Research Article

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A novel breathable package system to improve the fresh fig (*Ficus carica* L. 'Dottato') shelf life

Matera Attilio,* Altieri Giuseppe, Genovese Francesco, Scarano Luciano, Genovese Giuseppe and Di Renzo Giovanni Carlo

Abstract

Background: The postharvest management of fresh figs is a susceptible phase that could impair the quality standards. Given the high perishability, their marketing is limited to around the production areas using open punnets and when marketed non-locally the use of modified-atmosphere packaging enables their quality maintenance up to 7–14 days, depending upon the cultivar, storage temperature, and packaging system. We show the results of the effectiveness of an innovative packaging system endowed with a breathable device (Blow Device®, BD) for fresh fig storage. BD was evaluated in comparison with a sealed (S) and a macro-perforated film-based tray (MF), at 2 and 8 °C.

Results: The lowest rot decay incidence was observed in S and BD (5–20% after 21 days). S significantly mitigated rot and physical–mechanical decay rate compared with BD and MF. However, S led to anoxia, with relevant carbon dioxide (CO_2) content (30–40%), tray volume increasing, and the highest titratable acidity values. The exploitation of BD led to 10–15% oxygen (O_2) and 5–10% CO_2, along with storage. After 14 days, the figs packed with BD had a negligible mass loss (0.2%) and excellent marketing quality parameters at both temperatures tested.

Conclusion: Exploiting an open or sealed container for extend the fresh fig' storage is not appropriate due to the severe effect of O_2 or CO_2 accumulation, respectively. BD enables the maintenance of high quality standards for up to 21 days at 2 °C, suggesting it could represent a profitable and sustainable solution to prevent decay after picking and reduce food losses along with wider marketability.

Keywords: food packaging; fresh figs; MAP; breathable film; food loss

INTRODUCTION

Ficus carica L. of Cilento is an Italian Protected Designation of Origin fruit whose production is limited to a small area in the Campania region.[1] The most widespread fig variety is 'Dottato', characterized by light, thin, elastic skin and delicate and sweet flesh, which lends itself well to the drying and transformation process and is also excellent for fresh consumption.

'Dottato' is a bifer cultivar, meaning its fruit (syconium) blooms twice a year, producing the *fioroni* and *fornito*; the latter are the figs used for the food industry (e.g. drying, fresh, jam).

'Dottato' harvesting is carried out manually due to the extreme sensitivity to physical damage of the product, which does not enable the use of industrial harvesting technologies.

The postharvest management of fresh figs is a susceptible phase that could impair the chemical, physical, and sensory characteristics. Souring, skin bruising, splitting, and fungal growth are the leading causes of decay postharvest, affecting dramatically the product's shelf life.[2-4] Amongst the microbial agents causing perishability in postharvest storage, the major ones are *Alternaria* rot (caused by *Alternaria tenuis*, which appears as small, round, brown-to-black spots over the fruit surface), black mould rot (caused by *Aspergillus niger*, which appears as dark or yellowish spots in the flesh with no external symptoms), grey mould or *Botrytis* rot, and fig endosepsis (caused by *Fusarium moniliforme*). The ostiol, the natural opening point of the fruit, is the most sensitive area through which the pathogens can reach the fruit's internal cavity.[5]

Given the high perishability, the marketing of the product is limited to around the production areas when using open punnet, usually made up of plastic (polypropylene (PP) or polyethylene terephthalate (PET)). For the same reason, most of the production is used for drying or jam production. Modified-atmosphere

* *Correspondence to: Attilio Matera, SAFE – Scuola di Scienze Agrarie, Forestali, Alimentari ed Ambientali, Università degli Studi della Basilicata, via dell'Aten, Italy. E-mail: attilio.matera@unibas.it*

SAFE – Scuola di Scienze Agrarie, Forestali, Alimentari ed Ambientali, Università degli Studi della Basilicata, via dell'Ateneo Lucano, 10, 85100, Potenza, Italy

packaging (MAP) is a low-cost technology widely used to preserve the quality of fresh figs. It allows the extending of the figs' shelf-life length up to 21 days, depending on the features of the cultivar and packaging system.[6-8] The principle of MAP is to fill the package headspace with a specific gaseous mixture that can slow down the product's pathological and chemical–physical decay. The optimal gaseous mixture should contain a low amount of oxygen (O_2; 5–10%), to reduce the product's respiration and avoid anoxia, and low–medium amount carbon dioxide (CO_2; 10–20%) as a hindrance against the growth of microorganisms, especially moulds. Throughout the storage period, furthermore, because of product respiration rate and microbial activity, the initial gaseous concentration in the surrounding MAP headspace is unavoidably altered. This process leads to CO_2 content increasing and a O_2 reduction up to a steady-state value, with time characteristics dependent on the temperature, initial gaseous mixture, and packaging system used.

Indeed, current problems in MAP design are the elimination of water vapour due to fruit respiration[6] and the difficulties in controlling the in-package atmosphere and humidity during commercial shipments. To date, the features of the packaging material and its ability to be 'permeable' to water vapour or specific gases (such as O_2, CO_2, and ethylene) are so crucial that packaging manufacturers have built many films made with different technologies, making their surface more or less permeable to one or more gases or volatile compounds. Therefore, in the last decade, attention has been paid to those technologies performing gas-selectivity action throughout cold storage up to the consumers.

In packaging design, knowledge of the CO_2 and O_2 permselectivity coefficient β is critical in evaluating the suitability of a material for the medium–long-term storage of a fresh food product.[9]

The β value for breathable packaging should be close to 1 so that it can be exploited for storing fresh food products, especially for those fresh products that can withstand medium–high CO_2 content without experiencing injuries.[10,11]

Breathable packages made with micro-perforated films avoid the increasing water vapour and, if properly designed (i.e. hole size and density tuned with respect to the product so that $\beta \sim 1$), they allow an approximate control of the O_2 and CO_2 diffusion through the holes, avoiding the fermentation process by anaerobic bacteria and mitigating rot growth.[12]

Given the potential advantages of perforated film, breathable packages with selective permeability have been tested to extend the storage of fruit and vegetables. However, significant water loss and substantial modification of the colour and flavour have been observed if the packaging system is not adequately designed.[6,7,13-15]

Concerning fresh figs, the synergism of perforated film and active packaging[7] is figured out as the holes' size and density per pack underlie bthe reathable packaging design, resulting in an undesired partial pressure of the gases at steady state if not correctly designed.

