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Image Analysis Assessment of the Shelf Life of Fresh Strawberries

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Extending the shelf life of food products like strawberries (*Fragaria ananassa*) is one of Europe's main goals to improving food safety and reduce food waste. In this study, a model has been developed to estimate and predict the quality of strawberries. Strawberries appearance and colour parameters has been determined by image analysis and traditional methods. Pictures of strawberries stored at 5-35 ºC were taken daily for 15 days. In total, 48 images were recorded and analysed. The colour images (RGB images) were processed in the laboratory using a specific image acquisition and analysis program. A linear model has been developed with high accuracy (R^2=0.83) to estimate appearance based only in image analysis. This approach allows the use of this technology in the food chain industry.

1. Introduction

Strawberries (*Fragaria ananassa*) are very perishable and highly susceptible to postharvest fungal infection (Melo et al., 2020). For these reasons, new strategies are needed to improve shelf life in concordance with the framework of the European objectives for reducing food waste and increase food safety. In keeping with this, the European project BiofreshCloud (biofreshcloud.es) aims at developing novel tools for optimizing the food production-distribution chains of tomato and strawberry of Spain and Turkey.

The conventional methods to assess quality on fruit and vegetables such us detecting and quantifying fungal decay, like traditional microbiological and/or physicochemical techniques are expensive, time- and labour-consuming, require professional experience and have limited applicability (Leiva-Valenzuela and Aguilera, 2013).Most of these traditional methods require inspection trough laboratory analytics and sensory analytics are destructive, not being applicable to maintain the quality and safety of food until it is consumed and to prevent the development of pathogenic or spoilage microorganisms.

Image-processing and computer vision techniques can be applied in the food industry and farming as an alternative to the reference methods for determining fruit quality. This new technology allows to assess food attributes such as size, shape and colour (Yusuf et al., 2018). Monitoring fruit weight (Basak et al., 2022) and colour (Nugroho et al., 2021) by pixel counting and processing can be used to identified external quality parameters of strawberries.

The aim of this study is to quantify external attributes such as size, colour and appearance using image analysis to develop a linear modelling approach able to reliably evaluate strawberry quality during storage at different temperatures and, hence, predicting its shelf life.

2. Materials and methods

2.1 Fruit samples

Table 1 shows the parameters evaluated in this study and the methodology used.

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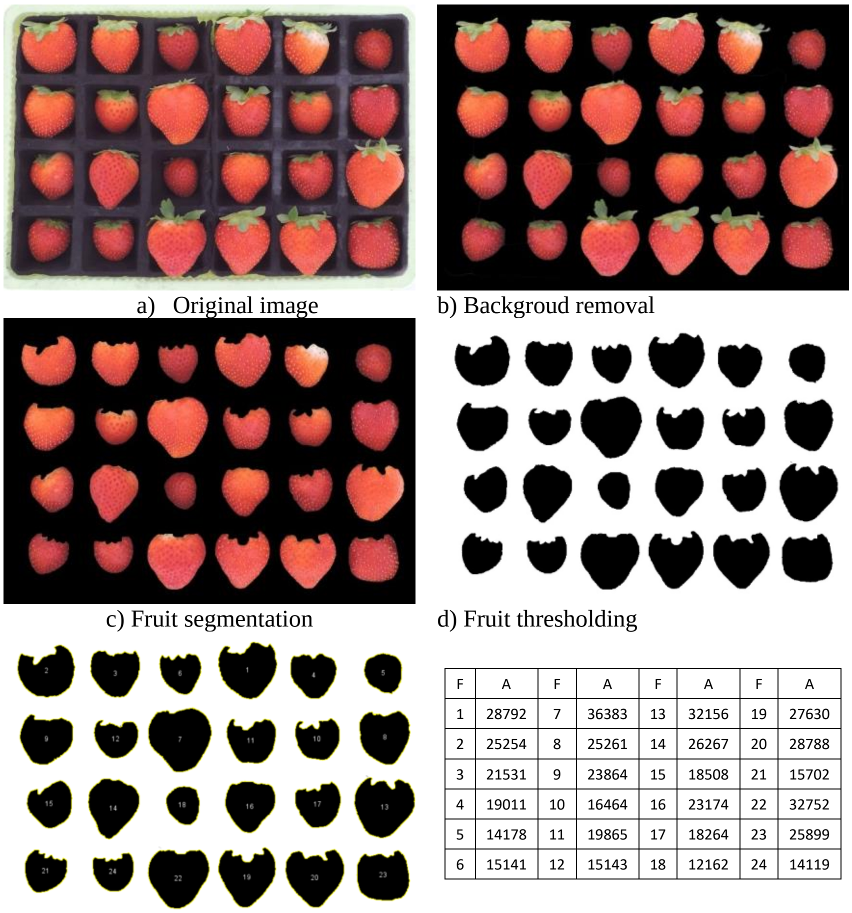
Table 1: Parameters evaluated in the study.

