by immersion in chlorinated water (50 ppm) for two min. After that, water in excess was eliminated by using an Essoreuse 1642 manual centrifuge. Polyethylene trays of 250 mL were packaged with 80 g of cubes, sealed and stored at 5, 10, 15, and 20 °C for 432, 81, 54, and 27 h, respectively. Furthermore, with the goal to perform at least nine times the physicochemical and sensory evaluations, sampling was done at intervals of 48, 10, 6, and 3 h at 5, 10, 15, and 20 °C, respectively.

However, at 15 °C it was not possible to do nine times the evaluation due to time constraints.

In each sampling time, a total of 134 trays were retrieved in such a way that 20 were utilized to do the sensory evaluation by the trained panel, 14 for the determination of physicochemical variables, and 100 for sensory evaluation by consumers.

Microbiological evaluation

Before carrying out the sensory and physicochemical evaluation, a microbiological quality control was done. Total counts of mesophilic and psychrophilic aerobic bacteria, total coliforms as well as molds and yeasts were determined and results were compared with the limits established by the International Fresh-cut Produce Association (IFPA 2003).

Physicochemical evaluation

Color Color was measured on four cubes from each of four trays designed for this purpose in each treatment by a Minolta Chroma Meter CR-300 colorimeter with a D65 as the reference illuminant and using a 10° observation angle (Konica Minolta Sensing Americas, Inc. 101 Williams Drive Ramsey, NJ 07446 USA). Chroma (C) and hue angle (h°) were calculated as follows:

$$C^* = (a^{*2} + b^{*2})^{\frac{1}{2}} \quad (1)$$

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

Where: L^* is a color space coordinate indicating lightness of the color; a^* is a color space coordinate indicating changes between green and magenta; b^* is a color space coordinate indicating changes between blue and yellow; C^* is chroma which indicates the intensity of a particular color and h° is the hue angle which indicates the perception of the color in a similar way like human eye.

Total soluble solids Total soluble solids (TSS) were measured with an ATAGO PR-101 digital refractometer (Nova-Tech International, Inc. 800 Rockmead Dr Ste 102. Houston, TX, U.S.A.) using nine cubes randomly chosen from each tray.

Firmness Firmness was determined in three cubes using a Chatillon TCM200 (Labquip Ltd. 170 Shields Ct., Unit 2 Markham, Ontario, Canada L3R9T5) force gauge with a 1.2 mm diameter punch using a speed of 8 mm·s⁻¹. The penetration of the probe was 1 cm and the speed was adjusted with the goal to have enough time for change between samples. The results were expressed as the force needed to penetrate the tissue in Newtons.

Titrateable acidity and pH For titrateable acidity, three portions of 20 g per tray were homogenized with 50 mL of distilled water. Thereafter, a 50 mL volume of the supernatant was titrated with 0.1 N NaOH to a pH 8.1 endpoint with Mettler DL21 automatic titrator (Mettler-Toledo, LLC, 1900 Polaris Parkway, Columbus, OH 43240, U.S.A.). Titrateable acidity was expressed as a percentage of citric acid. The pH was also determined with the automatic titrator.

Sensory evaluation

Recruitment and selection of judges Twenty-nine candidates were recruited based on their interests, availability, health, habits, and food preferences. Pre-selected candidates were evaluated to know their threshold in basic tastes, odor identification, and discriminating capabilities of color, odor, texture, sweetness, and acidity *stimuli* through triangular tests (AENOR 1997). Final selection was done based on a sequential analysis ($P1=1/3$, $P2=2/3$, $\alpha=0.05$ and $\beta=0.05$) as described (Meilgaard et al. 1999). The final trained panel was made up of ten judges (6 men and 4 women).

Descriptors and judge training Fresh-cut mango samples with different storage times were prepared with the goal to reach an agreement as to what terms will be used to describe the sensory changes by the different judges. These were established from a list generated by the panel members, as well as others utilized in previous works on fresh-cut fruits, by using the Checklist method (Moskowitz 1983). Once the terms were selected, a consensus was reached on their use to evaluate the sensory changes in the product. The final list of sensory attributes and their definitions are:

Appearance which is related to the general aspect or visual impact of the product; Brightness which is related to the shiny or opaqueness and wilted appearance of the product due to changes in surface humidity; Superficial browning which is related to the presence of brown or dull hues, specially in the cut zones; Odor which is related to the natural aroma, typical of the fruit product; Flavor which is related to the characteristic flavor of the fruit, that combines sweetness with a certain degree of acidity; Texture which is related to the strength or resistance of the tissue to teeth biting, considering that it is a ripe fruit; External Color which is related to the uniformity in the characteristic color of mango pulp; Acidity which is related to the intensity of this basic taste in the sample and Sweetness which is related to the intensity of sweetness in the evaluated sample.

Quantification of changes in critical attributes was performed using samples with different degrees of deterioration during training sessions (ISO 1994). The data from

each session were statistically analyzed by variance analysis with a level of significance of 5 % to detect significant differences among the judges. Training was considered finished when there were no longer any significant differences based in the variance analysis of the results generated by the different judges.

Trained panel evaluation The evaluation was performed in individual booths with artificial light and controlled temperature of 25 ± 2 °C (ISO 1988). Each judge received the samples randomly chosen with a code number consisting of three random digits. The first characteristic to be evaluated was odor, followed by brightness, color, browning, flavor, texture, acidity, and sweetness. The intensity of each attribute was indicated by placing a mark on a non-structured lineal scale of 10 cm long, anchored at both ends, as described next: “*optimum*” and “*intense off-odor*” for odor, “*very bad*” and “*optimum*” for appearance, “*none*” and “*optimum*” for brightness, firmness and sweetness; “*none*” and “*excessive*” for browning, “*optimum*” and “*excessive*” for acidity, and “*optimum*” and “*very bad*” for flavor and color. Quantification was done by measuring the distance (cm) from the left anchor up to the mark made by the judge. All the samples were kept at a temperature of 12 °C. The judges were instructed to drink water in between samples as neutralizer.

