Is It Possible to Do a Reliable Assessment of Bergamot Colour in the Field with a Smartphone Camera?

Matteo Anello[1], Fernando Mateo[2], Bruno Bernardi[1](✉), Souraya Benalia[1], Giuseppe Zimbalatti[1], Jose Blasco[3], and Juan Gómez-Sanchis[2]

[1] Dipartimento di Agraria, Università degli Studi Mediterranea di Reggio Calabria, Località Feo di Vito, 89122 Reggio Calabria, Italy
bruno.bernardi@unirc.it
[2] Department of Electronic Engineering, University of Valencia, Valencia, Spain
[3] Instituto Valenciano de Investigaciones Agrarias (IVIA), Moncada, Spain

Abstract. Bergamot (*Citrus bergamia*, Risso et Poiteau) is a citrus fruit cultivated in a narrow coastal strip of about 150 km in the province of Reggio Calabria (southern Italy). It is used in various sectors, including medicine, cosmetics, perfumery and the food industry. Having regard to this, the purpose of this work is to present the intermediate results of an ongoing industrial doctoral thesis, in the framework of the National Operative Program PON Research and Innovation 2014–2020 funded by the Italian Ministry of University and Research (MUR). In particular, the paper deals with the assessment of bergamot fruit colour directly in the field. The first step was to take pictures of fruit at different stages of ripening using a smartphone coupled with a portable black chamber. Secondly, bergamot colour was measured in the laboratory using a Konica Minolta CM-700d portable spectrophotometer, which had been calibrated beforehand. The Citrus Colour Index (CCI) was then calculated for both methods. The results obtained in calculating the accuracy of the CCI showed that using the smartphone combined with the low-cost camera gave results equivalent to those of the spectrophotometer ($R^2 = 0.93$).

Keywords: Fantastico · Citrus Colour Index · Mobile Camera · Spectrophotometer · Image analysis

1 Introduction

Citrus bergamia Risso et Poiteau, known as "Bergamot," grows almost exclusively in Calabria, southern Italy, along the southeast coast around Reggio Calabria. As reported by Maruca et al., 2017, the microclimate of this narrow strip of land, spanning approximately a hundred kilometres, and covering an area of 1,200 hectares, is characterized by alluvial and clay-rich soils abundant in mineral salts. This specific geographical orientation results in wet winters and warm, humid summers, which significantly contribute to the optimal growth and production of the bergamot plant. While this citrus variety is highly sensitive to sudden temperature fluctuations and springtime mists, it displays resistance to windy conditions, helping to reduce the risk of fungal infections.

R. Berruto et al. (Eds.): SHWA 2023, LNCE 521, pp. 269–275, 2024.
https://doi.org/10.1007/978-3-031-63504-5_27

Cultivated trees are small and evergreen and can reach 5 m in height. Three cultivars are grown, namely: ‘Fantastico’, ‘Femminello’ and ‘Castagnaro’. “Castagnaro,” whose fruits yield perhaps the lowest-valued essential oil (EO), but can be harvested for production for a longer period than any other variety. “Femminiello,” which is less robust and sturdy compared to Castagnaro, produces a smaller quantity of a superior, excellent EO. “Fantastico”, believed to be a hybrid of the first two varieties, was certainly introduced more recently, around 1940, but now represents a significant portion of all the trees in Calabria (Valussi et al., 2021).

According to the geographical area, the hesperidium produced between November and March is slightly flattened and has a subglobose to pyriform shape. The peel, characterised by a shiny green at the beginning of the productive season and turning to pale yellow when the fruit is ripe, contains numerous glands enclosing the essential oil (Quirino et al., 2022).

Although today the juice holds a high interest considering its nutraceutical properties (Di Donna et al., 2020; Giuffrè et al., 2019), the peel essential oil remains the most requested derivative (Gioffrè et al., 2020), so much so that it obtained the protected designation of origin “Bergamot of Reggio Calabria - essential oil”. Around 90% of the global production comes from a small area not exceeding 1400 ha in Calabria (Amato et al., 2013). Widely used in perfumery for its intense fragrance and freshness, at the beginning of the productive season is a greenish volatile oil that becomes brownish-yellow at the end of the season. It also finds application in other sectors such as food, cosmetics and medicine, considering its antimicrobial, anti-inflammatory, analgesic and anti-proliferative properties (Navarra et al., 2015).