Parameters	Description
Treatments: Temperature and time	Four storage temperatures: 5 ºC, 15 ºC, 25 ºC, 35 ºC
	Storage time: 0, 3, 6, 9, 12 and 15 days
Fruit units	24 fruits per treatment
Fruit weight	Fruit weight in g/fruit using a precision balance
Weight loss	% fruit weight in g/fruit related to initial weight using a precision balance
Appearance	Evaluation of appearance by a sensory panel (scaled 1-5)
Fruit size	Fruit size area estimated by image analysis
Colour	L*, a* and b* colour parameters



F	A	F	A	F	A	F	A
1	28792	7	36383	13	32156	19	27630
2	25254	8	25261	14	26267	20	28788
3	21531	9	23864	15	18508	21	15702
4	19011	10	16464	16	23174	22	32752
5	14178	11	19865	17	18264	23	25899
6	15141	12	15143	18	12162	24	14119

Figure 1: Segmentation and blob analysis of strawberry surface size by image analysis. Original image (a) processed image to eliminate the background (b), fruit surface separation from the rest of the image (c), fruit surface segmentation(d), fruit thresholding, (e) fruit area identification and (f) fruit area measurement.

2.2 Image analysis

A system for the automatic evaluation of fruit quality (Sola-Guirado et al., 2020) has been used. Pictures were taken every three days for 15 days. In total, 48 images were recorded and analysed per treatment. The colour images (RGB images) were analysed following this procedure (Figure 1):

1. Image acquisition: The camera captures the image, which is loaded by the software.
2. Image processing: The analysis of images obtained was performed in the laboratory using a specific image acquisition and the analysis program ImageJ. ImageJ is a public domain software for analysing scientific-image connected with other software programs such as Fiji and ImageJ2, among others (Schneider et al., 2012).

3. Fruit segmentation: A manual segmentation of the image was made by applying a threshold as a function of the intensity values of the RGB image between 0 and 255.
4. Calculation of fruit size: Each fruit image is cropped and fitted to a rectangle that circumscribes the shape of the fruit. A calibration factor (pixels per mm) is then applied. Fruit area (mm^2) is the conversion of the total number of pixels by their distance.
5. Size loss by image analysis (SLIia): The segmentation was performed by sweeping the image pixel by pixel and labelling each pixel as black or white, depending on whether the pixel value was greater or lower than the threshold (Gonzalez and Woods, 1992). Thus, a ratio of the percent size loss of the strawberry was obtained Eq (1).

$$\text{Size loss by image analysis (SLIia)} = \frac{At_0}{A_{tn}} \times 100 \qquad (1)$$

Where A_{to} is the fruit size area determined by image analysis at the beginning of the experiment and A_{tn} is the fruit size area during the storage time. Colour was determined in every fruit per each group using a Spectrophotometer CM-23d (Minolta Company, Chuo-Ku, Osaka, Japan). Three measurements were done in different areas of each fruit being automatically averaged by the device. Colour was expressed through CIELab colour scale, where L*-value refers to lightness, a* value refers to the change from green (-60) to red (+60) and b* value the change from blue (-60) to yellow (+60) (Giannoglou et al., 2021).
A Multiple linear regression (MLR) model (P<0.001) was developed with four influencing factors as independent variables (time, temperature, colour parameters and fruit size) and appearance as the dependent variable.

3. Results and discussion

3.1 Image analysis results

Figure 2 shows processed images of the fruits at different storage times and temperatures. A higher deterioration was observed increasing storage times and temperatures. Wang et al. (2018) also suggested the use of a predictive quality model for strawberries during storage to calculate their shelf life based on the storage temperature, aiding on optimizing their storage management and reducing the economic losses.