Consumer evaluation Overall acceptability was evaluated by consumers (50–53 people, 24 to 52 years old) who were recruited among the personnel of the Centro de Investigación en Alimentación y Desarrollo (Research Center for Food and Development) in which the study was carried out. Evaluation was performed in four different sessions upon completion of the storage times for each temperature. Panelists received ten samples per session in random order, one for each storage period. They scored the samples using a 9 point hedonic scale, anchored at both ends and in the middle with the expressions described next: to the left side: “I dislike it a lot”, in the middle: “I am indifferent”, and to the right side: “I like it a lot”.

Mathematical procedure utilized to estimate the product shelf life by using physicochemical variables

The mathematical procedure developed in this work is described in several sections. The first section is related with the calculation of the limits in each physicochemical variable based on the end of the product shelf life as determined from the sensory attributes; in the second one, zero and first order kinetic models are tested to describe the changes in sensory attributes and physicochemical variables and in the third one, the models are validated with a real experiment.

Determination of the physicochemical variables cut-off points from sensory attributes

It is possible to determine the sensory shelf-life as the storage time when the first significant change in acceptability is detected. This methodological approach assures product quality throughout the whole shelf-life because it reflects the point in time when consumers noticed the first detectable difference in the sensory characteristics of the product with respect to the fresh one. At this point in time, consumers detect the first significant change in the sensory characteristics of the product as compared with the fresh product. In this way, the acceptability limit (S) is calculated as the first sensory attribute score significantly different from the attribute of the fresh sample, as described next.

- a) The acceptability limit by consumer was calculated for each storage temperature, based on the lowest significant difference (LSD) according to the next equation:

$$S = F - \text{LSD} = F - Z_{\alpha} \sqrt{\frac{2 \cdot \text{CME}}{n}} \quad (3)$$

Where S is the acceptability limit of a stored sample; F is the acceptability scored in the fresh sample; LSD is the lowest significant difference; Z_{α} is the α^{th} quantile of the standard normal distribution; CME is the mean square error from the variance analysis, and n is the number of consumers.

- b) A Pearson’s correlation analysis was performed to identify the sensory attributes showing the greater degree of association with each the physicochemical variables. From the analysis, only those variables with an effective causal dependence between them were taken into account.
- c) Sensory cut-off point for each sensory attribute was obtained by interpolation from the limit of product acceptability by consumers using the regression line between consumers’ acceptability scores and intensity of each attribute evaluated by the trained panel. The estimation of the sensory shelf-life requires the selection of a cut-off point that is the criteria to know when the product had failed to meet a certain quality level, which is the maximum deterioration acceptable. That is, sensory shelf-life is the storage time in which the product reaches some predetermined deterioration level, above which it is not acceptable anymore by the consumer and it is rejected (Garitta et al. 2004; Gimenez et al. 2012).
- d) After finding the sensory attributes and physicochemical variables with the largest Pearson’s correlation coefficients, it was carried out a regression analysis between them.
- e) In order to obtain the cut-off points of each physicochemical variable, it was taken into account the sensory

attributes with the largest correlation. The cut-off point for each physicochemical variable was obtained based on each sensory attribute by interpolation from the sensory cut-off point on the regression line developed as described above.

- f) Due to the fact that more than one sensory characteristic were found to be highly correlated with every physicochemical variable, it was necessary to develop a mathematical procedure to obtain a unique value. This unique value was calculated depending upon the results as follows: If the cut-off points values are similar, it was calculated from the arithmetical mean of the data. Further, if the cut-off points were very different from each other, the unique value was established as the lowest or highest value of the data, depending upon whether the variable value was increasing or decreasing during storage, respectively. That is, some variables are directly correlated with the fruit quality (ascending behavior), whereas others are inversely correlated with fruit quality (descending behavior).

Shelf-life estimation

With the goal to evaluate the usefulness of the physicochemical cut-off points to estimate shelf-life, zero-order and first-order kinetic models were developed and fitted to describe the changes in the sensory attributes and physicochemical variables. The models were obtained from the general equation:

$$\pm \frac{dQ}{dt} = kQ^n \quad (4)$$

Where Q refers to the quality characteristic; t is time; n is the apparent reaction order for the Q characteristic; k is the apparent reaction constant. The sign “+” is applied to characteristics which show a tendency to increase over time and the sign “−” is applied to characteristics showing a decrease tendency.

The shelf-life of fresh-cut mango at each storage temperature was estimated using:

$$Q_e = Q_0 - kt_s \quad (5)$$

Where Q_0 is the value of the quality characteristic at the beginning of the experiment; Q_e is the value reached by the characteristic at time t_s (cut-off point); t_s is the end of shelf-life; and k is the apparent reaction constant.

Physicochemical cut-off points can also be used to estimate shelf-life, considering the effect of temperature on the kinetic constants through the Arrhenius model (Saguy and Karel 1980; Taoukis et al. 1997)

Validation of physicochemical cut-off points

In order to validate the accuracy of the fruit shelf-life estimated from the physicochemical cut-off points, an

experiment was performed with fruits from the same mango cultivar and under the same processing conditions. The storage time and temperatures as well as sampling time were carried out exactly as described in sample preparation and treatment section. Overall acceptability was evaluated during storage using a 9 point hedonic scale. The shelf-life was established as the time needed to reach a score of 6.0, which corresponds to “I like it a little”, and it is considered as the limit of commercial acceptability (Muñoz et al. 1992). Shelf-life real data were compared to the shelf-life time estimated through the fitted model using physicochemical cut-off points.

Statistical analysis

The data of each session during judge training were analyzed through an analysis of variance based in a completely random design with factorial arrangement, in which the main factors were judges and samples with different storage times.

The correlation between sensory attributes and physicochemical variables was evaluated with Pearson’s correlation coefficient considering the following criteria: low correlation from 0.1 to 0.3, medium from 0.3 to 0.5, and high correlation from 0.5 to 1.0, according to Cohen (1988).

Before correlation analysis, a significance test was performed to determine the goodness of fit, of sensory and physicochemical data to the theoretical normal distribution, through the Kolmogorov Smirnov test, due to the fact that Pearson’s correlation coefficient is a parametric statistic, and whenever data distributions are not normal, it may be less useful than non-parametric correlation methods, such as Chi-square, Point biserial correlation, Spearman’s ρ , Kendall’s τ , and Goodman and Kruskal’s lambda.