The storage in controlled-atmosphere (CA) environments with 2% O_2 (filled with nitrogen) represents an effective technique to increase the shelf-life of fresh figs up to 29 days at 2 °C,[16] but exploitation of this technology is confined to the warehouses, packing houses, or food industries owning a CA plant.

Concerning the emerging solutions for food packaging, with particular reference to fruit and vegetables, the innovative 'Blowd' device (BD), allowing bidirectional gas flow, patented by Di Renzo *et al.*,[17,18] provides breathable properties and gas selectivity ($\beta \sim 1.5$) to every kind of film used to package fresh products (such as fruit and vegetables).

BD technology has been extensively described for its diffusional and hydrodynamic properties and the advantages arising from its exploitation for fruit and vegetables storage. Several simulations performed with Matlab® (The MathWorks Inc., Natick, MA, USA), involving two versions of BD, one for fruit with low metabolic activity and one for high metabolic activity, determned the suitability of this device for storage of products with different metabolic activities.[19] Moreover, the device has been successfully used to extend the shelf life of rocket leaves in MAP, reduce mass loss, and preserve the quality of clementines (*Citrus clementina* Hort. Ex Tan) during cold storage.[20,21]

Taking into account the breathable features provided by BD to a food pack and the experimental protocols of the literature review, we tested the efficacy of BD on the storage of *F. carica* 'Dottato'. This work presents the results of the experimental trials carried out using BD, a perforated film and a sealed packaging, combined with MAP and cold rooms.

MATERIAL AND METHODS

Plant and packaging equipment

Fresh figs (*F. carica* 'Dottato') *fornito* were harvested (handpicked) on September 9th 2020, early in the morning, in Southern Italy (Tenuta Marchese-Cardone, Via Cannetiello 8, Agropoli, SA,I) at the commercial ripening stage, placed in their conventional packaging (open PP tray) and transferred to the laboratory. The packaging materials used for the experiment were as follows: 0.65 dm^3 volume PP trays (Europack S.r.l., Schio, Italy); PET (12 μm)/PP (50 μm)-based laminate film, allowing O_2 and CO_2 permeability of 110 mL m^{-2} bar^{-1} per 24 h and 500 mL m^{-2} bar^{-1} per 24 h at 23 °C respectively and a water permeability of 3 g m^{-2} per 24 h at 38 °C (Gopack, Palazzo Pignano, Italy); PP based Blow device (BD) (7). The film on the trays was heat-sealed using a UNICA 20 semi-automatic sealing machine (Valko, Bottanuco, Italy), whereas the BD was welded on the film through a valve-sealing machine built by MAC-Lab.[9,22]

Experimental procedure

The figs were selected for their integrity, shape, and colour; afterwards, they were randomly placed in PP trays (six unwashed fruits per pack) and packed in a modified atmosphere (15% CO_2, 5% O_2) using the sealing machine (150 °C, 1 s). A randomized complete block experimental design was performed, using 20 trays for each treatment. The trays were randomly assigned to each treatment, corresponding to three packaging systems:

- S, figs packed in a sealed tray;
- BD, figs packed with a 400 μm diameter hole plus BD covering the hole;
- MF, figs packed with a 400 μm diameter hole.

The experiment was carried out at 2 and 8 °C, to simulate a warehouse and retail storage; and for up to 28 days, they were sampled and analysed. A total of 120 trays were arranged for the storage. Figs were analysed as soon as possible after harvesting (30 fruits); and, at weekly intervals, five trays for each treatment were randomly removed and analysed.

Analyses

Headspace gas composition

The percentage of O_2 and CO_2 in the headspace was measured using a Checkmate 3 instrument (PBI Dansensor, Ringsted, Denmark); five trays were used at each sampling. A volume of

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about 8 mL was taken from the package headspace for the gas analysis.

Differential pressure measurement

To study the packaging system behaviour, the gaseous pressure increase due to product respiration and microbial growth was monitored using a U-tube differential manometer filled with water. To measure the inner pressure in the trays, a needle was hermetically placed in series to the right-open of the U-tube. The needle introduced into the package allowed us to measure the differential pressure ΔP with respect to atmospheric pressure; the barometric pressure in the laboratory was 93 500 Pa.

Mass loss

The percentage variation of the mass (%ML) in the tray was determined by the mass difference between the initial net mass and the net mass at each sampling time, using a precision digital electronic scale (±0.01 g) (Gibertini Europe, Novate Milanese, Italy).

Disorder incidence

The disorder incidence (DI) measure was given by the rotten area on the fruit skin at each sampling time. To measure DI, the decay spots (skin bruising, splitting, fungal growth) and a rot scale index were taken into account. The rot scale index used was from 1 to 5:[6] 1 = normal, 2 = the affected area is up to 5%; 3 = the affected area is 5–20%; 4 = the affected area is 20–50%; 5 = the affected area is >50%.