Essential oil is considered a natural product obtained from raw material of plant origin using several methods, including steam distillation, mechanical processes from the epicarp, or dry distillation, after separation of the aqueous phase from any physical processes (ISO 9235:2013).

Identifying the optimal ripening degree becomes thus fundamental. This has been often based on growers’ experience through the visual analysis of fruit colour (Benalia et al., 2023). However, this technique presents several limits, as it is subjective.

Hence, to avoid this subjectivity, the present study is based on the use of a low-cost portable device coupled with a smartphone camera to assess bergamot fruit colour in the field comparing it with data acquired by a spectrophotometer Konica Minolta. The final objective was to obtain the colour characteristics in the HunterLab space and then compare the accuracy of the two systems in the calculation of the Citrus Colour Index (CCI). Nowadays, mobile phones have introduced a new way of thinking and approaching decision-making for farmers, enabling them to access vital information about markets and weather from relevant sources more efficiently (Chhachhar et al., 2014).

2 Material and Methods

Bergamot fruit sampling was collected considering the cultivar ‘Fantastico’ on a private farm in Brancaleone, province of Reggio Calabria (Lat. N 37° 58′49″, Long E 16° 05′25″). On each date, sampling was conducted in the morning (8:00–12:00 a.m.) on ten bergamot trees growing in two areas (lateral and central) of the same orchard. Ten healthy fruits were randomly selected from each tree. For each fruit, 4 images were taken to cover the whole area, making a total of 100 fruits and 400 images per date.

Sampling was performed considering fruit ripening evolution evaluated by the Citrus Color Index (CCI), using the Citrus Color Chart developed by the Valencian Institute of Agricultural Research (IVIA). The CCI defined by Jimenez Cuesta *et al.* (1981) is used in the citrus industry to assess the optimal harvesting period or determine the suitable period to apply post-harvest treatments such as degreening (Vidal et al., 2013; Benalia 2015). It is calculated considering the three coordinates in the HunterLab colour space, which can be read directly from a photoelectric colourimeter (tristimulus method), according to the equation (1) when parameters "a" (green to red), and "b" (blue to yellow) are the two chromatic components, varying from –120 to + 120 while "L" indicates the brightness level between 0 and 100 (black and white).

$$CCI = \frac{1000 \times a}{L \times b} \tag{1}$$

A Citrus Color Index (CCI) with a negative value indicates that the fruits exhibit shades of dark green to green. Values close to zero suggest that the fruits display a range of colours from green to yellow and orange, small positive values mean a yellow colour, and high positive values mean red-orange. Figure 1 shows an example of some fruits selected based on the CCI from -9 to + 6 using the Citrus Color Chart.

Fig. 1. Fruits classification according to Citrus Color Index

A smartphone model Huawei P9 Lite, equipped with a portable inspection chamber, was used for bergamot image acquisition in the field. The inspection chamber (Fig. 2), a non-destructive device, consists of a plastic tube internally blacked using a black sheet to create a uniform ambient, enabling keeping the camera settings invariable and performing image acquisition under the same conditions independently from field conditions. Lighting was enhanced using an LED ring light to reach 6500 K and reduce shadow effects.

The smartphone camera was set up manually using different settings about ISO, f/stop and exposure time. ISO, f-stop (aperture), and exposure time are all key parameters in photography that influence exposure and the appearance of the captured image. Settings compared were:

ISO 100, f/stop 2, exposure time 1/200
ISO 100, f/stop 2, exposure time 1/250
ISO 100, f/stop 2, exposure time 1/320