Goodness of fit of kinetic models was evaluated based on the determination coefficient (R^2) and analysis of residuals around zero.

In the case of sensory analysis, the results comes from the analysis of 50 persons and the whole experiment was repeated two times. Also, for every sampling point, color was determined four times, total soluble solids nine times, firmness three times, pH three times, titratable acidity three times and microbiological analysis three times.

All the analyses were done with a 95 % degree of confidence, using STATGRAPHS Plus software (Statgraphics 2000).

Results and discussion

Microbiological changes

The initial populations of mesophilic and psychrophilic aerobic bacteria in the fresh cut mangoes samples were 1.3

and 1.0 log of colony forming units per gram of product (CFU-g⁻¹), respectively. In the case of molds and yeasts, and total coliforms they were 1.7 and 1.0 log CFU-g⁻¹, respectively. These values were lower in all cases than upper limits for microbiological quality established by the International Fresh-cut Produce Association (IFPA 2003). During storage, the growth of mesophilic and psychrophilic aerobic bacteria, as well as molds and yeasts remained below the maximum limits. Mesophilic bacteria reached values of 4.7, 4.7, 4.9, and 5.2 log CFU-g⁻¹ by the end of the storage time at 5, 10, 15, and 20 °C, respectively. At these same temperatures, psychrophilic bacteria reached values of 3.0, 3.1, 4.7, and 5.9 log CFU-g⁻¹, respectively. In the case of molds and yeasts, values of 4.1, 4.3, 4.9, and 5.5 log CFU-g⁻¹ were obtained at 5, 10, 15, and 20 °C, respectively. Besides, total coliforms reach values of 1.6, 2.7, 4.2, and 4.3 at 5, 10, 15, and 20 °C, respectively. These results clearly indicate that storage temperatures of 5 and 10 °C decreased microbial growth as compared with the higher temperatures tested, throughout storage time in all the microbial groups analyzed. These results agrees with those reported by Allong et al. (2001) who found that microbial counts were maintained at low levels throughout storage at 5 °C in mango slices. Results at 5 and 10 °C also agrees with those obtained by Allong et al. (2000) in 'Julie' and 'Graham' mangoes slices at 5 and 10 °C. These authors reported an increase in susceptibility to microbial attack of 'Graham' mango slices when temperature increases to 22–24 °C during 36 h.

In the case of fresh-cut mangos stored at 15 and 20 °C, both mesophilic and psychrophilic aerobic bacteria, molds and yeasts showed values below the limits established by the International Fresh-cut Produce Association (IFPA 2003). However, coliforms reached the mentioned limits. These results were taken into account to set the maximum time of storage at each temperature for the experiment.

Physicochemical and sensory changes

Out of the different sensory attributes evaluated in the present experiment, all of them showed significant differences ($p \leq 0.05$) during storage with the exception of superficial browning and acidity. The absence of browning is most likely due to the physiological characteristics of the mango cultivar utilized in the present experiment. In agreement with these results, González-Aguilar et al. (2000), reported that mango cultivar 'Ataulfo' requires antioxidant treatments as part of the minimal processing protocol, whereas other mango cultivars are not susceptible to browning. These differences explain the lack of significant differences in browning during the present experiment. This is an advantage of the 'Haden' cultivar compared with other cultivars of mango used for minimal processing.

Table 1 shows the changes in sensory attributes of fresh-cut mango, evaluated by the trained panel during storage at 5 and 10 °C. At 5 °C, the attributes of odor, color and firmness decreased significantly ($p \leq 0.05$) at day 16th of storage time with respect to the initial day. In the case of flavor and sweetness, a decrease ($p \leq 0.05$) was observed until day 18th of storage. Furthermore, in the case of brightness and appearance, a decrease ($p \leq 0.05$) was observed after 10 and 12 days of storage time, respectively.

At 10 °C, the maximum storage time was 3.4 days. Under these conditions, the sensory attributes of odor, appearance, brightness, color, firmness and flavor showed a significant difference ($p \leq 0.05$) at 3.4 days of storage. By other side, sweetness showed a significant reduction ($p \leq 0.05$) after 3 days. The results obtained at 15 and 20 °C are not shown. However, changes in the sensory attributes in mango stored under these temperatures occurred very fast. At 15 °C, significant decrease ($p \leq 0.05$) in odor and appearance was observed after 1.3 days of storage whereas brightness and sweetness scores showed a significant change ($p \leq 0.05$) after 1.8 days. Furthermore, a decrease in color, firmness, and flavor scores was observed after 2 days. At 20 °C, brightness and sweetness scores showed significant decrease after 0.6 days of storage (14.4 hours) whereas odor, appearance, color, firmness and flavor scores decreased significantly ($p \leq 0.05$) after one day.

These results indicate that the first sensory attributes showing changes at 5 °C were brightness and appearance, followed by color, odor and firmness. Furthermore, the attributes showing changes at later time points were flavor and sweetness. The changes in all sensory attributes scores occurred in similar way at 5 and 10 °C. In the case of fresh-cut mango stored at 15 °C, the first changes were observed in odor and appearance, followed by brightness and sweetness, whereas at 20 °C the first changes were observed in brightness and sweetness.

Alteration of brightness and firmness agrees with the results reported by Aked (2000), who showed that appearance is the most important attribute of fresh-cut products, and it is related with size, color uniformity and intensity, turgidity and brightness.

Table 2 shows the firmness, TSS, the color space coordinate L* as well as C and h° evaluated in fresh-cut mango during storage at 5 and 10 °C. The pH and acidity values are not included in the table mainly because no statistically significant ($p > 0.05$) differences were found during the storage time.