Chemical and physical–chemical analyses

The skin was removed from the figs, and the flesh was homogenized using a laboratory blender (Moulinex, Madrid, Spain). The homogenate was used for the subsequent tests: solids soluble content (SSC) was measured using a digital refractometer (Atago Co. Ltd, Tokyo, Japan); titratable acidity (TA) was determined by titration with 0.1 mol L^{-1} sodium hydroxide up to pH 7.8 (OIV-MA-AS313-01, 2009) and expressed in grams of citric acid per kilogram of product;[7] pH and TA were determined for each homogenate in 5 g aliquots diluted in 50 mL of deionized water. TA analysis was conducted using a T50 automatic titrator. The colour of the skin and of the flesh was evaluated using a colorimeter (Minolta CR 400 ChromaMeter; Minolta Corp., Tokyo, Japan). A total of three points per fruit were taken, gathering 90 results per treatment at every sampling time. The colour parameters L^* (brightness, corresponding to a black–white scale, where 0 is black and 100 is white), a^* (red trend), and b^* (yellow trend) were recorded using the CIELAB colorimetric system. Total phenol content (TPC) was measured after ultrasonic extraction. Briefly, ultrasonication was conducted using a Termoline ultrasonic bath at 35 °C. To 1 g of homogenate kept in a 25 mL capped long glass vial was added 10 mL of 75% v/v ethanol. The vial was transferred into the shaker and ultrasonic bath for maceration and ultrasonication for 30 min. Afterwards, the samples were centrifuged at 2000 × g for 10 min. The supernatant was filtered and used to determine TPC.[23]

Physical–mechanical analyses

Testing was performed using an Instron Universal 5500 Series Electromechanical Machine (Instron Mechanical Testing Systems, Norwood, MA, USA) equipped with a 500 N load cell. For each test, six samples were used; that is, the six figs of each tray. Firmness (resistance to compression) was measured by compressing the fruit with a 3.5 cm diameter flat probe at a speed of 1 mm s^{-1} up to a deformation of 25% of the product. From each run, the maximum force (newtons) was detected.

Statistical analyses

Data were analysed using Matlab software v. R2016a. Two-way analysis of variance was performed to investigate the effect of storage time and packaging system on each parameter. Tukey's honestly significant difference test was used to determine any significant difference ($\alpha = 0.05$) between means. Therefore, in each graph, different uppercase letters indicate a significant difference between treatments at that storage time. Different lowercase letters indicate a significant difference between storage days in every treatment. Finally, multivariate analysis (principal component analysis) was performed to explain how the parameters and treatments correlate.

RESULTS

Headspace gas and inner pressure evolution in the trays

Figure 1 shows the evolution of the gases during storage. As expected, the highest percentage CO_2 increase was observed in

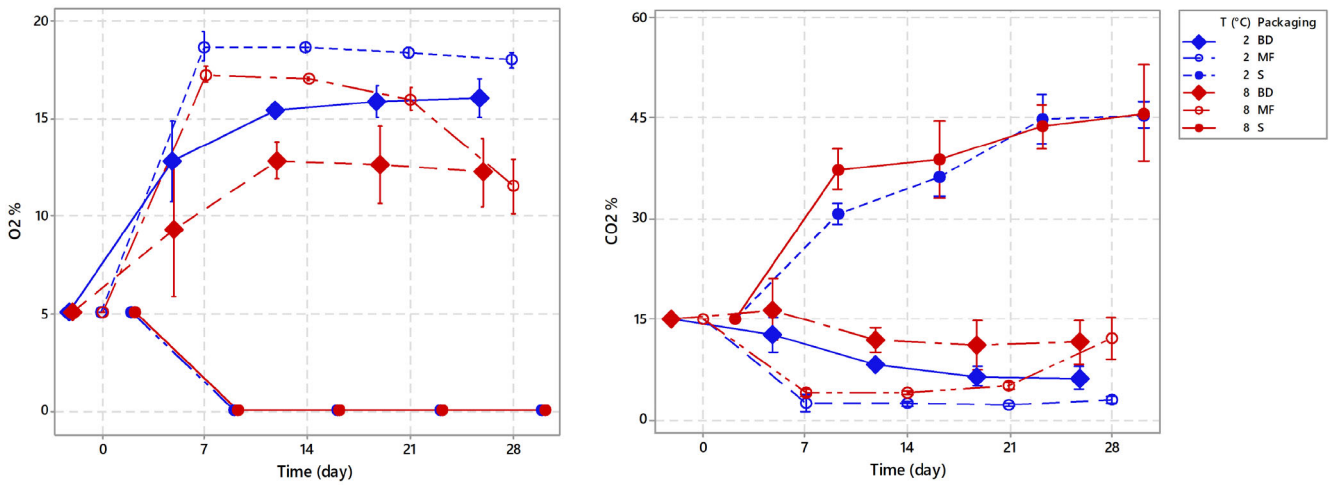

Figure 1. Evolution of oxygen (O_2) and carbon dioxide (CO_2) in the headspace over the storage period.

S ($P < 0.01$): after 7 days it was around 30% at 2 °C, and it rose to 45% after 28 days at both temperatures tested. In these trays, O_2 content was at 0% after 7 days up to the experiment's end, both at 2 and 8 °C. The O_2 content in MF was quite high, ranging between 16 and 18% throughout the storage period, whereas CO_2 ranged between 2 and 4%. Medium-high CO_2 content (13%) was detected in those trays packed with BD stored at 8 °C, whereas in the same trays at a lower temperature it ranged between 12 and 8%. The O_2 content in BD was close 12% in the trays stored at 8 °C, whereas it was >15% at 2 °C. The application of the 400 µm diameter hole in these experimental conditions did not guarantee maintaining the initial gas concentration, favouring high respiratory rate and rot growth.

The tray inner pressure evolution is shown in Fig. 2; no data are shown with respect to MF, as no differential pressure was detected across the tray, so $\Delta P = 0$ at each sampling time. As expected, the inner pressure in S rose greatly because of the system's low O_2 and CO_2 permeability. Apart from the result from the measurements, there was clear evidence of overpressured trays after 14 days, reflecting the unsuitability of this system (S) for medium–long-term storage or marketing of figs. BD effectively balanced the partial pressures of the main gases and the total pressure of all gaseous species in the container. Through the macro-hole, the internal pressure was balanced at every sampling time; that is to say, the macro-hole prevented the package from bloating but did not perform a permselective effect until it reached high CO_2 contents inside the container. Based on the headspace gas composition results, in BD, different O_2 and CO_2 inner partial pressures were detected compared with the control (MF, 400 µm hole), especially at 2 °C. In BD, the O_2 and CO_2 inner partial pressures differed from the outer. In MF, the inner O_2 and CO_2 partial pressures are similar to O_2 and CO_2 room partial pressures. The exploitation of BD brought breathable features to the system as it enabled control of the headspace gas composition in the tray, overcoming the drawback of its management after packing and during distribution.

