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Application of computer vision systems for assessing bergamot fruit external features

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All relevant data are within the paper and its Supporting Information files.

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Abstract: Bergamot *Citrus x bergamia* Risso & Poiteau is an emblematic Citrus species of Reggio Calabria province (Southern Italy) where more than 90% of the global production thrives. The present work deals with the use of a non-destructive technique based on a computer vision system to evaluate bergamot fruit peel colour, as well as dimensional features. To this purpose, experimental trials considered three bergamot cultivars, namely 'Femminello', 'Castagnaro' and 'Fantastico'. Bergamot fruit RGB images were taken using a laboratory inspection chamber equipped with a lighting system and a digital camera Nikon D5200 directly connected to a personal computer, to enable remote image acquisition. First, images were pre-processed according to a previously created colour profile. After that, bergamot fruit colour was analysed and expressed in terms of Hunter *L*, *a*, and *b* coordinates, which were used to calculate Standard Citrus Colour Index (CCI). In addition, dimensional features and shape descriptors were measured for each cultivar. Statistical data analysis, by applying the Kruskal-Wallis test at *p*<0.05 on CCI data highlighted significant differences between the assessed cultivars, and discriminant analysis (LDA) applied on CCI and dimensional features enabled a classification rate of 78.86% between cultivars, proving the reliability of computer vision techniques in assessing bergamot external features.

1. Introduction

Bergamot *Citrus x bergamia* Risso & Poiteau (Pellegrino *et al.*, 2015) is an emblematic Citrus species of Reggio Calabria province (Southern Italy), where more than 90% of the global production is located. Until recently, the production has been exclusively destinated to peel essential oil extraction and subsequent use in perfumery, cosmetic and pharmaceutic preparations, food flavouring and confectionery (Navarra *et al.*, 2015; Gioffrè *et al.*, 2020). However, the rising interest toward bergamot-based food and beverage for their high content in functional bioactive compounds is directing the production toward other market channels. This trend is also accompanied by the necessity of agrifood industries to develop particularly from a technological point of view, to keep up and adequately address global market requirements and standards. In fact, great attention has been paid, in the last years, to the development and implementation of non-destructive techniques based on artificial intelligence in industrial processes including agrifood sector, for their reliability, accuracy, and timeliness in determining qualitative parameters of the product, especially when employed in automated post-harvest processes. Several studies dealt with the use of computer vision systems for citrus fruit quality assessment or grading (Cubero *et al*., 2014; Lorente *et al.*, 2015; Zhang *et al.*, 2020; Riccioli *et al.*, 2021; Zhang *et al.*, 2022), but up to now, no one regarded bergamot fruits. In this context, the present work aims at assessing fruit peel colour, expressed in terms of Standard Citrus Colour Index (CCI) as well as dimensional features and shape descriptors, including fruit area, fruit perimeter, major axis, minor axis, circularity, roundness, aspect ratio and solidity of three cultivars of bergamot fruit, by means of computer vision systems.

2. Materials and Methods

Bergamot samples

Experimental trials considered three bergamot cultivars, namely: *Citrus x bergamia* Risso & Poiteau, ‘Femminello’, ‘Castagnaro’ and ‘Fantastico’. Fruits were collected at the end of their ripening stage (since mid-January to the beginning of February) in private farms located in Reggio Calabria province. A total of 248 fruits were used.

Methodology set-up and RGB image acquisition

Bergamot RGB image acquisition was performed using a laboratory squared inspection chamber equipped with a digital camera Nikon D5200 directly connected to a personal computer, to enable remote image acquisition, and a lighting system including 4 fluorescent linear lamps (BIOLUX T8- 18W/965, 6500 K) placed on the top of the inspection chamber in a 0°/45° configuration as shown in figure 1. The used camera was equipped with a CMOS 23.5 x 15.6 mm sensor, allowing getting a resolution of 24.1 million pixels; and a Nikkor f/2.8G lens with a 1:1 reproduction ratio.

Prior to image acquisition, several configurations of operational parameters were tested until getting the most appropriate one, which considered the following parameters: ISO: 100; exposition time: 1/125; diaphragm opening f: 5.6; 4 lamps (instead of 8), without polarizing filter.

