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Image analysis applied to quality control in transparent packaging: a case study of table olives in plastic pouches

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Abstract

Consumers consider food products sold in transparent packaging to be trustworthy and of higher quality, but only if the contained product is visually attractive. However, at points of sale, the appearance of food products can change, which affects their perceived quality and purchase intention. Image analysis could mimic the visual evaluations made by humans, and data processing allows to establish models to predict changes in food quality. This study aimed to evaluate the feasibility of the image analysis to monitor the perceived quality of table olives during storage as a system model. For this purpose, the brine colour, sensory acceptance and image analysis of table olives packed in transparent pouches were evaluated at two different temperatures. The proposed system was able to predict brine browning and to assess product sensory perception. Therefore, image analysis proved a non-destructive and fast tool to predict consumer acceptance of table olives packed in transparent pouches.

Keywords: Image analysis; Transparent packaging; Browning; Food acceptance

1. Introduction

The food quality concept is defined as "the combination of attributes or characteristics of a product that have significance in determining the degree of acceptability of the product to a user" [1]. For this reason, quality is a key factor for maintaining high-standard products and for meeting consumer expectations. This involves aspects like appearance, nutritional value, no alterations, and safety of use, among others. When consumers have to make their food choices in supermarkets, appearance is one of the most important factor because the first encounter with food products is often visual and will affect subsequent willingness to accept a product [2]. In fact, over three-quarters of food product purchase decisions are made at points of sale, and 90% of consumers make purchases after examining only the front of packs [3]. In this sense, different studies have suggested that consumers prefer packaging that enables them to see food products, and 54% of consumers agree that it is important to be able to see products through their packaging [4]. Billeter, Zhu, and Inman [5] found that consumers considered products in transparent packaging to be more trustworthy, and this packaging type led to more consumer preferences and purchase intention. Similarly, Chandran, Batra, and Lawrence [6] found that products presented in transparent packaging helped to increase expected product quality. However, transparent packaging only has beneficial effects for visually attractive products [3]. For this reason, the food industry and suppliers must ensure that product appearance maintains quality standards throughout products' shelf lives.

The ability of digital cameras and image processing in monitoring external food quality parameters has been shown for many products [7]. Using image analysis in the food industry for quality control purposes has increased in the last few years because it is a reliable cost-effective alternative to human inspections [8-10]. However, the quality control in supermarkets is mainly carried out by quality control assistants who must ensure that products are suitable for consumption and fulfil the quality standards that are required. Visual inspection is exposed to operators' decision variability and therefore, does not guarantee an absolutely correct assessment. For this reason, image analysis could also provide objective and reliable information about the quality characteristics and appearance of food products at the point of sale.

The procedure for the classification of table olives based on parameters of quality has been issued by the International Olive Council [11]. The method establishes the necessary criteria and procedures for the sensory evaluation. In the case of Spanish-style table olives, one of the main characteristics is its golden-yellow colour. This typical colouring appears because chlorophylls are degraded to several Mg-free derivatives during the elaboration process [12].

The use of thermal treatments, applied to table olives to increase product stability and to guarantee inactivation of spoilage and pathogenic microorganisms, can lead to colour and texture degradation [13]. The severity of this effect will depend on specific aspects of the raw material, processing conditions, and other external aspects like storage conditions or packaging material. Doypack pouches offer the advantages of rigid containers (high stability, ease of use and presentation), and those of soft packages (low price, space-saving before and after use and ease of manufacture). However, these plastic containers are affected by thermal treatment, increasing their oxygen permeability [14]. Oxygen permeation into the packaging may cause rancidity of the product, browning and texture changes during storage. Brine browning is perceived as an important quality alteration that, when is perceived by the consumers through transparent packaging, leads to product rejection.

The aim of this study was to evaluate the feasibility of the image analysis technique to control the quality of table olives during storage. For this purpose, tables olive pouches, previously submitted to conventional thermal treatment, were stored at two different temperatures: room temperature to simulate standard storage conditions; 50ºC to accelerate ageing. The proposed system attempts to detect visual changes over time, predict browning and assess product sensory perception non-destructively.