Disorder incidence and mass loss

Figure 3 shows the evolution of the DI, along with the cold storage (left side), in the three packaging systems tested. As support, Fig. 4 shows picures of the fruits highlighting the rot evolution and general appearance. Figs started to decay after 7 days. Decay spreads out through the packaging systems with characteristics mainly depending upon the CO_2 and O_2 contents. The highest ranked altered fruits pertain to those trays with MP film. At each sampling, the DI in MF was consistently and significantly higher than in the other conditions. The rate of decay in MF ranged between 5 and 10% after day 7, reaching over 30%. After 14 days, in MF, DI was primarily due to skin damage, such as spot-browning and black mould rot, mainly at 8 °C. On the contrary, there is no evidence of mould or rot development in BD and S. No rotten fruits were found in those trays were, but decay did express itself in distinctive manners.

On day 7, the syrupy liquid contained in the syconium oozed through the ostiole, causing a greater sheen and stickiness to the touch of the fruits packaged in BD and S. A shift of the skin colour hues and side cracking was also observed in BD and MF. BD presented <5% figs with disorders after 14 days. Other workers found similar results using an aqueous phenolic bath as a pre-treatment and a micro-perforated pack; however, without pre-treatment, disorders reached 10% at the same sampling time.[7] Moreover, they did not track hindrance evidence to coliforms and *Enterobacteriaceae* growth on figs stored at 0 °C in a passive atmosphere reaching 5% CO_2 and 15% O_2 at steady state (7 days) but highlighted that mould growth in figs was inhibited up to 20 days under these storage conditions. In this experiment, mass loss of figs stored in the conventional packaging system ranged between 10% (7 days) and 30% (28 days) (data not shown). Furthermore, the hindrance to water vapour, the primary cause of mass loss, was very effective in all the packaging systems tested. Mass loss (Fig. 3, right side) was negligible (<1%) in all conditions, but MF had the highest values. This result agrees with other workers who detected <1% in figs packed with MF trays throughout 21 days of cold storage.[7] However, the exploitation of BD enabled the O_2 intake and CO_2 uptake at steady state to significantly slow fungal decay and respiration rate; resulting in a lower mass loss than MF and much lower than with other novel packaging technologies tested on figs with permselective gases (Xtend® MA/MH; StePac Ltd, Tefen, Israel), but not able to mitigate each mass loss (−6% after 21 days).

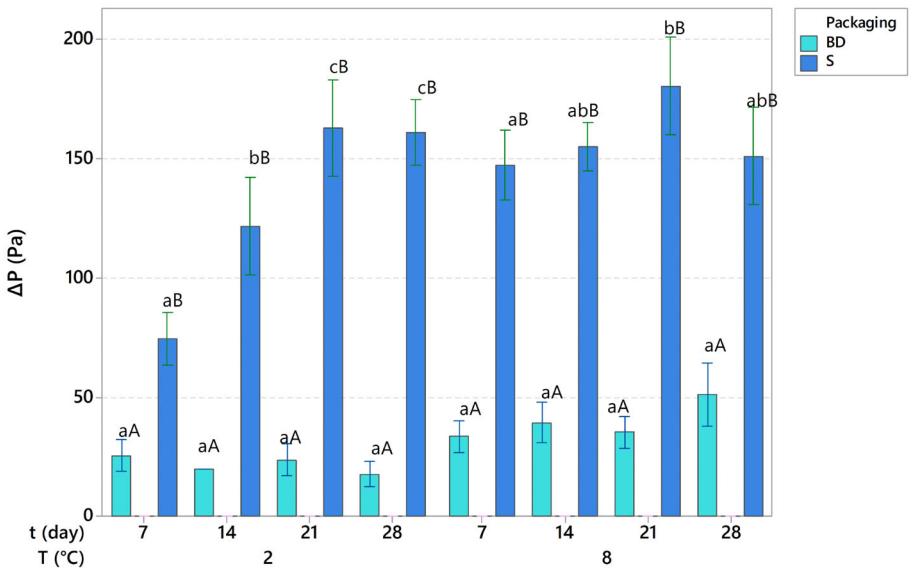

Figure 2. Differential pressure ΔP, with respect to atmospheric pressure, calculated in the trays at every sampling. In MF, $\Delta P = 0$ at every sampling.

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Chemical–physical analyses

Sugar content and TA. Figs are a very sweet product; the SSC of the batch analysed at harvesting was between 20 and 28 °Bx (Fig. 5). Concerning this parameter, all the packaging systems showed good control during the cold storage period as the value did not significantly change and was above 20 °Bx in all conditions, apart from the fruits stored in MF at 28 days, whose value dropped to 18 °Bx, probably due to the metabolism of the moulds[24] that thoroughly colonized the fruit at this stage (Fig. 4). Sugar content in 'Dottato' was higher than that found in 'Blanrick',[6] 'Brawn Turkey',[8] and 'Cuello Dama Blanco', but lower than in 'Cuello Dama Negro'.[7] The storage of these cultivars using MAP systems and permselective films enabled SSC retention, in agreement with our results.