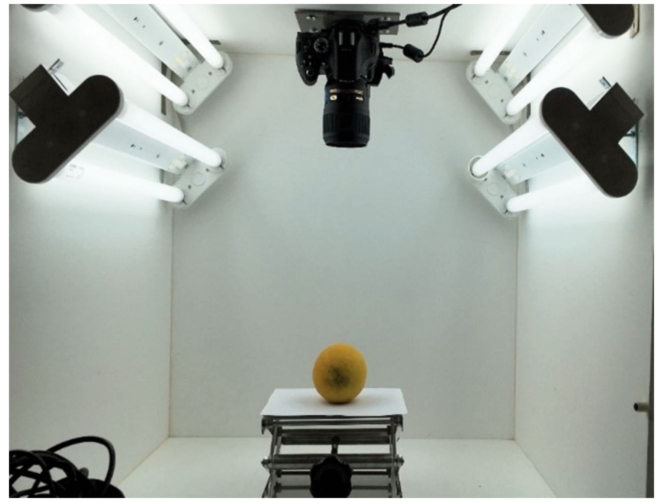

Fig. 1 - Bergamot RGB image acquisition using a laboratory inspection chamber equipped with a computer vision system.

Image analysis and bergamot colour determination

Bergamot images were calibrated, first, by performing the white balance, and subsequently the chromatic correction according to a previously created profile with the ColorChecker Classic target (X-Rite Inc., USA), through the Colorchecker Passport Software as performed in Benalia *et al.* (2017).

Bergamot RGB images were then analysed as perfomed by Benalia *et al.* (2016) using a specific application (Fig. 2) that enables to convert mean R, G, B values of all pixels contained in a selected Region Of Interest (ROI) into *L*, *a*, *b* coordinates considering the CIE illuminant D65 and the 10° observer standard (Cubero *et al.*, 2018).

Besides and for comparison purpose, bergamot

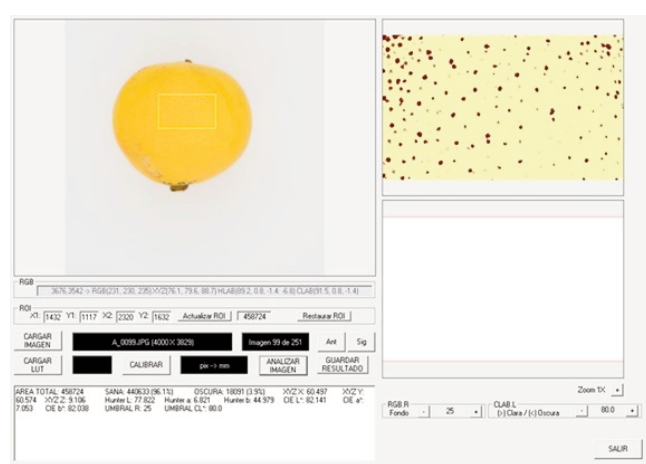

Fig. 2 - Bergamot colour determination through RGB image analysis.

fruit colour was determined by means of a portable Konica Minolta CM-700D spectrophotometer being the only widely standardized instrument used for instantaneous food colour evaluation in agrifood industries. To this end, six measurements were carried out randomly on each fruit.

Determination of dimensional features and shape descriptors

Dimensional features and shape descriptors, including fruit area in the image, fruit perimeter, major axis, minor axis, circularity, roundness, aspect ratio and solidity were determined using the software ImageJ 1.50i using Java 1.8.0.77 (Fig. 3), according to a previously set scale.

Data analysis

Hunter *L, a* and *b* values were used to calculate the Standard Citrus Colour Index (CCI) according to the following formula (Eq. 1) and to compare whether there is a difference between the examined cultivars.

$$CCI = 1000\, a/(L \cdot b) \quad \text{(Eq. 1)}$$

With *L* value indicating lightness (0 = darkness -> 100 = lightness), *a* value representing red (positive value) or green (negative value); and *b* representing yellow (positive value) or blue (negative value).

CCI data were statistically analysed using the open-source application R (version 3.3.1). Hence, data normal distribution was checked by applying the Shapiro-Wilk normality test, and according to the results, the most appropriate test was applied to compare the examined cultivars in terms of colour features.

Furthermore, CCI data as well as dimensional features and shape descriptors retrieved from bergamot RGB image analyses were used to build an exhaustive dataset and multivariate image analyses (MIA), particularly, Principal Component Analysis (PCA) and Discriminant Analysis (LDA) were applied using Past 4.12b (Hammer *et al.*, 2001).