A significant decrease ($p \leq 0.05$) at 5 °C in L* and firmness, was observed on day 12th of storage. By other side, in the case of TSS, C and h°, a significant decrease ($p \leq 0.05$) was observed at days 14th, 16th, and 18th of the storage time, respectively. At 10 °C, significant decrease ($p \leq 0.05$) in C and h° was observed after 3.4 days of storage. By other

Table 1 Changes in several sensory attributes of fresh-cut mango during storage at different temperatures

Temperature (°C)	Time (hours)	Odor	Appearance	Brightness	Color	Firmness	Flavor	Sweetness
5	0	8.4±1.2 ^a	9.2±0.4 ^a	9.2±0.6 ^a	9.2±0.6 ^a	9.3±0.7 ^a	7.9±1.2 ^a	8.2±1.5 ^a
	48	8.3±1.8 ^a	8.9±0.3 ^{ab}	8.7±1.4 ^{ab}	7.7±1.2 ^a	8.7±1.0 ^{ab}	8.2±1.0 ^a	8.6±0.9 ^a
	96	7.3±1.0 ^{ab}	7.6±1.1 ^{abc}	6.7±1.7 ^{abc}	6.8±1.6 ^{ab}	6.4±1.7 ^{ab}	7.6±1.7 ^a	8.2±1.6 ^a
	144	6.8±1.8 ^{abc}	6.5±0.9 ^{abc}	5.2±0.8 ^{abcd}	6.6±1.0 ^{ab}	6.9±1.9 ^{ab}	6.4±2.0 ^{ab}	7.2±1.8 ^a
	192	5.7±1.7 ^{abc}	5.8±1.3 ^{abc}	5.0±1.1 ^{abcd}	5.2±0.3 ^{ab}	4.0±2.7 ^{ab}	4.5±2.3 ^{ab}	6.5±2.1 ^{ab}
	240	6.5±2.0 ^{abc}	6.3±1.5 ^{abcd}	5.1±1.7 ^{bcd}	6.3±1.6 ^{ab}	4.8±2.5 ^{ab}	4.9±2.0 ^{ab}	6.2±1.7 ^{ab}
	288	4.4±1.5 ^{abc}	5.1±1.6 ^{bcd}	4.9±0.4 ^{bcd}	6.4±0.9 ^{abc}	4.6±2.5 ^{ab}	4.5±0.3 ^{ab}	5.1±1.9 ^{ab}
	336	4.5±2.3 ^{abc}	5.3±2.3 ^{cde}	3.8±3.2 ^{cd}	5.6±2.6 ^{abc}	5.3±2.2 ^{ab}	3.9±1.9 ^{ab}	4.9±3.0 ^{ab}
	384	3.2±2.3 ^{bc}	2.0±1.3 ^{de}	1.7±1.5 ^d	2.1±1.5 ^{bc}	5.0±2.2 ^b	4.1±2.3 ^{ab}	3.7±2.8 ^{ab}
	432	2.6±1.8 ^c	1.8±1.7 ^e	2.4±2.0 ^d	2.9±2.4 ^c	3.5±2.1 ^b	2.2±2.0 ^b	1.7±2.3 ^b
10	0	7.7±2.8 ^a	7.9±2.1 ^a	8.4±1.6 ^a	7.8±2.2 ^a	8.8±1.7 ^a	8.8±1.4 ^a	9.0±1.6 ^a
	9.6	7.5±1.4 ^a	7.7±1.4 ^a	7.7±0.8 ^a	7.9±1.1 ^a	7.9±1.1 ^a	8.2±0.8 ^a	7.7±1.7 ^{ab}
	19.2	7.3±1.4 ^a	8.1±1.8 ^a	7.8±1.7 ^a	7.9±1.3 ^a	7.6±2.4 ^a	7.8±1.9 ^a	7.1±2.6 ^{ab}
	26.4	7.1±1.6 ^a	7.4±1.9 ^a	6.8±1.9 ^a	7.2±1.8 ^a	7.9±2.2 ^a	8.1±1.8 ^a	7.9±2.1 ^{ab}
	36	6.9±1.2 ^a	7.0±1.6 ^a	6.8±2.0 ^a	7.8±1.4 ^a	6.4±2.3 ^{ab}	7.6±1.7 ^{ab}	7.2±1.9 ^{ab}
	45.6	6.7±1.7 ^a	6.9±1.6 ^a	7.0±2.1 ^a	7.1±2.3 ^a	6.4±1.2 ^{ab}	8.3±1.5 ^{ab}	7.8±1.9 ^{ab}
	55.2	6.5±1.4 ^a	6.6±1.6 ^a	6.8±1.6 ^a	6.7±2.1 ^a	6.2±3.0 ^{ab}	7.7±2.1 ^{ab}	7.6±2.1 ^{ab}
	62.4	6.4±1.7 ^a	6.1±0.9 ^{ab}	6.9±2.3 ^a	6.8±2.2 ^a	6.0±3.0 ^{ab}	7.2±1.6 ^{ab}	7.4±1.9 ^{ab}
	72	5.8±0.6 ^a	5.8±0.7 ^{ab}	5.8±1.4 ^{ab}	5.8±0.8 ^{ab}	5.5±2.1 ^{ab}	6.2±2.1 ^{ab}	6.2±2.0 ^b
	81.6	2.6±1.7 ^b	2.9±2.0 ^b	3.0±2.0 ^b	2.7±1.9 ^b	4.2±2.3 ^b	4.3±1.9 ^b	6.2±1.7 ^b

The values correspond with the mean and standard deviation obtained from 50 persons. Means within each column for each storage temperature with different superscripted letters are significantly different ($p \leq 0.05$)

side, a decrease ($p \leq 0.05$) in firmness, L^* , and TSS was observed after 1.5, 2.6 and 3.0 days of storage, respectively (Table 3). Although the physicochemical changes were also evaluated in fresh-cut mango stored at 15 and 20 °C, they are not included in this paper. However, it was observed that at 15 °C, h° and firmness decreased significantly at 1.8 days. At this temperature, the decrease in L^* and TSS was observed after 2 days as well as a significant decrease in C at 2.3 days. In fresh-cut mango stored at 20 °C, L^* , C , firmness and TSS decreased significantly ($p \leq 0.05$) at 0.9 days (21.6 hours). Likewise, significant decrease ($p \leq 0.05$) in h° was observed on the first day.

The decrease in TSS observed agrees with the results reported by Beaulieu and Baldwin (2002), who stated that TSS decreased in fresh-cut fruits during the first days of storage, in a product and temperature dependent manner.

In fresh-cut fruits, the speed of water loss (Barrett et al. 2010) and activity of cell wall enzymes are altered which induces the softening observed in several products (Varoquaux and Wiley 1994; Varela et al. 2007; Chuni et al. 2010).