In our experiment, the TA was expressed as grams of citric acid/kilogram of product (Fig. 5). At harvesting, the product had a shallow acidity value (0.6 g kg^{-1}). The order of magnitude agrees with that found at harvest by other workers for 'Cuello Dama Blanco' (0.9 g kg^{-1}), 'Cuello Dama Negro' (1 g kg^{-1}), and 'Blanrick' (0.7 g kg^{-1}), but in the latter case the TA was expressed as malic acid. During the cold storage of 'Dottato' the acidity in S increased by about 50% after 7 days, at both temperatures tested. Storage in MF ensured an acidity content not significantly different from the fresh product for up to 14 days at 2 °C, whereas at 8 °C the synthesis of acids was highly expressed already after 7 days. The most satisfactory result was in BD. The acidity values in figs stored with BD were quite unvaried throughout the shelf life at 2 °C, whereas at 8 °C there was an increase from 14 days onwards. The results suggest as the highest TA levels occurred mainly in S in conjunction with CO_2 accumulation up to 30–40%. This scenario in S was experienced earlier (after 7 days' storage at 2 and 8 °C). The rising acidity could be due to the high CO_2 content in the headspace, which solubilizes into the water and results in the formation of carbonic acid in the fruit tissues.[25] CO_2 close to 10%, as in BD in this experiment, confirms it does not significantly affect the acidity content during figs' long-term storage, as already observed by others.[7] However, this result is reachable only if unfavourable conditions for fungal growth in figs coexist (CO_2 10–15%, O_2 <5%),[16,26] otherwise the development of rots leads to acidification of the media, as observed in MF at 8°C.

Colour. The evolution of the CIELAB colour space coordinates *L**, *a**, and *b** is shown in Fig. 6, wherein the results of the figs' peel and flesh colour are shown in the left and right columns respectively. Statistical analysis suggests that packaging systems, temperature, and storage duration significantly affect all these parameters ($P = 0.000$), except for the *b** value of flesh, which did suffer a weak storage duration influence ($P = 0.057$). After packing, figs' whiteness decreased significantly in all conditions. There was a considerable variation of peel whiteness *L** in MF at 8 °C, corresponding to a reduction close to 50% of the value at harvesting. Figs stored in BD and S had a similar trend, showing a slight decrease after 7 days, with a prominent *L** value of figs stored in S; afterwards, the values in BD rose to exceed the values of S. This finding was true for the *L** value of both peel and flesh at 2 and 8 °C. However, the flesh whiteness seems strongly affected by high permanent CO_2 content in trays, as it largely fell in S during cold storage. *a** is the axis measuring how the colour moves from green (−*a**) to red (+*a**). A negative value (−2,5) of *a** characterized the peel's fresh product; after packing, it dropped to −5 and was almost constant in S. There were significant differences in *a** due to the treatments, temperatures, and their interaction. However, the colour shift in MF is mainly due to black rot development (Fig. 4), especially at 8 °C. It is worth noting that peel greenness in BD and S follows the same trend as *L**, showing a significant difference after 7 days, and they equalize at 14 days; afterwards, it is more expressed in BD. The flesh *a** value was close to 4 in the fresh product and underwent a significant reduction ($P < 0.05$). After 7 days' storage, figs packed at 2 °C with BD and MF did not exhibit significant variation, whereas when products were stored at 8 °C using only BD they were guaranteed non-significant variation after that period. The *b** value (yellow intensity) of the peel was significantly reduced after packaging in all conditions; however, after 7 days at 2 °C, no significant differences were observed between treatments, unlike what happened at 8 °C, where the value was slightly different between all the conditions, but significant. The *b** value of the peel in BD, from 7 to 28 days, was not different, but it decreased with temperature and packaging-dependent characteristics, so the most critical variation amongst the trials was in MF at 8 °C. In contrast, the *b** value of the MF flesh underwent more minor variation. Where the O_2 content was higher, more excellent stability of this parameter was observed, suggesting that high CO_2 concentrations may have an essential role in impairing fig flesh colour. Although optimal storage conditions were established to prevent decay and mass loss in BD and S, colour trends during long-term storage indicate

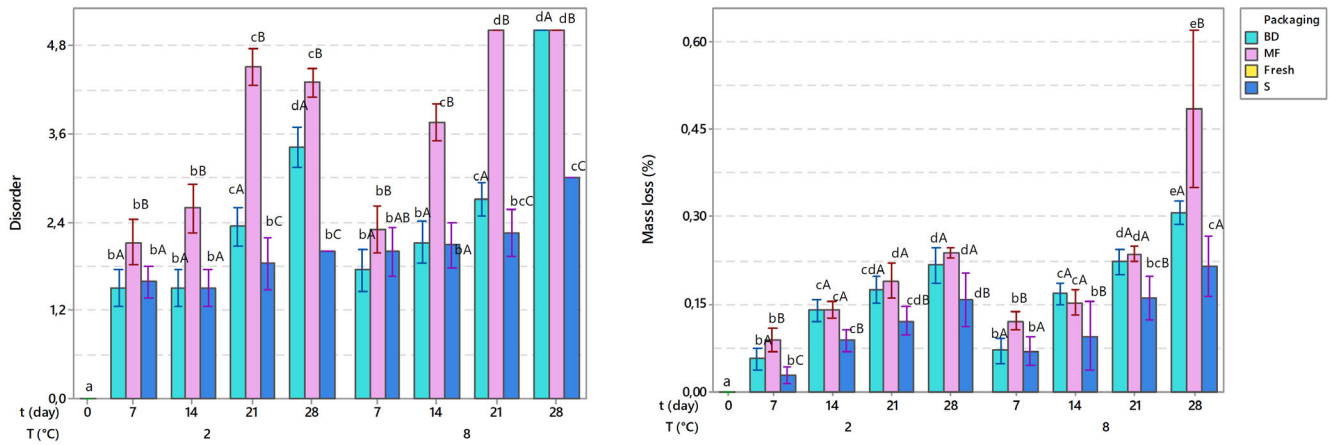

Figure 3. Evolution of disorder incidence (scale 1–5) and mass loss (%) over the storage period.