2. Materials and Methods

2.1. Materials

One hundred pouches of pitted Spanish-style green table olives packed in brine were employed for this study. Pouches were provided by *Cándido Miró* S.A. (Alcoy, Alicante, Spain). The material of the plastic pouches was polyester and polypropylene (PET + PP G), supplied by SPgroup (Villarrubia, Córdoba, Spain) (O_2 permeability < 82 cm^3/m^2/day). Each pouch (dimensions 15 x 10 cm) contained 75 g of table olives and 95 g of cover brine. Cover brine consists of aqueous salt solution (40 g/L), citric acid (3.2 g /L) and lactic acid (5.3 g/L).

2.2. Experimental design

The green table olive pouches were divided into two groups. The first group was stored at 21 ºC in a thermostatic chamber (JP Selecta S.A., Abrera, Barcelona, Spain) with natural convection and with no humidity control. This was the control group (standard storage conditions at points of sale). The second group was stored at 50 ºC, since high temperature accelerates the degradation reactions of olives and brine browning. The objective of selecting this high temperature was to induce radical changes in brine colour to be detected by consumers at points of sale and to lead to reject purchase intention. Our previous studies demonstrated that no colour variation in olives or cover brines happens at lower temperatures during a 10 weeks of storage [15]. These previous experiments were considered to select the storage temperatures and time.

During the storage period, samples were analysed at 3- or 4-day intervals. The experiment lasted 11 weeks with 13 sampling days. The first day of storage, all the samples were taken for image acquisition and sensory analyses. Then three pouches were randomly selected and opened, and brine colour and the image analysis of all the olives included in packages were individually measured. The remaining samples were stored under the same temperature conditions (21 ºC or 50 ºC). On the next sampling day, the same above-described procedure was carried out. Ten pouches were opened and analysed on the last sampling day.

2.3. Sensory evaluation

The sensory evaluation of table olives was carried out by a 12-member trained panel. This panel included individuals of both genders whose age range went from 25 to 45 years. This panel was formed by the Food Technology Department staff members at the Universitat Politècnica de València (Spain), which had participated in previous studies of table olive sensory evaluation. The training process included theoretical and practical sessions following International Olive Council standard regulation guidelines [11]. For this study, the sensory panel was also trained to classify table olives according to the product's visual aspect inside pouches and determine product acceptability. The main objective was to establish the limit that would indicate if the product would not be accepted by consumers.

On each analysis day, panellists evaluated 20 pouches (10 randomly selected samples at each storage temperature) using a 5-point Likert-type scale, where a score of 1 corresponded to "Unacceptable" and 5 to "Acceptable". Finally, assessors were asked if they considered the product suitable for retail sale. This item was included in the questionnaire to establish the browning level at which the product would be rejected at points of sale.

2.4. Brine colour determination

Brine colour was determined as the difference in absorbance at 440 and 700 nm (A440 - A700), as described by Sánchez-Gómez, García-García and Garrido [16]. Brine was drained from pouches and filtered through a 1.2-μm cellulose filter (Scharlab, Barcelona, Spain). Brine absorbance was measured by a spectrophotometer (Thermofisher Scientific, Helios Zeta UV-VIS).

2.5. Imaging device

Images were obtained by a standard device developed previously by Verdú et al. [17], which was designed to be easily implemented as part of an online inspection on the production chain. Images of olive pouches were taken by the Logitech HD Pro Webcam C920 (Trade Mark, City, Country), which had a CMOS sensor that operated at a resolution of 2304 x1535. The angle of view (AOV) of the lens was 78°, which gave a field of view (FOV) of approximately 100 mm at the work distance. Camera exposure and gain settings were configured to the auto mode. The device was placed inside a dark cabin to keep it away from uncontrolled light. The controlled light inside the cabin was produced by two halogen lamps 50W 230 V HI-SPOT (Havells Sylvania, Gennevilliers, France), which emitted an indirect light to reduce reflections, were used: one at the front and one at the back (Verdú et al., 2019). The distance between the camera and the sample was set to obtain a constant image size (**Fig. 1**). The image was recorded at a resolution of 1.920 x 1.080 pixels. Captured images were transferred to a "Vaio" Notebook with an Intel® Core™ i5 CPU processor and a 64-Bit operating system to be edited by the Logitech v 2.51 software.