The decrease in L^* values observed in this study are similar with the results recorded in mango cubes of ‘Keitt’, ‘Kent’, and ‘Ataulfo’ cultivars stored at 5 °C (Gonzalez-Aguilar et al. 2008). Similar results were observed by Rattanapanone et al. (2001) in fresh-cut mangos stored at

room temperature. According to González-Aguilar et al. (2004) decrease in L^* can be also an indicator of browning in fresh-cut fruits.

In this experiment, a significant decrease in h° and C values were observed, indicating a reduction in color intensity as a consequence of the degradation and loss of pigments observed during sanitation of fresh-cut produce, as a result of rupture of cells (Vitti et al. 2003). Also, a decrease in h° indicates changes towards a red/orange color in fresh-cut mango (Plotto et al. 2006). In the case of h° , it had been reported increases in the case of mango cultivars ‘Kent’ and ‘Tommy Atkins’ and a decrease in ‘Keitt’ (Plotto et al. 2010). These controversial results are most likely due to the differences in the mango cultivars between the present experiment and the other experiments mentioned.

Cut-off points of sensory attributes

The acceptability limits calculated based in Eq. 3 were 5.1, 4.6, 5.3 and 5.3 for 5, 10, 15 and 20 °C of storage temperature, respectively.

In Fig. 1, it is shown the lineal regression model utilized to obtain the sensory cut-off point from the calculated limits of product acceptability by consumers. Due to the constraint in space, only the graphs corresponding to texture (Fig. 1a) and flavor (Fig. 1b), evaluated at 10 °C, are shown to

Table 2 Changes in the L* space coordinate, hue angle and chroma as well as in several physicochemical variables evaluated in fresh-cut mango during storage at different temperatures

Temperature (°C)	Time (days)	L*	C	h°	Firmness (N)	TSS
5	0	61.6±3.7 ^a	61.6±4.9 ^a	88.8±2.4 ^a	0.4±0.1 ^a	13.8±0.8 ^a
	2	61.8±6.5 ^a	61.8±10.2 ^a	89.4±1.2 ^a	0.4±0.1 ^a	13.1±1.5 ^a
	4	56.7±4.2 ^{ab}	56.7±10.4 ^{ab}	88.0±3.7 ^a	0.3±0.1 ^{ab}	13.0±1.3 ^a
	6	56.0±8.6 ^{ab}	56.0±4.8 ^{abc}	87.1±2.3 ^a	0.3±0.1 ^{ab}	13.2±0.5 ^a
	8	53.3±6.9 ^{abc}	53.3±8.0 ^{abc}	87.1±2.2 ^a	0.3±0.1 ^{ab}	12.0±1.3 ^a
	10	53.0±5.8 ^{abc}	53.0±8.7 ^{abc}	86.8±1.4 ^a	0.3±0.1 ^{ab}	11.7±0.4 ^{ab}
	12	52.9±3.9 ^{bc}	52.9±10.3 ^{abc}	84.6±2.8 ^a	0.2±0.1 ^b	11.0±1.2 ^{ab}
	14	51.5±3.3 ^{bc}	51.5±12.7 ^{abc}	84.1±4.9 ^{ab}	0.2±0.1 ^b	11.3±0.9 ^b
	16	50.0±5.3 ^{bc}	50.0±5.0 ^{bc}	84.3±3.6 ^{ab}	0.2±0.1 ^b	10.8±0.9 ^b
	18	46.8±2.9 ^c	46.8±7.9 ^c	80.3±4.0 ^b	0.2±0.1 ^b	10.1±1.5 ^b
10	0	61.5±3.8 ^a	61.5±7.5 ^a	88.8±2.4 ^a	0.4±0.1 ^a	13.1±2.2 ^a
	0.4	59.5±3.9 ^{ab}	59.5±8.5 ^{ab}	88.4±2.4 ^a	0.3±0.1 ^{ab}	12.4±1.0 ^{ab}
	0.8	59.5±2.5 ^{ab}	59.5±7.8 ^{ab}	88.1±1.7 ^a	0.3±0.1 ^{ab}	12.9±0.6 ^{ab}
	1.1	59.3±6.8 ^{ab}	59.3±7.9 ^{ab}	87.5±2.8 ^a	0.3±0.1 ^{ab}	12.3±1.6 ^{ab}
	1.5	58.4±3.8 ^{ab}	58.4±8.1 ^{ab}	87.4±1.8 ^{ab}	0.2±0.1 ^b	12.3±1.0 ^{ab}
	1.9	57.9±5.4 ^{ab}	57.9±6.9 ^{ab}	87.3±2.0 ^{ab}	0.2±0.1 ^b	11.8±0.9 ^{ab}
	2.3	57.6±4.9 ^{ab}	57.6±11.3 ^{ab}	86.8±1.7 ^{ab}	0.2±0.1 ^b	11.4±3.9 ^{ab}
	2.6	57.1±5.0 ^b	57.1±8.4 ^{ab}	86.8±1.9 ^{ab}	0.2±0.1 ^b	11.3±0.7 ^{ab}
	3.0	56.6±3.6 ^b	56.6±8.6 ^{ab}	85.9±2.3 ^{ab}	0.2±0.1 ^b	10.6±1.1 ^b
	3.4	53.4±4.1 ^b	53.4±7.2 ^b	85.9±2.1 ^b	0.2±0.1 ^b	10.5±0.6 ^b

The values correspond with the mean and standard deviation of three determination for L*, firmness and TSS and four determinations for chroma and h°. Means within each column for each storage temperature with different superscripted letters are significantly different ($p \leq 0.05$)

L* is a color space coordinate indicating lightness of the color; C* is chroma which indicates the intensity of a particular color; h° is the hue angle which indicates the perception of the color in a similar way like human eye

illustrate the procedure. From the Fig. 1, it is clear that the interpolation between acceptability and the different sensory attributes make possible to obtain the limits for each sensory attribute at the different storage temperatures tested.