Figure 4. Pictures of figs during the storage (0, 14, and 28 days), with the Blow Device (B), perforated film (MP), and sealed tray (S) at 2 and 8 °C. The product stored at 2°C in a standard open tray is the control. The product in each packaging system after 28 days at 2 °C is showed at the bottom.

a preserving effect of flesh tone colour indexes (L^*, a^*, b^*) when figs were stored with low CO_2 (<5%) and high O_2 (>15%) contents. On the contrary, fig peel colour is best preserved with low O_2 content. A similar result was observed in the 'Mavra Markopoulou' cultivar, where storage in 2% O_2 resulted in a reduced loss of green peel colour and a decrease in flesh lightness during post-storage at 20 °C compared with those samples packed in the air.[27]

Total phenolic content. The TPC results, expressed as micrograms of gallic acid equivalent (GAE) per gram of product, are presented in Fig. 7. After harvesting, TPC was 498,8 ± 16 μg GAE g^{-1}, a value higher than those found analysing 18 cultivars using the same extraction and assay methodology.[23] After 7 days, TPC dropped; it decreased in all conditions according to the temperature, ranging between 50–52% at 2 °C and 58–72% at 8 °C. This significant drop could reflect a metabolic response of the product after harvesting or along with the storage, rather than an oxidative stress condition. This is supported by the fact that storage in S (0% O_2) resulted in a TPC reduction by 50% and 70% at 2 °C and 8 °C respectively, suggesting that the TPC trend follows a packing-independent trend, probably due to the phenolic metabolism in postharvest. Similar results were found by other authors,[28,29] who found during storage a floating evolution of TPC and experienced a reduction in TPC both in fresh figs coated with edible films and the control (uncoated). TPC, in BD, after 7 days ranged between 250 and 350 μg GAE g^{-1}; it was unvaried up to 14 days

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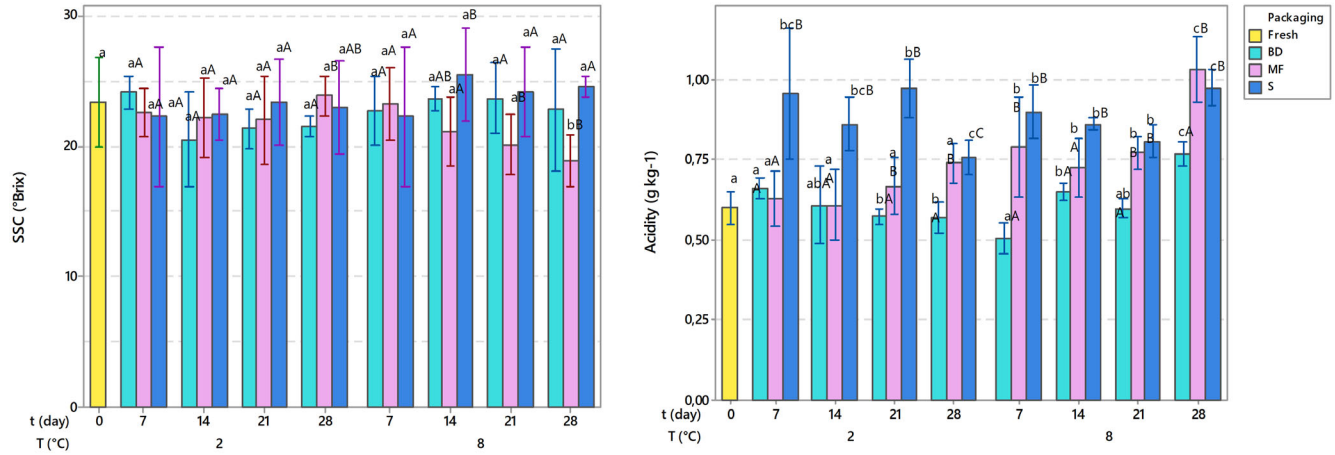

Figure 5. Evolution of solids soluble content (SSC) and acidity (expressed as citric acid).

when stored at 2 °C, but after 7 days at 8 °C it dropped to 180 and remained quite unvaried. Even if a batch of fruits were stored without oxygen (S), there is no evidence of a higher TPC in those products. The results of this test show high variability of the TPC between the proposed packaging systems and during cold storage. These variations may be due to the presence and high activity of enzymes such as phenylalanine ammonium lyase or polyphenol oxidase, responsible, respectively, for the synthesis and degradation of phenols.[30] Therefore, defining a trend that characterizes the evolution of phenols in this experiment

