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An Innovative Smart Device to Control Modified Atmosphere Packaging (MAP) of Fruit and Vegetables

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This paper describes an innovative smart device (BLOW®) for controlling gaseous exchanges between the inside and outside atmosphere of a sealed container during storage of solid or liquid food produce.
The smart device has been tested in preliminary trials carried out on rocket leaves (*Eruca sativa*), under two modified atmospheres (MAP) (5% O_2 and 5% CO_2 for MAP A and 5% O_2 and 10% CO_2 for MAP B) and stored at low temperature (4°C +/- 1°C), in order to evaluate the shelf-life.
Results show that not significant differences were found among treatments for both mass loss and colour (except L for MAP B treatment using BLOW®).
After 12 days of cold storage vitamin C content resulted higher and significantly different in all the treatments with respect to control, resulting also in a better "appearance" and "odour" score (on a scale from 1 to 5) for MAP treatments. The tested smart device shows interesting capabilities to improve the quality of fruit and vegetables. The use the smart device, even without MAP, allowed to obtain an effective shelf-life increase of the packed rocket leaves stored at 4°C.

1. Introduction

The present work refers to an innovative smart device named BLOW® (Di Renzo et al., 2015; 2016) for controlling gaseous exchanges between the inside and outside atmosphere of a box during storage of solid or liquid produce.
This smart device relates to the field of the conservation of fruits and vegetables and packaged food and has as its object the control of the composition of the head space inside containers for solid or liquid food products presenting a metabolic activity i.e. the need to have oxygen available or to dispose of water vapour and/or carbon dioxide and/or gaseous metabolites in a controlled manner following natural metabolic processes which develop in tissues of animal and vegetable origin, commonly referred to as "ageing", maturation or breathing processes.
The food market demands high quality standards in packaging and product innovation creates a growing demand for new technological solutions in the packaging industry (Dainelli et al., 2008).
Currently, the most widespread approach is the development and use of polymer films with the aim of achieving improvements in the organoleptic and microbial quality of the food product treated. At present it is known that for proper preservation of foodstuffs it is necessary to maintain a correct atmospheric composition and that this objective is achieved by using a correct packaging. Packaging methods are crucial for maintaining the organoleptic and nutritional characteristics of the product over time and to extend the shelf life thereof (Kalia and Parshad, 2015).
Modified atmosphere packaging (MAP) is a technology that gives the advantage of packaging perishable products after harvest and maintaining them in that state by extending their shelf life, thereby restraining distribution costs without any effect on the nutritional value or the organoleptic quality of the product (Mastromatteo et al., 2010). The MAP technology is based on the removal of the surrounding atmosphere of the product and substituting with an altered or modified atmosphere.

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Gases that are mainly used in MAP are carbon dioxide, nitrogen and/or oxygen (Rutherford et al., 2007). MAP in combination with low temperature storage is an effective tool to prolong shelf-life of food products. Generally, low O_2 or high CO_2 concentrations decrease respiration, reduce the number of postharvest pathogens, and the rate of deterioration (Kader et al., 1989).
The deterioration processes in the product are simultaneously slowed down as the respiration decreases and thereby shelf life can be prolonged. In order to prevent anaerobic conditions inside a package, as a result of the product's oxygen consumption, it is necessary to use permeable packages so that oxygen can be transferred from the surrounding air into the package.
The choice of packaging material is very important and is a strategic choice for the production manager, since it affects the final characteristics of the product and constitutes a significant part of the production costs (Rojas-Grau et al., 2009). Generally, depending on the objective to be achieved and the characteristics of the food product to be preserved (transpiration rate or oxygen consumption and production of carbon dioxide and metabolites), the choice of material used for packaging is made based on the desired barrier against gases and water vapour, depending on the desired amount of each gas (oxygen, carbon dioxide , ethylene and vapour) to be exchanged with the outside environment over time (Agar et al., 1999). To date, the appearance of the packaging material and its ability to be "permeable" to certain gases, possibly selectively and in a directional manner (carbon dioxide, ethylene/volatile substances and water vapour from the inside outwards and oxygen from the outside inwards) is so important that packaging manufacturers have created a multitude of plastic films made in different materials and with different layers or with surface treatments or with micro-holes on the surface of the film which make the surface more or less permeable to one or more gases or volatile substances (Restuccia et al., 2010).
However, these solutions have several drawbacks in terms of efficacy (real barrier action), cost-effectiveness (impact on production costs) and adaptability to existing packaging machines available on the market (for example, for issues of the material being thermoweldable in "flowpack" machinery or in welding machines in general).
The need is therefore felt to solutions overcoming the drawbacks described above and in particular that do not require the production of specific films to be adapted each time to the various product types and which make it possible to manage the gaseous relationships between the inside and outside of the box, and possibly to select the types of gas and flows in relation to the desired duration of storage and the type of food product contained.
Hence, the purpose of the present work is to test a smart device (BLOW®, Di Renzo et al., 2015; 2016) which makes it possible to meet the above requirements. In particular, preliminary trials were carried out on packaged rocket leaves (*Eruca sativa*), under two modified atmospheres (5% O_2 and 5% CO_2 for MAP A and 5% O_2 and 10% CO_2 for MAP B) and stored at low temperature (4°C +/- 1°C), in order to evaluate the product shelf-life.