Figure 1

Images were captured in RGB format (red, green and blue) with 5168 x 2907 pixels and were saved in .JPG. Image processing and data extraction were carried out with the following steps:

Step 1. Histogram extraction: histograms from each R, G and B channel of images were generated as a spectrum. They represented the frequency of the pixels of each colour value present on images. Spectra were normalised by dividing each value by the total number of pixels on the image. The obtained spectrum was called "original data" and labelled as O.

Step 2. Spectra transformation: a second block of spectra was generated by multiplying the number of pixels of each colour value by the square of its own colour value. These new spectra were called “transformed data” and labelled as T.

Step 3. Area calculation: the last step was done by calculating the area described by the curves generated by the T data (AT). To this end, the T value of each colour value for the three channels was summed. So, the number of data lowered from 765 (255 tones * 3 channels) to three (one area per channel).

2.6. Statistical analysis

A one-way ANOVA was conducted with the sensory evaluation and brine colour data to test if significant differences appeared throughout the storage period. The least significant difference (LSD) procedure was used to test for differences between averages at the 5% significance level. Statistical data processing was performed with the Statgraphics Centurion software (Statpoint Technologies, Inc., Warrenton, VA, USA). The data from the images were firstly explored by following the unsupervised method. Principal Component Analysis (PCA). PCA was used to explore the interdependency of tones and their loads to explain the variance obtained during the experiment. Moreover, Support Vector Machines for classification (SVMDA) were employed to classify samples as “good” or “bad” according to the information provided by the panellists. The dependence of the image data and the sensory/colour measured data was tested by the Support Vector Machines for Regression (SVMR). This was used to obtain regression models among the image data and sensory evaluations, product acceptance and absorbance values. SVMR can be used to carry out non-linear regressions between both datasets. SVM is a powerful supervised learning methodology based on the statistical learning theory, and is frequently used for spectral analyses [18]. Procedures were performed with PLS Toolbox 6.3 (Eigenvector Research Inc., Wenatchee, Washington, USA), a toolbox extension in the Matlab 7.6 computational environment (The Mathworks, Natick, Massachusetts, USA).

3. Results and Discussion

3.1 Sensorial and physicochemical evaluations

The visual appearance of the table olive pouches was evaluated during the storage period. The samples maintained at room temperature were considered by the assessors to be "acceptable" throughout the study. The cover brines of these samples did not present any sediment, browning or turbidity. However, the scores given by the panellists for the samples stored at 50 ºC significantly decreased during storage, mainly from the second week of the study (**Fig. 2a**). On the first analysis days, samples from both batches obtained similar scores (more than 4) in all cases. From storage day 15, the scores given to the samples stored at 50 ºC progressively decreased until the last sampling points, when they obtained the lowest scores. As expected, when the scores given by the panellists decreased, the purchase intention percentage also lowered. For the samples stored at 50 ºC, purchase intention gradually went down from 100% at the beginning of the study to day 28 when all the samples were considered to not be acceptable for commercialising (**Fig. 2b**).