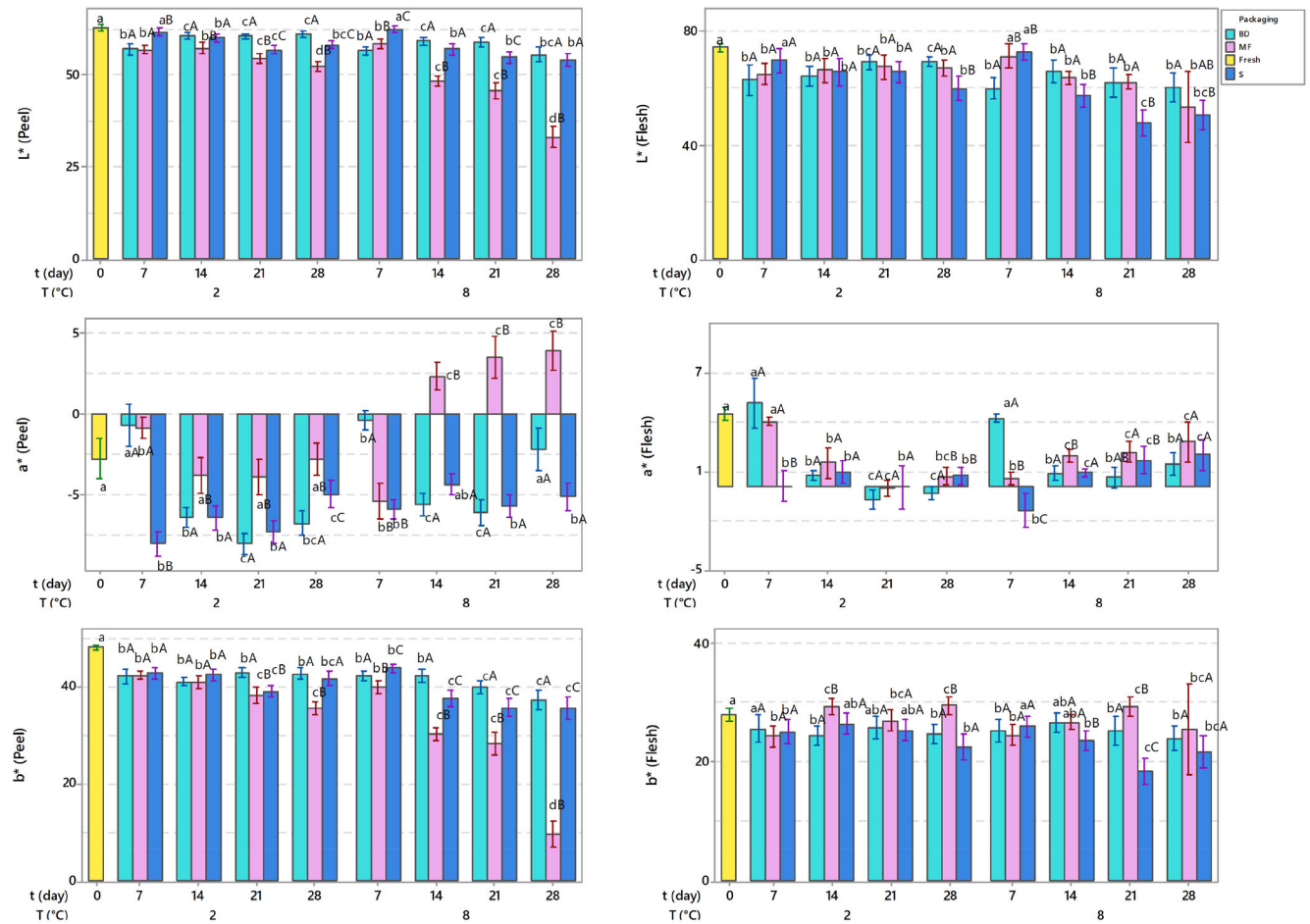

Figure 6. Evolution of CIELAB coordinates *L**, *a**, and *b** detected for figs' peel and flesh.

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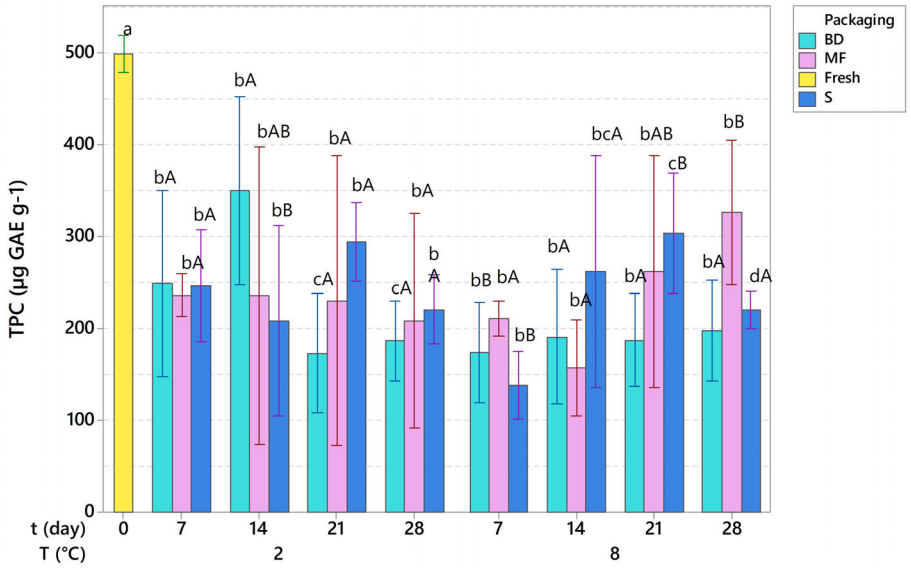

Figure 7. Evolution of total phenolic content (TPC).

is difficult. The graphs indeed show strong oxidation in the first stage in all conditions, especially at a temperature of 8 °C; however, the values were relatively stable over time.

Physical–mechanical assessment

Figure 8 shows the results of the compression test carried out using six fruits for each test. At harvest, the firmness value was 3.23 ± 0.63 N. At first sampling, all fruits had undergone a significant reduction. The storage in MF guaranteed constant values only at 2 °C, whereas at 8 °C the reduction was faster and was undoubtedly worsened by the development of rot. In BD, the firmness values are lower than in MF at 2 °C, whereas at 8 °C they are unvaried up to 21 days and afterwards are higher than for MF, suggesting there is an effect of the interaction temperature–packaging system on firmness. General appearance and firmness are attributes that most impact the consumer's choice; however, the latter cannot be perceived without handling the item. The loss of consistency may be associated with increased ethylene production, which usually comes with cell wall degradation. In fact, firmness can be impaired due to the action of cellular enzymes in the fruit tissues, in particular by polygalacturonase and pectin-methylesterase, and to a decrease in turgor due to water loss.[31] In this experiment, the notable primary observation is the lowest texture reduction in those fruits packaged in S (anoxia condition), at both temperatures tested. This result is in agreement with Kader, who reported that a high CO_2 concentration in the environment inhibits the activity of cell wall hydrolase enzymes that cause fruit softening,[32] and Alturki[33] reported that figs stored under MAP best preserve firmness when stored under very high (80%) CO_2 content.