2. Materials and methods

2.1 Smart device description

BLOW® is a device for controlling gaseous exchanges between the inside and outside of a package for solid or liquid food products. The main body of the smart device is made of acetalic resin.
For these tests it has been used the model S with operative characteristics shown in Figure 1.

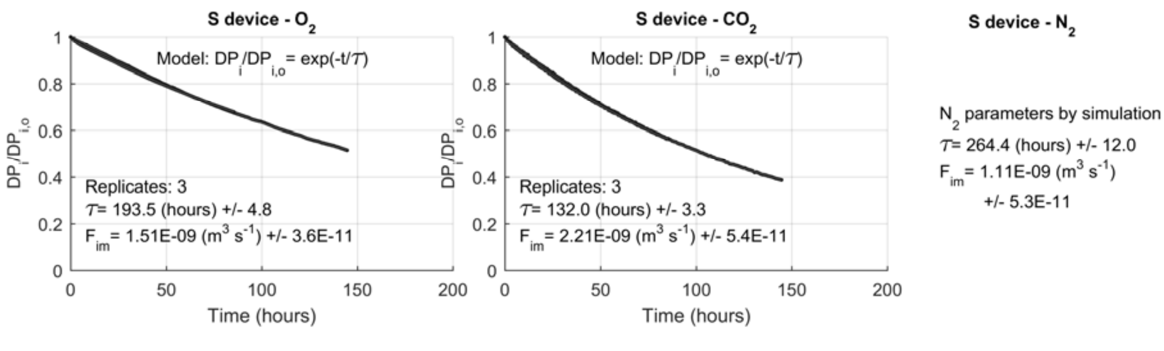


Figure 1: Operative characteristics of smart device used for trials. F_{im} represents the diffusion coefficient measured for O_2, CO_2 and N_2. DP represents the differential pressure across the smart device, DP_o represents the initial differential pressure. τ is the smart device measured time constant that is related to F_{im}.

The control device is applied to the container communicating with the inside of the container (see Figure 2).

 (a)  (b)

Figure 2: (a) Application of the smart device to sealed container. (b) The sealed container as it appears with the smart device applied.

The smart device comprises an adhesive adapted to glue the main body of the package. BLOW® makes it possible to place the preservation atmosphere inside the container in communication with the outside, adjusting the gaseous exchanges over time depending on the characteristics of the food product packaged, using the pressure variations which are naturally created in the controlled temperature storage environment, typical of the cold chain (cold rooms, vehicles or refrigerated containers, refrigerated distribution and household refrigerators).