Table 3 Limit of acceptability and cut-off points of sensory attributes of fresh-cut mango stored at 5, 10, 15, and 20 °C

Characteristic	Temperature (°C)			
	5	10	15	20
Acceptability limit (S)				
Sensory cut-off point	5.1	4.6	5.3	5.3
Odor	4.9	4.7	6.0	4.8
Appearance	4.7	4.9	6.0	5.3
Brightness	4.2	4.9	5.2	4.6
Color	4.9	4.8	5.9	5.5
Texture	4.8	5.2	6.2	6.2
Flavor	4.5	5.9	5.6	5.3
Acidity	2.7	3.6	3.8	4.6
Sweetness	5.0	6.5	5.9	4.7

Using the mathematical procedure described in the last paragraph, the sensory attributes cut-off points obtained based in the limit of acceptability by consumers at different temperatures are shown in Table 3. These values set the lower limits of acceptability at the different storage temperatures of fresh cut mango based in the different sensorial attributes analyzed. Fresh-cut mango showing lower values than these, could be rejected by consumers.

Correlation between physicochemical variables and sensory attributes

The results of Kolmogorov Smirnov test to evaluate the sensory attributes goodness of fit and physicochemical variables, to normal distribution, indicate p -values from 0.267 to 0.986 in the case of physicochemical variables and p -values from 0.161 to 0.796 for sensory attributes evaluated by the trained panel. These results validate the assumption of normality for both data sets.

In Table 4, it is shown the Pearson's correlation coefficients among physicochemical variables and sensory attributes evaluated by the trained panel in fresh-cut mango stored at 5, 10, 15, and 20 °C. It was found a high

Fig. 1 Use of the lineal regression equations to interpolate the limit of acceptability by consumers in order to obtain the sensory cut-off point. Due to constrain in space, only two out of all the graphs created are shown to illustrate the procedure. The graphs correspond to the determination of the cut-off points of texture (a) and flavor (b) sensory attributes, evaluated in fresh-cut mango stored at 10 °C

Fig. 2 Use of the lineal regression equations to interpolate the sensory cut-off points and to obtain the physicochemical cut-off point. Due to constrain in space, only two of all the needed graphs are shown to illustrate the procedure. The graphs correspond to cut-off point of L* value, obtained from appearance (a) and brightness (b) sensory attributes in fresh-cut mango stored at 5 °C

Table 4 Pearson's correlation coefficients (r^2) between physicochemical variables and sensory attributes evaluated in fresh-cut mango stored at 5, 10, 15, and 20 °C

Physicochemical parameters	Sensory characteristics	Temperature (°C)			
		5	10	15	20
L*	Appearance	0.92*	0.93*	0.74*	0.70*
	Brightness	0.94*	0.87*	0.85*	0.80*
	Color	0.87*	0.89*	0.69*	0.72*
C	Appearance	−0.92*	−0.85*	−0.65*	−0.59*
	Color	−0.87*	−0.81*	−0.62*	−0.62*
h°	Appearance	0.88*	0.87*	0.62*	0.70*
	Color	0.75*	0.82*	0.61*	0.74*
Firmness	Texture	0.89*	0.88*	0.73*	0.90*
TSS	Flavor	0.95*	0.78*	0.64*	0.76*
	Sweetness	0.95*	0.87*	0.79*	0.74*

L* is a color space coordinate indicating lightness of the color; C* is chroma which indicates the intensity of a particular color; h° is the hue angle which indicates the perception of the color in a similar way like human eye

*Significant at $p \leq 0.05$

correlation ($p \leq 0.05$) between appearance, brightness, and color with the L^* space color coordinate. It had been mentioned that the L^* space of color coordinate corresponds to brightness and is related to freshness in fresh-cut vegetables (Fizman 2005). Therefore, a large L^* value in fresh-cut fruits is related with a good appearance, while low values can indicate browning in some fresh-cut fruits including mango (González-Aguilar et al. 2000, 2004).

Appearance and color showed a large and negative correlation ($p \leq 0.05$) with the chroma (C) values, which is to be expected, since a higher saturation or intensity of the yellow color of mango indicates a more advanced stage of ripeness which gives to the consumer a less attractive appearance. Appearance and color also showed a large and positive correlation ($p \leq 0.05$) with the hue angle (h°) values. In this case, the correlation was positive due to the fact that larger values of h° correspond with the typical yellow color of mango pulp.

The sensory attribute of texture showed a large and positive correlation ($p \leq 0.05$) with the firmness evaluated instrumentally. This finding corresponds with the expected results since loss of firmness in fresh-cut mango during storage is perceived directly by the judges as a softening due to the higher degradation of the cells wall with the advance of fruit ripeness (Varela et al. 2005).

The flavor and sweetness sensory attributes showed a large and positive correlation ($p \leq 0.05$) with TSS in all the storage temperatures tested (Table 4). These findings agree with studies carried out by Kader (2002) that suggested that

flavor comes from the perception of the stimulus given by soluble substances such as sugars and acids in fruits.

Correlation between physicochemical variables and sensory attributes showed differences as the storage temperature increased. At 5 and 10 °C, correlations were high (r^2 from 0.75 to 0.95), which indicates that under these conditions there is a direct and significant association between the physicochemical variables and sensory attributes evaluated in fresh-cut mango. However, correlation coefficients decreased as the temperature increased to 15 and 20 °C. These results suggest that the effect of a physicochemical change on a specific sensory attribute vary when temperature increases, probably due to the larger effect of the temperature on the physicochemical changes and in consequence on the sensory quality. However, fresh-cut mango fruit usually is stored at temperatures between 5 and 10 °C in which it was found a large correlation between physicochemical variables and sensorial attributes. Therefore, data generated in this work strongly suggests that it is feasible to evaluate the possibility of using the physicochemical variables with the highest correlations as objective indicators of sensory changes during the storage of fresh cut mango at temperatures in the range of 5 and 10 °C.