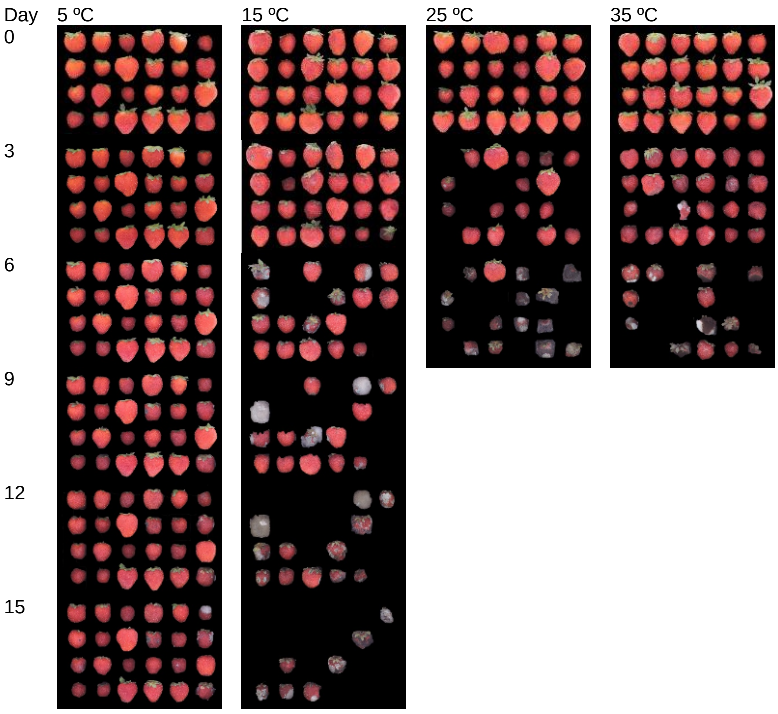


Figure 2: Processed images of the fruits at different storage times and temperatures.

Table 2 shows the Pearson correlation, the determination coefficient and standard error obtained for the fruit weight and colour parameters using image analysis and traditional method. The correlation Pearson values obtained ranged between 0.52 and 0.94 being significant at $p < 0.01$ in all cases.
A good determination coefficient (R^2) equal to 0.88 was obtained between the values for fruit size obtained by images analysis and the values of fruit weight determined in laboratory using a pression balance. Similarly, yellowness (b*) values presented a Pearson coefficient of 0.71 and R^2 equal to 0.51. Lower values of R^2 and Pearson coefficients were found for Lightness (L*) and redness (a*) values and theses values were significantly different (t student, $p < 0.05$). Image analysis overestimated those values. However, considering the Lab values together, both methods for the assessment quality attributes such as weight loss and colour parameters showed similar results for the samples analyzed (Figure 3). Other authors have also used simple linear-based regression (LR) and a nonlinear regression, i.e., support vector regression (SVR) models, using pixel numbers as input parameter in modelling fruit weight (Basak et al., 2022). For colour determination, the correlation was R^2= 0.79. Nugroho et al., (2021) also found similar accuracy for the estimation of the redness (a*) (76.74 %) and yellowness (b*) (66.89 %) parameters, with no significant difference between image analysis results and the conventional method for colour measurement. However, these authors found that the lightness (L*) colour parameter significant differed between both methods.

Table 2: Pearson correlation (p value), correlation coefficient (R^2) and standard error (SE) for the comparison measurements of fruit weight and colour parameters using image analysis and conventional method. Showed values are mean ± standard deviation (SD). Different letters indicate *significantly differences between measurements (p<0.05).*

Parameter	Reference method Mean ± SD	Image analysis Mean ± SD	p value	R^2	SE
Fruit weight	11.02 ± 3.53 a	11.03 ± 3.30 a	0.94	0.88	1.20
L*	46.40 ± 9.19 b	37.03 ± 2.73 a	0.53	0.28	6.73
a*	39.39 ± 12.80 b	34.50 ± 3.34 a	0.52	0.27	2.84
b*	19.21 ± 10.73 a	22.72 ± 4.00 a	0.71	0.51	5.55