2.2 Smart device characterization

The fluid-dynamic behaviour of the smart device has been preliminary characterized considering the flow of each gas through the smart device as produced by two superimposing mechanisms (Paul and Clarke, 2002; Del Valle et al., 2003): the first one being an ordinary diffusion flow (considering negligible the Knudsen flow) and the second being a hydro-dynamical flow due to differential pressure across the smart device described by Poiseuille's law in laminar flow conditions, as a result the overall molecular flow results composed of diffusion flow and hydro-dynamical flow (Schneider, 1978; Del-Valle et al., 2003; Webb, 2006; González-Buesa et al., 2009). Using this theoretical background it has been measured the gas permeability coefficient to various gases (as O_2, CO_2, N_2, H_2O) and its hydro-dynamical coefficient representing the smart device response to package differential pressure.

2.3 Product physical-chemical parameters

Fresh cut rocket leaves (*Eruca sativa*) were harvested from some farms in Campania Region (Italy), in the area of ‘Piana del Sele’. Leaves were firstly packaged in open plastic boxes, stored in cold room (4°C and RH >95%) immediately after harvest. Unwashed samples of wild rocket (of about 100 g) were packaged with a commercial packaging line in polyethylene terephthalate (PET) boxes (185 mm × 145 mm × 70 mm) and wrapped with oriented polypropylene film (OPP). The packages were then transferred to the laboratories of the University and stored at 4°C and RH >95% until the experimental trials.
A number of 125 packaged boxes have been numbered and weighed, then subdivided into the following experimental lots (20 trays for each treatment):

- **CwoL** (untreated product stored at 4°C for 12 days);
- **CwL** (untreated product stored at 4°C for 12 days with BLOW®);
- **AwoL** (treated product with a modified atmosphere, MAP A 5% O_2 and 5% CO_2 stored at 4°C for 12 days);
- **AwL** (treated product with a modified atmosphere, MAP A 5% O_2 and 5% CO_2 stored at 4°C for 12 days with BLOW®);
- **BwoL** (treated product with a modified atmosphere, MAP B 5% O_2 and 10% CO_2 stored at 4°C for 12 days);
- **BwL** (treated product with a modified atmosphere, MAP B 5% O_2 and 10% CO_2 stored at 4°C for 12 days with BLOW®).

A CheckMate3 instrument (Dansensor s.r.l., Italy) has been used to measure the gas concentration (O_2 % and CO_2 %) inside the box. All samples were stored at 4°C in darkness for a period of 12 days.
The following parameters were evaluated during cold storage: colour (L*, a* and b*), mass, vitamin C content and quality parameters. Destructive measurements (5 boxes) were performed on days 0 (T0), 3 (T1), 6 (T2), 9 (T3) and 12 (T4).
Leaves colour was measured at three points over the leaves surface with a Minolta colorimeter (Spectrophotometer CM-2002), equipped with an 8-mm measuring head and a C illuminant (6774 K). The meter was calibrated using the manufacturer’s standard white plate. Leaf colour changes were quantified

using L* (lightness), a* (red-green component) and b* (yellow-blue component) colour space (Jiménez-Cuesta et al., 1981).
The rocket samples were weighed calculating mass loss (ML%) with reference to T0.
Vitamin C content was determined according to the method described by Wright and Kader (1997) for the determination of ascorbic (AA) and dehydroascorbic (DHAA) acids content by HPLC and results were expressed as mg of vitamin C per gram of product.
Sensory measurements have been made on the basis of a scorecard by a panel of 8 trained people. The scorecard had a five-grade descriptors (1-5) for both "appearance" and "odour", which respectively corresponding to “dislike a lot”, “dislike a little”, “neither like nor dislike”, “like a little” and “like a lot”.

2.4 Statistical data treatment

All data have been shown as Tukey's notched box plots using Matlab® software and its Statistics and Machine Learning Toolbox®. The letters for Tukey's grouping of means have been calculated directly from Tuckey's box plots on the basis of a 5% significance level; therefore, means with different letters are significantly different. When p-values are used they originate from a post-hoc analysis using Tukey's Honestly Significant Difference (HSD) algorithm.