Cut-off points of physicochemical variables

The cut-off point of a physicochemical variable was calculated based in the sensory attributes showing the largest correlation coefficient with that particular variable. In this

Table 5 Cut-off points of physicochemical variables in fresh-cut mango at different storage temperatures and calculated from the sensory attribute showing the largest correlation. Also, it is included the unique cut-off point which corresponds with the arithmetical mean in the column B for each temperature

Physicochemical variables	Sensory Characteristics	Temperature (°C)							
		5		10		15		20	
		Cut-off points							
		A	B	A	B	A	B	A	B
L*	Appearance	52.1	52.0	55.2	54.9	51.7	53.4	52.3	53.5
	Brightness	52.2		54.8		54.8		54.3	
	Color	51.8		54.8		53.6		53.9	
C	Appearance	36.2	36.3	46.0	46.4	48.7	47.1	52.0	50.3
	Color	36.4		46.8		45.5		48.7	
h°	Appearance	85.0	84.8	86.0	85.9	82.7	83.2	86.0	86.3
	Color	84.7		85.8		83.8		86.6	
Firmness (N)	Texture	0.25	0.25	0.24	0.24	0.35	0.35	0.24	0.24
TSS	Flavor	11.4	11.4	10.5	10.5	11.5	11.6	11.3	11.3
	Sweetness	11.4		10.5		11.7		11.3	

Column A: cut-off points based on different sensory attributes ; Column B: cut-off point of the physicochemical variable

L^* is a color space coordinate indicating lightness of the color; C^* is chroma which indicates the intensity of a particular color; h° is the hue angle which indicates the perception of the color in a similar way like human eye; TSS is the total soluble solids

context, L^* was found to have a large correlation with appearance and brightness. In Fig. 2, it is shown that the interpolation in a regression line between the L^* value against appearance and brightness at 5 °C gives the values of 52.1 and 52.2, respectively which corresponds with the cut-off points for the L^* value based on these two sensory attributes. Due to space constraints, we are only showing these two cases, but the procedure followed was the same for the other physicochemical variables. Because of the utilization of more than one sensory attribute to calculate

the cut-off point for a given physicochemical variable as well as the large similitude among the values obtained, it was calculated the arithmetic mean of the different cut-off points following the criteria established and explained in the section of methodology. In Table 5, it is shown the cut-off points obtained for the different physicochemical variables analyzed. It can be seen that appearance, brightness, and color were used to calculate cut-off points for L^* values, appearance and color to obtain the cut-off points of C and h° , texture to calculate the cut-off point for firmness, and

Table 6 Coefficients of Determination (R^2) and reaction constants (k) for zero ($n=0$) and first ($n=1$) order kinetic models, fitted to sensory and physicochemical changes in fresh-cut mango stored at 5, 10, 15, and 20 °C.

Variable	Temperature (°C)							
	5		10		15		20	
	R^2	k	R^2	k	R^2	k	R^2	k
<i>n=0</i>								
Sensory								
Appearance	0.913*	0.016	0.978*	0.075	0.985*	0.107	0.975*	0.215
Texture	0.959*	0.016	0.967*	0.056	0.926*	0.101	0.896*	0.207
Flavor	0.948*	0.012	0.979*	0.061	0.900*	0.080	0.983*	0.193
Sweetness	0.938*	0.015	0.942*	0.039	0.842*	0.072	0.771 *	0.167
Odor	0.951*	0.014	0.863*	0.064	0.954*	0.109	0.975*	0.239
Color	0.810*	0.014	0.781*	0.056	0.854*	0.080	0.792*	0.175
Brightness	0.920*	0.016	0.957*	0.080	0.917*	0.092	0.725*	0.153
Physicochemical								
L^*	0.931*	0.033	0.859*	0.081	0.920*	0.165	0.934*	0.257
C	0.931*	0.033	0.857*	0.122	0.920*	0.166	0.933*	0.259
h°	0.911*	0.018	0.975*	0.036	0.890*	0.073	0.836*	0.084
Firmness	0.972*	0.0004	0.779*	0.002	0.938*	0.003	0.962*	0.004
TSS	0.946*	0.008	0.821*	0.031	0.830*	0.032	0.813*	0.069
<i>n=1</i>								
Sensory								
Appearance	0.774*	0.0034	0.639	0.0088	0.485	0.0108	0.536	0.0231
Texture	0.694	0.0018	0.915*	0.0072	0.594	0.0098	0.929*	0.0148
Flavor	0.883*	0.0027	0.581	0.0058	0.487	0.0151	0.595	0.0220
Sweetness	0.783*	0.0030	0.568	0.0025	0.728*	0.0110	0.633	0.0292
Odor	0.910*	0.0027	0.564	0.0091	0.590	0.0118	0.545	0.0292
Color	0.649	0.0024	0.547	0.0089	0.428	0.0101	0.604	0.0210
Brightness	0.819*	0.0032	0.513	0.0075	0.626	0.0139	0.724*	0.0246
Physicochemical								
L^*	0.919*	0.0003	0.854*	0.0006	0.922*	0.0012	0.937*	0.0019
C	0.700*	0.0003	0.883*	0.0017	0.892*	0.0027	0.787*	0.0043
h°	0.909*	0.00008	0.975*	0.0002	0.894*	0.0004	0.835*	0.0004
Firmness	0.878*	0.0006	0.842*	0.0025	0.913*	0.0038	0.949*	0.0055
TSS	0.945*	0.0003	0.835*	0.0011	0.749*	0.0011	0.819*	0.0024

L^* is a color space coordinate indicating lightness of the color; C^* is chroma which indicates the intensity of a particular color; h° is the hue angle which indicates the perception of the color in a similar way like human eye; TSS is the total soluble solids

*Significant at $p \leq 0.05$

Table 7 Acceptability scores of fresh-cut mango stored at 5, 10, 15, and 20 °C during different days, evaluated by consumers using a 9 point hedonic scale. It is also shown the time of storage in days for each score

Temperature (°C)							
5		10		15		20	
Time (days)	Acceptability score	Time (days)	Acceptability score	Time (days)	Acceptability score	Time (days)	Acceptability score
0	7.4	0	7	0	7.2	0	7.1
2	7.1	0.4	6.7	0.3	6.6	0.1	6.7
4	6.6	0.8	6.4	0.5	6.5	0.3	6.6
6	6.3	1.1	6.2	0.8	6.3	0.4	6.5
8	6.1	1.5	6.1	1.0	6.1	0.5	6.5
10	6.1	1.9	6.1	1.3	6	0.6	6.4
12	5.7	2.3	6	1.5	5.7	0.8	6.2
14	4.7	2.6	4.9	1.8	5.4	0.9	6.1
16	4.3	3.0	4.1	2.0	5.3	1.0	6.1
18	4.2	3.4	3.9	2.3	4.2	1.1	4.2

flavor and sweetness to obtain the cut-off point for TSS. Furthermore, it is possible to see that L^* is clearly related