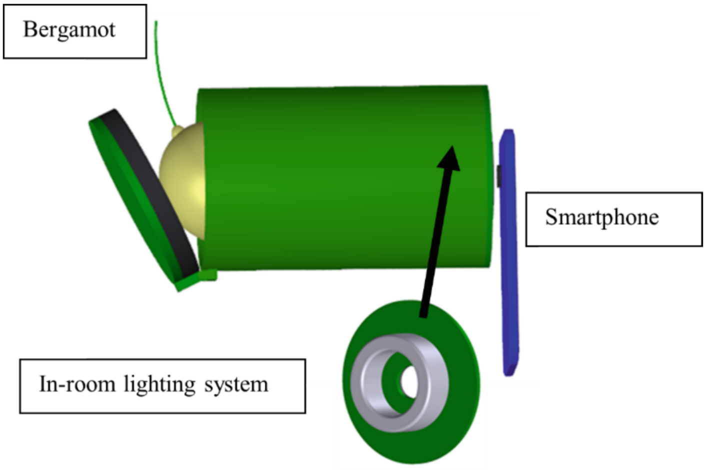

Fig. 2. Image acquisition system

ISO 100, f/stop 2, exposure time 1/400

ISO represents the sensitivity of the camera's sensor to light. A higher ISO value makes the sensor more light-sensitive, allowing photography in low-light conditions. However, a higher ISO can introduce noise or grain into the image. A lower ISO is ideal for optimal lighting conditions. The aperture, measured in f-stop values, controls the amount of light entering the camera. A lower f-stop value indicates a wider aperture, allowing more light and a shallower depth of field. Conversely, a higher f-stop value indicates a narrower aperture, reducing the amount of light and increasing the depth of field. Exposure time, measured in seconds or fractions of a second, determines how long the camera's sensor captures light. Short exposure times capture quick snapshots and reduce the risk of motion blur. Longer exposure times capture more light and can create intentional long-exposure or motion blur effects. The choice of appropriate values depends on the desired effect and shooting conditions. In combination, these three parameters allow control over exposure, depth of field, and motion effects in a photo. The images were stored in a JPEG format. In addition, the colour of each fruit was further analysed in the laboratory using the portable spectrophotometer Konica Minolta CM-700d considering the CIE Illuminant D65 and the 10° observer standard for comparison purposes. The instrument was calibrated according to a white tile reference ($L^* = 99.32$, $a^* = -0.12$, $b^* = -0.13$). The Konica Minolta CM-700d colourimeter is a precise instrument used to measure the colour of objects or surfaces. It works by illuminating the target with a known light source and then detecting and processing the reflected light using a sensitive sensor. Every fruit with a mean of three measurements in different zones represented a replicate.

2.1 Colour Assessment Comparing Mobile Camera and Conventional Instrumental Colour Analysis

To evaluate the accuracy of the colour acquisition by the mobile camera, the CCI index was calculated considering data from both conventional colour analysis and bergamot image analysis. This was performed later using Food Color Inspector software, a tool specially developed for this purpose at the Laboratory of Artificial Vision of IVIA (Spain). This application converts RGB values of the pixels of the entire image or a selected region of interest (ROI) to HunterLab space. The first step consists of the conversion of RGB values to XYZ values, and then from XYZ to HunterLab (Cubero, 2012). The obtained CCI values (portable spectrophotometer vs mobile camera) were compared using the coefficient of determination (R^2) (Fig. 3).