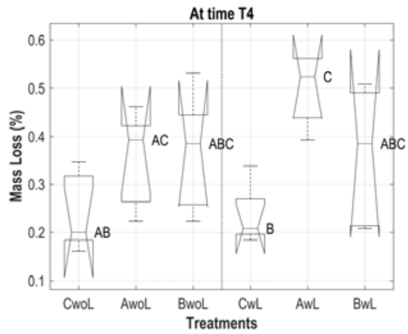
3. Results and discussion

3.1 Mass loss % (ML%)

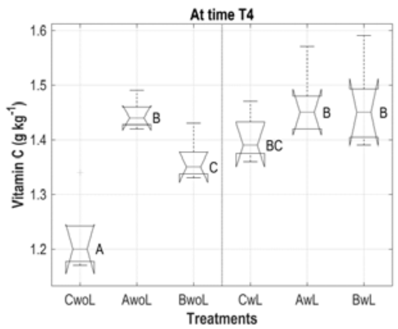
Figure 3a shows the mass loss at the end of cold storage. Mass loss reaches a maximum value of 0.50% for the AwL treatment being this significantly different from both CwoL and CwL, this high value results however acceptable being <1%. Both comparisons AwL vs. CwL and AwL vs. CwoL show a p-value <0.01 being highly significant.

3.2 Vitamin C content

Figure 3b shows the vitamin C content at the end of cold storage. The use of smart device improves the vitamin C retention with respect to control, i.e. CwL is significantly higher than CwoL. The use of MAP A is comparable to its use with the smart device (AwoL vs. AwL) whereas MAP B shows a significant improvement when the smart device is used (BwoL vs. BwL).



(a)



(b)

Figure 3: (a) Mass loss at time T4 (after 12 days of cold storage). (b) Vitamin C content evaluated at time T4.

3.3 Colour evaluation

Figure 4 shows the colour parameters evaluation (L, a and b) at time T4 (end of cold storage). The only significant difference is shown by L parameters. The use of smart device does not improve the control treatments nor MAP A treatments. For MAP B treatments the smart device bring to a significant improvement of L (BwoL vs. BwL) being lower for BwL. In this last case (BwL) it will expect a better appearance of the product.

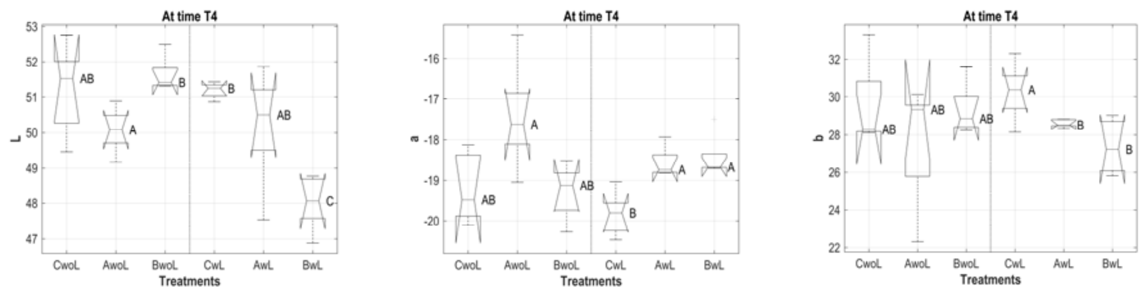


Figure 4: Colour evaluation at time T4 (after 12 days of cold storage) of L, a and b parameters.

3.4 Headspace evaluation

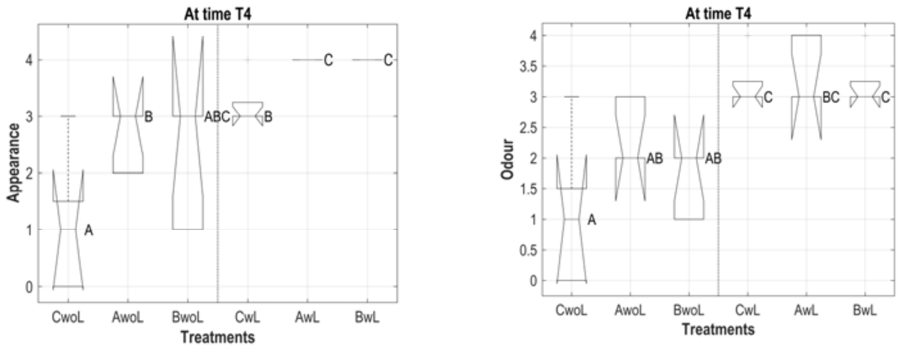
Table 1 shows the mean percentage concentration of CO_2 and O_2 into package at the end of cold storage. The use of the smart device significantly lowers the CO_2 concentration in control treatments, increasing the O_2 concentration. No other significant effects are shown in MAP treatments.