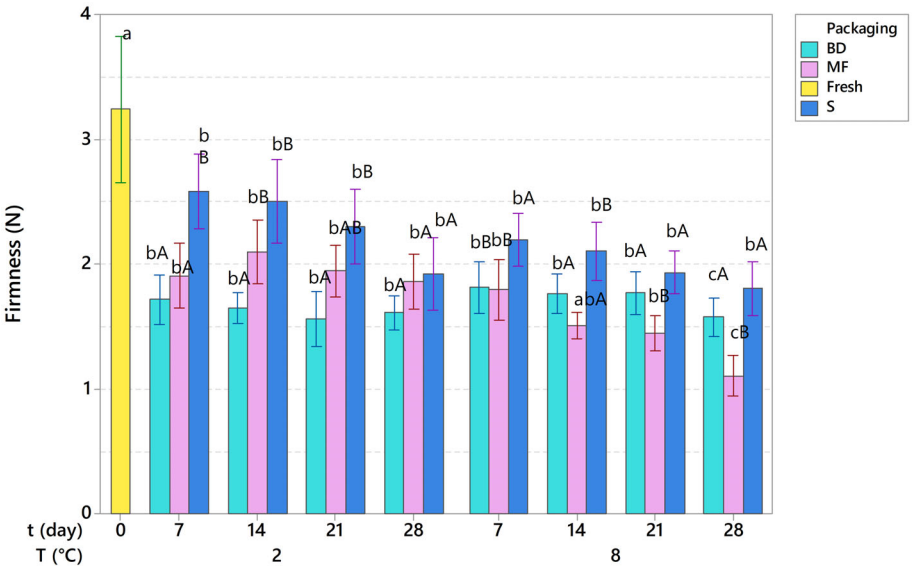

Figure 8. Evolution of firmness over the storage period.

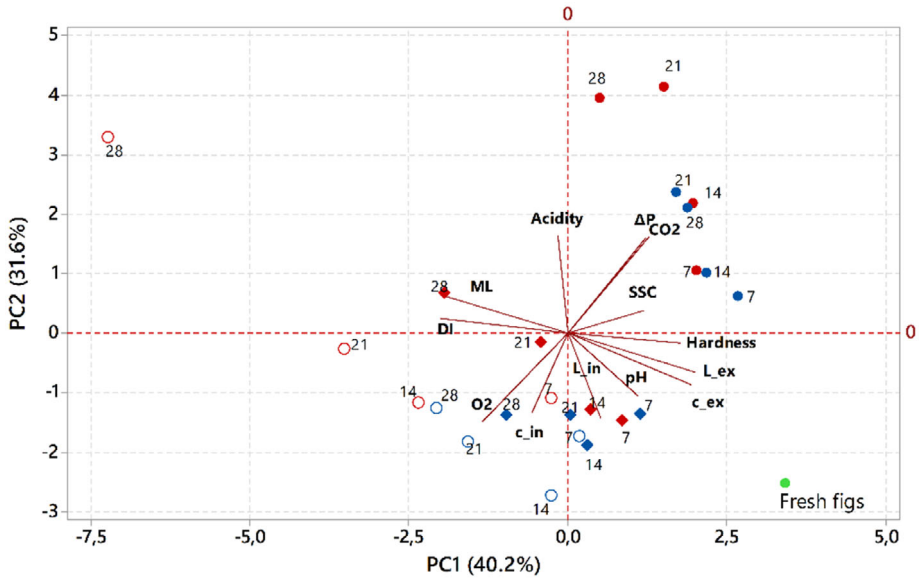

Figure 9. Biplot graph (score plot + loading plot) of multivariate statistical processing obtained from the relationship matrix with the disorder incidence (DI), mass loss (MS), oxygen (O2) and carbon dioxide partial pressure (ΔP_{CO2}), acidity, solid content soluble (SSC), L^* of flesh (L_in) and peel (L_ex), C^* of chroma flesh (c_in) and peel (c_ex) calculated as square root of (a^{*2} + b^{*2}), pH, hardness, in products stored at 2 °C (blue) or 8 °C (red), in S (filled circle), BD (diamond),and MF (open circle). Product at harvesting is the green circle (fresh figs).

Multivariate analysis

Multivariate analysis was performed using principal component analysis. Figure 9 shows the biplot graph (score plot + loading plot) of multivariate statistical processing obtained from the relationship matrix with the measured parameters and the product at every sampling. The model succeeded in explaining about 70% of the sample variance and separated the samples according to the packaging system used. The samples packaged in S are arranged in the first quarter and are well separated from the rest of the samples because of the higher CO_2 content, internal pressure of the tray, and higher acidity. Products packaged with MF, positioned opposite, had the greatest variation of the chroma hues and high decay index. The last quarter, wherein the fresh product is placed, also contains 60% of the samples packaged with BD, in particular the products packaged up to 14 days, both at 2 and 8 °C, and figs at 21 days packed with BD at 2 °C. It is worth noting as the samples move towards the PC1 from the right to the left side of the graph. On the extreme right, the fresh sample is placed, and the samples move towards PC1 according to the storage period and packaging system (MF or BD), mainly due to modification of the hardness, decay index, and exterior colour (L^* and C^* peel). These are the main parameters that discriminate between MF from BD along time, whereas S was separated because of the highest value of acidity and lowest value of flesh chroma (due to the significant reduction of b^* in S).

CONCLUSIONS

In this study, a device (BD) controlling the gaseous mixtures in food containers was tested for the preservation of fresh fig of Cilento. We compared three packaging systems, allowing us to study the evolution of the qualitative parameters of the figs in response to changes in the composition of the surrounding atmosphere at 2 and 8 °C. Storage in a sealed container increased CO_2 up to 35% over the storage period, causing a more acidic but more consistent product than all. The container with a 400 µm macro-hole without BD was not suitable for containing the leakage of CO_2, which was insufficiently high to prevent the development of black mould. When BD was used, the gaseous concentrations ranged between 5 and 10% for CO_2 and between 10 and 15% for O_2, demonstrating the breathable and permselective properties to gases exerted by the valve. The findings of this activity suggest that the use of a sealed tray for fresh fig medium-long storage is not appropriate due to the severe effect of the CO_2 accumulation on packaging appearance and fig acidity, whereas the use of a BD enables to preseve the quality standards for up to 21 days at 2 °C. The BD insertion on the film used for packaging opens a new scenario for figs' storage. The possibility to preserve the quality during industrial storage, marketing, and even in the domestic refrigerator represents a significant added value in the chain of fresh figs.

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CONFLICT OF INTEREST

The authors Giovanni Carlo Di Renzo, Giuseppe Altieri, and Francesco Genovese declare that they are the inventors of the patented breathable device (BlowDevice).

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