Cover brine colour was determined by the difference in absorbance at two wavelengths (A440- A700). The initial value came close to 0.2 (**Fig. 2c**), and this value remained constant in the samples stored at room temperature throughout the study. The brine absorbance in the pouches maintained at 50 ºC progressively increased to reach a value of 0.36 at the end of the storage period. It is considered that the bigger this difference in absorbance, the darker brine colour is [19]. Brine colour has been used in table olive production for different purposes. This parameter can be employed to control olive fermentation, to detect the presence of oxygen during storage and to evaluate the intensity of heat treatments, since colour is one of the parameters that directly reflect the quality of vegetables subjected to heat treatments [20]. Brine colour is also affected by several factors, such as processing type, olive cultivar, fruit dimension when brining, product type (whole, pitted or stuffed) or cover brine composition [21-23], for this reason it is difficult to establish a single reference for this parameter. García-García, Sánchez-Gómez, and Garrido-Fernández [24] found lower A_{440}-A_{700} values in Gordal cultivars than in Hojiblanca and Cacereña cultivars. They attributed these variations to the specific processing conditions applied (number and concentration of lye treatment, washing systems, number and type of reused solutions or sterilisation processes) rather than to cultivars and presentation. Despite this variability, golden-yellow coloured brines are preferred to brown tones, and browning colourations are considered a quality defect that can determine a product's shelf life. Although there is no acceptance limit for cover brine colour for olive commercialisation in any standard, several studies have established their own A_{440}-A_{700} parameter values, above which brine colour is considered unacceptable. Montaño, Sanchez and Rejano [25] set a brine colour acceptance limit for Spanish-style green table olives of 0.23 AU, and this value has been employed by several authors as acceptance limit [14]. In other studies, this limit has been set at 0.4 [16,26]. According to our results, it was established that brine browning negatively influenced consumer liking and purchase intention. In this sense, after considering the obtained sensory evaluation results, the end of shelf life in the present study can be established in the samples stored at 50 ºC between days 18 and 20 because at this point, more than 25% of the assessors would reject the product in supermarkets. This limit corresponds to a brine colour below 0.27, which is a similar value to that initially established by Montaño et al. [25] and, therefore, it could be considered the threshold of acceptability of the product herein studied.

3.2 Image evaluation

Once the data from images (RGB tones) were obtained, a PCA analysis was run to reduce data dimension and to evaluate the distribution of samples in the PCA space. The first two components expressed 54.18% of total variance, but only PC1 (39.45%) could be related to evolution. **Fig. 2d** shows the means and standard errors for the PC1 values. As seen, when only the first principal component was employed, the data for each sampling day were spontaneously clustered and displayed the same behaviour as overall acceptability and purchase intention, but behaved inversely to absorbance. Thus the 765 data that characterised each sample (255 tones * 3 channels) were reduced to only one (PC1 component). The tones that most strongly influenced PC1 (highest loadings) were those included between two intervals for each channel (red channel: tones between 33–110 and 155–233; green channel: tones between 21–80 and 137–212; blue channel: tones between 12–28 and 86–117).

Figure 2

Fig. 3a shows the mean of the relation between the number of pixels of each tone and the total pixels of each channel for the data obtained during the study. Additionally, the red lines indicate he evolution of one of the tones of each influential interval (tones 80, 200 and 20 for the red, green and blue channels, respectively). As we can see, for the three channels the number of each tone evolved during the experiment. For the darkness tones (lower tone values), there were generally very few pixels at the beginning, which increased during the experiment, while the behaviour of the clearness tones was the inverse. This tone evolution was clearly observed when the images taken on days 0 and 42 were segmented at tones 80 and 200 for the red and green channels, and at tone 20 for the blue channel (**Fig. 3b**). We can see that very few pixels appear with tone 80 on day 0, more appear for tone 200, and the opposite happens with the image on day 42. These results agree with those obtained by Romeo et al. [20], who studied the effect of thermal treatments on olive colour. These authors observed that the a* parameter displayed a distinct tone, from green to red, in pasteurised table olives and they associated this change in colour with browning reactions, enzyme-catalysed or chemical oxidisation reactions. For the blue channel, the number of pixels at tone 20 increased from day 0 to day 42. The more pixels for the darkness tones could be related to product browning caused by polymerisation of *o*- diphenols, which is associated with heat treatments. Piscopo, De Bruno, Zappia and Poiana [27] observed how phenolic content in green table olives decreased after heat treatment, while melanoidin concentrations increased. Melanoidins are polymers of high molecular weight with biological and health implications, besides colour and taste modification on food [28].

Figure 3

3.3 Using image data to evaluate the quality of olives

To evaluate if the information drawn from the image data was able to predict the quality of table olives, classification of samples as being good or bad was firstly done by the SVMDA method employing the information obtained from the sensory evaluation. **Table 1** shows a confusion matrix of the sample classification for each storage day by employing the O data. The first classification mistake took place on day 11 when one sample of 50 was classified as bad when it was actually good. The same result occurred on day 14. These mistakes could not be disputed by the industry because no bad sample should be classified as good. Moreover, from day 18 to 35, one sample or two were classified as good every day when they were actually bad. This result could be more negative for the industry because bad samples would be classified as good.