3. Results and Discussion

Citrus Colour Index (CCI) values calculated from bergamot image analysis were compared with those obtained using the portable spectrophotometer for each cultivar. The obtained results are shown in the following figure 4. Particularly, the coefficient of

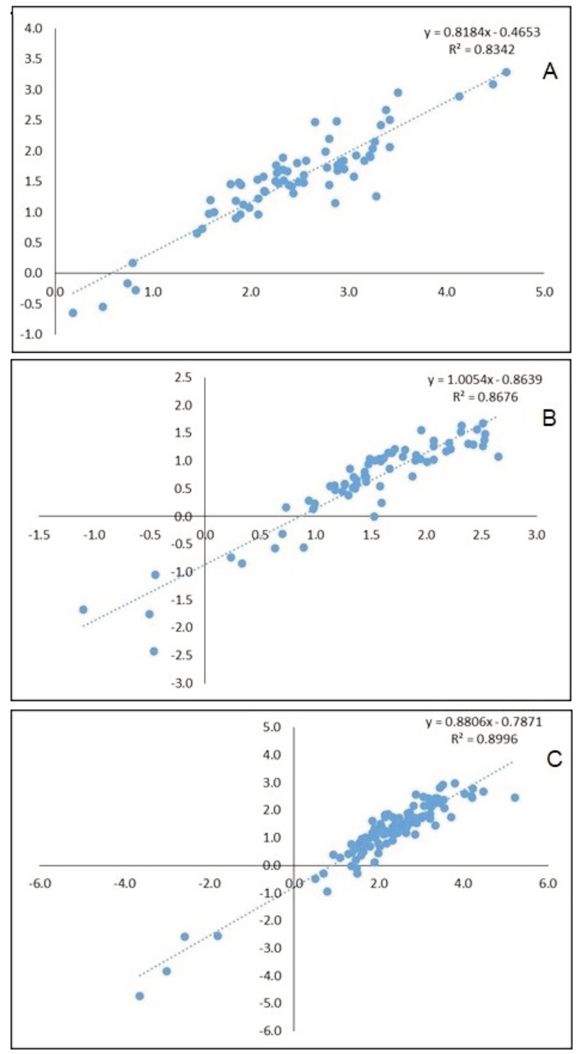

Fig. 4 - Standard Citrus Colour Index (CCI) from Image analysis Vs portable spectrophotometer. A: 'Castagnaro', B: 'Fantastico and C: 'Femminello'.

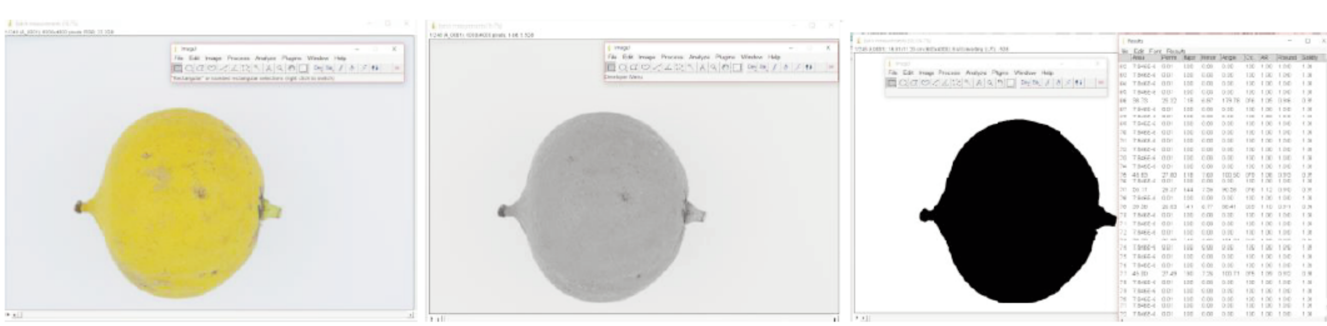

Fig. 3 - Bergamot dimensional feature and shape descriptor calculation through RGB image analysis using ImageJ.

determination R^2 was equal to 0.83, 0.87 and 0.90 respectively for the cultivars Castagnaro, Fantastico and Femminello, making it possible to substitute colour analysis using conventional instruments with that based on image analysis. Indeed, diversely from the portable spectrophotometer, which offers the possibility to only analyse a small area of the fruit surface, image analysis allows assessing fruit colour of the whole surface of each fruit.

The obtained R^2 values in this study are, however, lower than those reported by Vidal *et al.* (2013), who tested two algorithms for the estimation of oranges cv. Navelina CCI based on computer vision. This difference could mainly be attributed to the difference in the used hardware and operation parameters. Indeed, up to now, a standardized methodology concerning the use of CVS is still missing.

The results of Shapiro-Wilk test demonstrated that CCI data do not follow a normal distribution. Therefore, the non-parametric test Kruskal-Wallis was applied.

The outputs highlighted a significant difference between the cultivars in terms of CCI at $p<0.05$ (Table 1). CCI mean and median values are reported in Table 2. CCI mean values were equal to 3.01±1.51 for cv. Castagnaro and 2.36±2.26 for cv. Femminello, indicating a yellowish colour, while it was much lower for cv. Fantastico with a value of 1.21±1.52 corresponding to a greenish colour yet (Table 2).