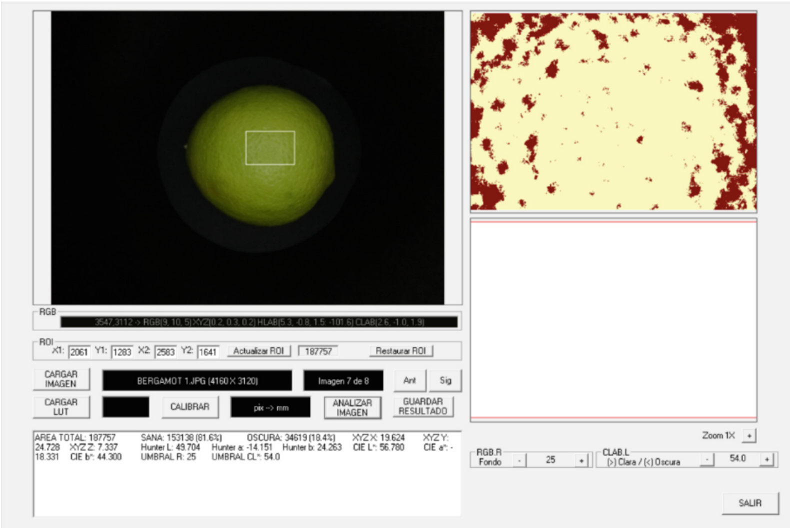

Fig. 3. Inspector programme used for image analysis

3 Results and Conclusive Considerations

Concerning the accuracy of the CCI, the best linear regression value ($R^2 = 0.93$), when comparing the image analysis of the mobile camera and the spectrophotometric results, was found with the mobile camera set to ISO 100, f-stop 2 and an exposure time of 1/200 (Fig. 4). This result is to be expected as the lighting conditions in the field are more stable thanks to the use of the low-cost portable inspection chamber. This tool is specifically designed to eliminate the effects of natural light on image capture, optimise data collection from smartphones and create an environment that limits the influence of external factors and standardises the data collected.

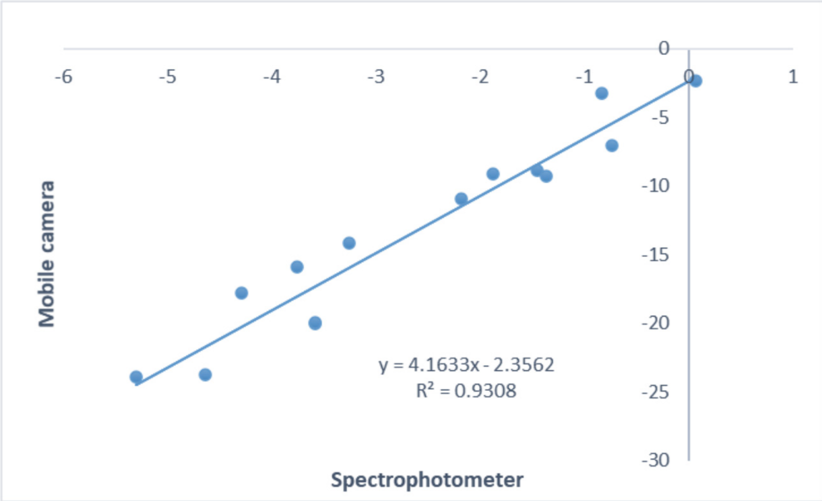

Fig. 4. Linear regression between CCI obtained using the mobile camera image analysis vs the spectrophotometer

These preliminary results were useful in demonstrating the efficiency of a mobile camera instead of traditional instruments for colour assessment, considering the possibility of analysing the whole surface of the fruit, which is very important considering the great variability and heterogeneity of citrus colours, especially when they change from green to yellow. As reported by Sola-Guirado et al, 2020, one of the most complex challenges in agriculture is the evaluation of fruit parameters in the field and techniques based on new tools and sensors could guarantee a reasonable and accurate control of several parameters to safeguard the quality and commercial value of agricultural production (Fazari et al., 2021) from the perspective of agriculture 4.0.

Acknowledgements. This research was funded by the Italian Ministry of University and Research (MUR) in the framework of a doctorate grant funded within the National Operational Program "Research and Innovation 2014–2020, Innovative Doctorates with Industrial Characterisation". PhD course in Agricultural, Food and Forestry Sciences (SAAF) at the University *Mediterranea* of Reggio Calabria (XXXVI cycle).

The authors are thankful to "Azienda Agricola Patea" for providing bergamot fruit free of charge during the whole period of sampling.