Table 8 Shelf-life of fresh-cut mango based on limit of commercial acceptability, established as a value of 6.0 in the 9 point scale. It is also shown the shelf-life estimated from physicochemical and sensory cut-off points through the zero order kinetic model

Variable	Temperature (°C)			
	5	10	15	20
	Experimental shelf-life (acceptability score ≤6.0)			
	10–12	2.3–2.6	1.3–1.5	1.0–1.1
Estimated shelf-life (days)				
Sensory				
Appearance	9.5	2.8	1.4	0.9
Texture	16	3.3	1.8	1
Flavor	11.9	2.8	1.4	0.9
Sweetness	9.8	4.5	1.6	0.9
Odor	10.9	3.3	1.4	1
Color	11.5	2.8	1.6	0.8
Brightness	10.5	3	1.5	0.9
Physicochemical				
L*	13.5	3.9	2.3	1.5
C	7.2	4	2.4	1.9
h°	9.2	3.5	2.8	1.2
Firmness	13.2	3.6	2.1	1.5
TSS	13.1	4.6	2.8	1.6

L^* is a color space coordinate indicating lightness of the color; C^* is chroma which indicates the intensity of a particular color; h° is the hue angle which indicates the perception of the color in a similar way like human eye; TSS is the total soluble solids

with color and brightness, whereas firmness is related with texture. Also, TSS can be associated with sugars and organic acids and therefore related with flavor and sweetness of the fruit. Besides, chroma and hue are related with both the color and the intensity of it. Indeed, from the Table 4, it can be seen that color and appearance are the two sensory characteristics showing the largest correlation with chroma and hue.

The cut-off points of the different physicochemical variables are derived directly from the cut-off points of the critical sensory attributes evaluated by the panel which in turn were calculated based in the limit of acceptability by consumers. In this sense, these physicochemical cut-off points can be used as objective indicators to monitor changes in sensory attributes and acceptability. Moreover, it is possible to use them as objective indicators to estimate shelf-life during storage. Shelf-life estimation based on these cut-off points is more objective and reliable than estimation based solely on a significant change in

Table 9 Pearson's correlation coefficients (r^2) obtained between the shelf life estimated based on physicochemical variables and consumer acceptability scores at the different temperatures of storage

Temperature	Physicochemical variables				
	L	C	h°	Firmness	TSS
5 °C	0.93*	−0.77*	0.92*	0.95*	0.95*
10 °C	0.91*	−0.91*	0.95*	0.80*	0.93*
15 °C	0.92*	−0.90*	0.90*	0.89*	0.87*
20 °C	0.72*	−0.64*	0.65*	0.76*	0.73*

*Significant at $p \leq 0.05$

physicochemical variables and/or sensory attributes, without taking into account the opinion of the consumers. Furthermore, they have the advantage of being easy to use, fast and inexpensive.

Deterioration kinetics

The Table 6 shows coefficient of determination (R^2) and apparent reaction constants (k) corresponding to each sensory attributes and physicochemical variables evaluated in fresh-cut mango, obtained from the zero and first order models. The best fitting of the zero order kinetic model agrees with results of several studies indicating that the main deterioration reactions in foodstuffs show a zero and first order kinetics (Piagentini et al. 2005; Van Boekel 2008; Yan et al. 2008). The lowest coefficient of determination calculated was 0.725 which is still rather high considering that the model is describing a natural phenomena.

Validation of cut-off points to estimate shelf life

An experiment was carried out to validate the models obtained with the methodology above describe. In Table 7 it is shown the results of acceptability of fresh-cut mango stored at 5, 10, 15, and 20 °C during different days, evaluated by consumers using a 9 point hedonic scale. The criteria utilized to determine the shelf life was based in the time needed to reach the limit of commercial acceptability which corresponds with a score of 6.0 (Muñoz et al. 1992). From Table 7, it can be seen that the shelf life was 10–12 days at 5 °C; 2.3–2.6 at 10 °C, 1.3–1.5 at 15 °C and 1.0–1.1 days at 20 °C.

In Table 8, it is shown the shelf-life of fresh-cut mango in days, estimated from sensory and physicochemical cut-off points using the zero order kinetic model obtained. In the table, it is also shown the experimental shelf life obtained from Table 7. The results shows that the shelf life calculated using the kinetic model and based in the cut-off points of the sensory attributes predicts better the experimental shelf life as compared with the shelf life calculated based on the physicochemical cut-off points. Furthermore, calculation based in the physicochemical cut-off points showed a tendency to overestimate the shelf life, in general. However, it can be seen that the prediction is accurate enough to be utilized in an industrial scale. By other side, it can be observed that the physicochemical changes measured instrumentally correlates very well with the changes in sensory attributes. Therefore it is possible to conclude that physicochemical variables can be used to estimate deterioration in sensory attributes and shelf-life at the storage temperatures tested in the present work.

The results above described, agrees very well with the large correlation obtained between the shelf life of fresh-cut mango fruits estimated by consumers acceptability and

physicochemical variables summarized in Table 9. In this table, it can be seen that there is a large correlation either positive or negative between physicochemical variables and consumer acceptability scores in the different temperatures tested in the present experiment.

The results of the present experiment strongly indicate that the methodology described can be use to establish cut-off points for the physicochemical parameters, based on consumer acceptability and sensorial attributes evaluated by a trained panel. Moreover, these cut-off points can be used as objective indicators to estimate shelf-life during storage of fresh-cut mango fruits at different temperatures.

Conclusions

Cut-off points of physicochemical variables, based on sensory changes, allowed to estimate with good precision the shelf-life through deterioration kinetic models, and to monitor sensory changes during storage.

It is possible to use physicochemical variables as predictors of shelf-life of fresh-cut mango with almost the same degree of reliability as the one obtained through a sensory analysis by a trained panel or consumers.

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