Table 1: Mean O_2 and CO_2 concentration into package at time T4 (after 12 days of cold storage), in round brackets are shown the standard deviations.

	CwoL (air)	CwL (air)	AwoL ($5\%O_2$ $5\%CO_2$)	AwL ($5\%O_2$ $5\%CO_2$)	BwoL ($5\%O_2$ $10\%CO_2$)	BwL ($5\%O_2$ $10\%CO_2$)
$\%O_2$	14.7 (1.9)	18.0 (1.8)	4.3 (1.1)	4.7 (0.6)	4.2 (0.1)	5.0 (2.1)
$\%CO_2$	8.5 (0.5)	5.3 (0.9)	5.8 (1.4)	5.7 (1.0)	10.8 (0.2)	11.0 (1.7)

3.5 Evaluation product "appearance" and "odour"

Figure 5 shows the "appearance" score (Figure 5a) and the "odour" score (Figure 5b) at time T4 (end of cold storage). Significant differences are shown by treatments using the smart device. The use of smart device dramatically improve both "appearance" and "odour" score in control treatments (CwoL vs. CwL). The use of smart device improves the "appearance" in MAP A and the "odour" in MAP B. The use of MAP with the smart device allows to achieve higher scores for both considered quality parameters. The results of treatment BwL are related to results obtained for the same treatment with regard to colour parameter and vitamin C content.



(b)

(a)

Figure 5: (a) Evaluation of "appearance" at time T4 (after 12 days of cold storage) using a trained panel test. (b) Evaluation of "odour" at time T4 using a trained panel test.

4. Conclusion

There were not significant differences between the various treatments for mass loss and colour (except L for BwL treatment), although the treatments have proved to be better than the controls with regard to the other quality parameters investigated in this work.

Data of vitamin C content show that after 12 days of refrigerated storage all treatments are significantly different from control without BLOW®, moreover, AwL and BwL treatments have higher vitamin C content compared to other treatments.

For "appearance" and "odour" parameters the results showed that at the end of storage period the control without the smart device (CwoL) showed the worst aspect (score lower than 2 on a scale of 1 to 5) while MAP treatments have a better appearance. Among these last treatments, that included the presence of the smart device, AwL and BwL exhibit the best "appearance" score of 4.

Data related to "odour" score confirmed that at the end of storage period the samples stored in air, with the smart device, have the highest score without off-odours, according to the judgement of the evaluators.

Compared to what reported with other Authors (Amodio et al., 2015), the findings of this work confirm that the smart device can be used to control the atmosphere into package and the quality of rocket leaves extending the product shelf-life. The use of the smart device, even without MAP, allows to obtain a shelf-life increase of the packed rocket leaves stored at 4°C.

The first trials performed using the smart device confirm that it is suitable to be used to preserve fruit and vegetables packed using MAP. Blow allows the gas exchange inside the head space of packed food products and this characteristic results very important for product presenting a metabolic activity, like fruit and vegetables. However, the identification of the suitable device, in term of gas exchange capacity and its selectivity with respect to the gaseous compounds it requires further investigation in order to fit the “breathing” capacity of the smart device with the specific requirements of the product in terms of cellular breathing, atmosphere requirement, package inside volume and quantity of product packed, permeability of the film used for packaging. Considering the operating mode of BLOW® and its strict relation with the cold storage room environment and pressure, future investigations are required in order to define the management protocol of refrigeration plants to control the atmosphere inside the package.

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