References

Amato, A., Castellotti, T., Gaudio, F., Gaudio, G., Lovecchio, R., Pupo D'Andrea, M.R., Peluso, R.: L'agricoltura nella Calabria in cifre 2012; INEA–Istituto Nazionale di Economia Agraria: Roma, Italy (2013). http://dspace.crea.gov.it/handle/inea/742. Accessed 25 May 2022

Benalia, S., Calogero, V., Anello, M., Zimbalatti, G., Bernardi, B.: Application of computer vision systems for assessing bergamot fruit external features. Adv. Hortic. Sci. **37**(1), 111–116 (2023). https://doi.org/10.36253/ahsc-13911

Benalia, S., Bernardi, B., Cubero, S., Leuzzi, A., Larizza, M., Blasco, J.: Preliminary trials on Hyperspectral imaging implementation to detect Mycotoxins in dried figs. Chem. Eng. Trans. **44**, 157–162 (2015). https://doi.org/10.3303/CET1544027

Chhachhar, A.R., Qureshi, B., Khushk, G.M., Maher, Z.A.: Use of mobile phone among farmers for agriculture information. European J. Sci. Res. **119**(2), 265–271 (2014)

Cubero, S.: Diseño e implementación de nuevas tecnologías basadas en visión artificial para la inspección no destructiva de la calidad de fruta en campo y mínimamente procesada. Universidad Politecnica de Valencia, Tesis Doctoral (2012)

Di Donna, L., et al.: Vinegar production from Citrus bergamia by-products and preservation of bioactive compounds. Eur. Food Res. Technol. **246**(10), 1981–1990 (2020). https://doi.org/10.1007/s00217-020-03549-1

Fazari, A., et al.: Application of deep convolutional neural networks for the detection of anthracnose in olives using VIS/NIR hyperspectral images. Comput. Electron. Agric. **187**, 106252 (2021). https://doi.org/10.1016/j.compag.2021.106252

Gioffrè, G., Ursino, D., Labate, M.L.C., Giuffrè, A.M.: The peel essential oil composition of bergamot fruit (*Citrus Bergamia*, Risso) of Reggio Calabria (Italy): a review. Emir J. Food Agric. **32**(11), 835 (2020). https://doi.org/10.9755/ejfa.2020.v32.i11.2197

Giuffrè, A.M.: Bergamot (*Citrus bergamia*, Risso): the effects of cultivar and harvest date on functional properties of juice and cloudy juice. Antioxidants. **8**, 221 (2019)

ISO 9235:2013 Aromatic natural raw materials - Vocabulary (ISO 9235:2013) International Organization for Standardization (ISO), Geneva

Jiménez-Cuesta, M.J., Cuquerella, J., Martínez-Jávega, J.M.: Determination of a color index for citrus fruit degreening. In: Proceedings of the International Society of Citriculture, vol. 2, pp. 750–753 (1981)

Maruca, G., Laghetti, G., Mafrica, R., Turiano, D., Hammer, K.: The fascinating history of bergamot (citrus bergamia risso & poiteau), the exclusive essence of calabria: a review. J. Env. Sci. Eng. A **6**, 22–30 (2017). https://doi.org/10.17265/2162-5298/2017.01.003

Navarra, M., Mannucci, C., Delbò, M., Calapai, G.: Citrus bergamia essential oil: from basic research to clinical application. Front. Pharmacol. **6**, 36 (2015). https://doi.org/10.3389/fphar.2015.00036

Quirino, A., et al.: Citrus bergamia: kinetics of antimicrobial activity on clinical isolates. Antibiotics **11**(3), 361 (2022). https://doi.org/10.3390/antibiotics11030361

Sola-Guirado, R.R., Bayano-Tejero, S., Aragón-Rodríguez, F., Bernardi, B., Benalia, S., Castro-García, S.: A smart system for the automatic evaluation of green olives visual quality in the field. Comput. Electron. Agric. **179**, 105858 (2020). https://doi.org/10.1016/j.compag.2020.105858

Valussi, M., Donelli, D., Firenzuoli, F., Antonelli, M.: Bergamot oil: botany, production, pharmacology. Encyclopedia **1**, 152–176 (2021). https://doi.org/10.3390/encyclopedia1010016

Vidal, A., Talens, P., Prats-Montalbán, J.M., Cubero, S., Blasco, J.: In-line estimation of the standard colour index of citrus fruits using a computer vision system developed for a mobile platform. Food Bioprocess Technol. **6**, 3412–3419 (2013). https://doi.org/10.1007/s11947-012-1015-2