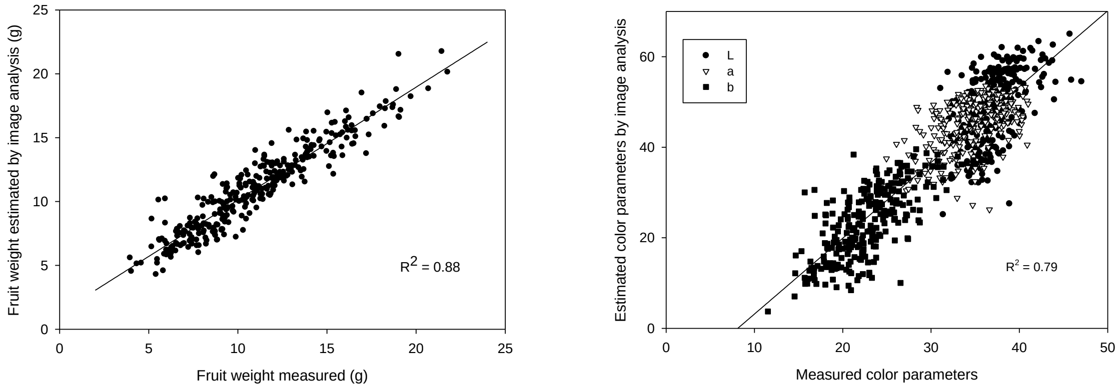


Figure 3: Linear regression between fruit size estimated by image analysis and fruit weight determined by the reference method (a). Linear regression between L, a* and b* colour parameter determined by image analysis and by the reference method (b).*

A linear model was developed relating visual appearance to time and temperature evolution together with fruit size changes during storage according to Eq (2).

$$Appearance\ (1-5) == +1.234 - 0.059\,t - 0.009\,T - 0.016\,L^* + 0.095\,a^* + 0.029\,b^* - 0.056\,A_{tn} \qquad (2)$$

Where A_{tn} is the fruit size area determined by image analysis at the storage time (t) and at a given temperature (T) and L*, b* and a* are the colour values obtained from image analysis.

A R^2 = 0.84 was obtained for the model predicting appearance based in image analysis. The a* values, representing the redness-green colour, exhibited higher values of the beta coefficients and the t statistics,

indicating its higher contribution to the model variability. Kadivec et al. (2016) also determined that the range of the changes in colour of stored strawberry was larger for a*, while for b* and L* they were relatively small. Thus, the visual perception of colour will be determined for the most part by the a* value.
Similarly, Ktenioudaki et al. (2022) also carried out a visual estimation of the fruit quality during 9-days of storage, attributing scores from 1 to 5 for strawberry appearance. A score of 3 was considered as the lower limit of acceptability for sale. The time (days) between harvest and the time to achieve this lower limit of acceptability (score 3) determined the shelf life of the fruit. By using the model of appearance and fixing this value, we can estimate the time needed for every fruit to reach an appearance level equal or lower than 3, considered not suitable for retail.
Figure 4 shows the shelf life predicted based on storage temperature by the model for appearance built by image analysis for colour and fruit size determination. Other authors have applied models for predicting shelf life with R^2 ranging between 0.82 and 0.88 using UV-VIS-NIR spectra (Joshi et al., 2022).

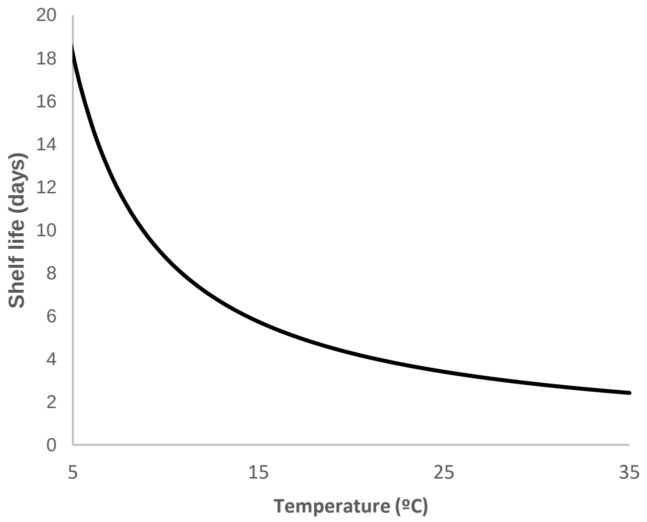


Figure 4: Shelf life predicted based on storage temperature by the model for appearance using image analysis for colour and fruit size determination.

4. Conclusions

This new approach allows a fast estimation of shelf life of strawberries and can be the grounds for future research and more extensive data collection for other fruits and vegetables. The approach evaluated in this study is valid to generate valuable tools and solutions for the fresh produce industry contributing to reduce food waste at the postharvest level.

Acknowledgments

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