As mentioned above, multivariate image analysis, particularly, Principal Component Analysis (PCA) and Discriminant Analysis (LDA) were applied considering CCI values as well as dimensional features and shape descriptors. Hence, the three cultivars were compared according to 9 variables. PCA highlighted that most of the variability was expressed by the first two components, with respectively 46.86% for PC1 and 21.38% for PC2. The first component PC1 is mostly and positively influenced by fruit area, fruit perimeter as well as by major and minor axis. To this regard, Giuffrè (2019) and Giuffrè and Nobile (2020) found significant differences between the bergamot cultivars when comparing both major and minor axes. However, diversely from our method they used conventional measuring method. The first component PC1 is also negatively influenced by roundness. The second component PC2 is, however, positively, and mainly influenced by roundness and subsequently solidity, while it is negatively affected by CCI and aspect ratio (Fig. 5).

Table 1 - Results of Kruskal-Wallis test for CCI according to the cultivar

Test	χ^2	*df*	*p*
Kruskal-Wallis: (CCI by cultivar)	46.55	2	$7.793e^{-11}$

Table 2 - Mean and median values of CCI according to the cultivar

Cultivars	Mean values ± St dev.	Median values
Castagnaro	3.01 ± 1.51	3.05
Fantastico	1.21 ± 1.52	1.57
Femminello	2.36 ± 2.26	2.61

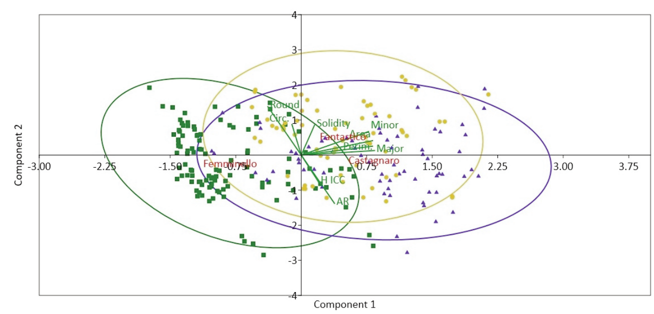

Fig. 5 - PCA score plot. Green filled square: 'Femminello', purple filled triangle: Castagnaro, yellow dots: Fantastico.

A better discrimination between the cultivars was obtained when LDA was applied (Fig. 6), and 80.49% of correctly classified fruit according to cultivar was reached. This rate decreases to 78.86% when Jackknif cross-validation method is applied (Table 3).

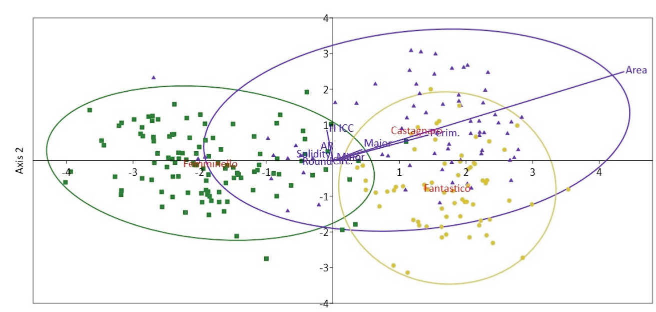

Fig. 6 - LDA plot. Green filled square: Femminello, purple filled triangle: Castagnaro, yellow dots: Fantastico.

This study focuses on the use of computer vision system to retrieve colour and dimensional features with the aim of distinguishing between three cultivars grown in the province of Reggio Calabria. As previously stated, no work dealing with this theme have been performed so far. To our knowledge the only one, which reports the characterization of bergamot physical properties using CVS is that of Rafiee *et al.* (2007), who measured fruit size, mass, projected area, fruit density, solid density, bulk density, bulk porosity, packing coefficient, density ratio, geometric diameter, sphericity and surface area of *Citrus medica*, which characteristics are different from *Citrus x bergamia* Risso & Poiteau.

Table 3 - Jackknife cross validation results resulting from discriminant analysis (LDA)

Given groups	Predicted groups			Total
	Femminello	Castagnaro	Fantastico	
Femminello	99	8	3	110
Castagnaro	13	42	14	69
Fantastico	0	14	53	67

4. Conclusions

The obtained results in this study confirm the reliability of computer vision systems in characterizing bergamot fruit external properties, considering particularly, colour and dimensional features. Although preliminary, the outputs clearly demonstrate the efficiency and accuracy of these techniques in distinguishing the examined cultivars, promoting therefore their implementation in bergamot post-harvest processes. Indeed, both features, i.e., colour and dimensions are important to be considered for the development of new technologies as they represent important qualitative indicators.

Further research activities should be performed to validate findings obtained in this study, and to investigate other aspects using CVS such as ripening progress and essential oil peel content.

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