Table 1

Data processing was carried out to increase classification accuracy. To do so, the number of pixels of each tone was multiplied by the square of the tone value. **Fig.**

4a-b show the mean and standard error of O and T, respectively, on days 0, 18 and 42. Unless there was a difference between the 3 days for tone spectra when O were used (Fig. 4A), differences increased with data processing, and further increased for the area described by the tone spectrum showing the most marked changes, which decreased with time. The classification was redone by employing T and AT (Table 2). The results revealed a slight improvement, which went from an accumulated mistake of 2% to 1.85% when T were used and improvement increased when AT were employed. In this case, only 1.23% of the accumulated mistake was made, and only 0.46% of the samples classified as bad were actually good. Mistakes were observed on days 18 and 21, when the panellists had more doubts. On these two days, 73% and 52% of the panelists respectively classified samples as good, but the remaining panellists classified them as bad.

Hence during this period is complicated to classify without mistakes because it is a period when the variability in panellists' responses peaked. No mistake was made for the periods that went from day 0 to 18 and from day 21 to 42, when samples were respectively good or bad.

Figure 4

Once the image data capacity to classify table olives as good or bad was demonstrated, the second study involved evaluating their capacity to be related to storage time, overall acceptability and absorbance. To do so, the SVMR statistical tool was used where O, T and AT were modelled to predict them. **Table 2** shows the accuracy values for the SVMR analysis. For them all, the correlation coefficient of cross-validation (R^2 CV) was higher, but the highest values were obtained with storage time predictions. In the sensorial evaluation, the RMSECV values were high, which could be due to the panellists' subjectivity. In fact, changes in olive packs were evaluated objectively by the absorbance method, which gave a good correlation coefficient, while the subjectivity of the evaluation made by panellists gave a correlation with a minor error. Unless the increase in accuracy was slight when employing AT, it is important to emphasise that using these data implies sharp drop in the data from 768 to 3, but this reduction also allowed the best sample classification as being good or bad.

Table 2

From the obtained results, it was established that the image analysis can also be applied to monitor colour changes that occur during table olive processing. Hence the microbial presence of certain strains with β-glucosidase activity, which change the colour of the medium from colourless to brown tones with variable intensities, or pouch permeability to oxygen, which leads to brine browning, can also be assessed by this non-destructive system.

4. Conclusions

Cover brine browning negatively affects the quality of table olives and consumer perception. This product devaluation can be detected by visual inspection of control assistants or could be measured by brine colour absorbance, leading to variability problems or product destruction, respectively. In this study, the table olives classification according to visual acceptability was successfully achieved with the data obtained from the image analysis, which was employed to predict if the table olive product was suitable for retail sales and would, therefore, be acceptable for consumers. Herein, the image analysis has demonstrated to be an interesting tool to determine brine browning and consumer acceptance of table olives packed in transparent pouches. This technique could be applied for quality control purposes throughout a food product’s shelf life, whose distinctive features are versatility, feasibility and easy use. Future research into this application will involve optimising the image capture procedure to improve the technique’s precision, and to test the effect of new packing materials and table olives preparation.

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Conflicts of interest

The authors declare no conflict of interest.

Compliance with ethics requirements

This article does not contain any studies with human or animal subjects.

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Figure captions

Fig. 1. Digital image capture system.

Fig. 2. Changes in overall acceptance (a), purchase intention (b), brine colour (c) and the PC1 values obtained from the PCA study employing the image acquisition data (RGB tones) (d). Black circles correspond to the olives stored at 50 ºC. Grey triangles correspond to the olives stored at room temperature (21 ºC). Vertical lines indicate standard error.

Fig. 3. Mean relative value between the number of pixels of each tone and the total pixels of each channel (red, green, blue) for the data obtained during the study (a). Images correspond to the segmentation at 20 (red), 80 (green) and 200(blue) tones on days 0 and 42 (b).

Fig. 4. Mean and standard error of the relation between the number of pixels of each tone and the total pixels of each channel (a) or those transformed (total pixels of each channel x tone^2) (b) for the data obtained on days 0 (black line), day 18 (dashed line) and day 42 (grey line).