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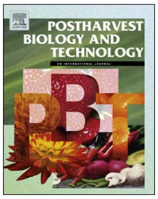

Characterization of an innovative device controlling gaseous exchange in packages for food products

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ABSTRACT

The work describes both the characterization carried out and the experimental results from an innovative device allowing the gas exchange across a sealed package. The device is especially suitable for fresh fruit and vegetable preservation during cold storage, as it allows for the management of the headspace atmosphere inside sealed packages containing food products presenting metabolic activity.

Characterization results confirm the device's suitability for managing the bidirectional gas flow. For each tested device, the hydro-dynamical parameter and the diffusion parameter have been measured to define its steady-state behaviour. The steady-state gas concentrations reached in the package show the aptness of the devices for use with specific products; these equilibrium gas concentrations depend on the device type and on the mass of product contained in the package.

The results of simulated storage demonstrate that some products (pomegranate arils and table grapes) require preconditioning of the package free volume to reach the optimal gas concentrations in a short time. Other products (black truffle) with very high metabolic activity could reach the optimal condition without package preconditioning depending on the free volume.

1. Introduction

Packaging methods and surrounding atmosphere composition are crucial for maintaining the organoleptic and nutritional characteristics of a product over time and to extend its shelf-life (Kalia and Parshad, 2015). Market demand for organic and pesticide/sulphite-free products creates increasing interest in treatments based on modified atmosphere shock treatment and/or packaging using low levels of oxygen and other gases having an effect on the metabolic activity of vegetable tissue or pathogens. Consequently, the food market requires continuous product innovation in packaging, thus creating a growing demand for new technological solutions (Dainelli et al., 2008).

Until now, the approach has been the development of polymeric films to achieve improvements in the organoleptic and microbial quality of the fruits and vegetables treated, as it is well known that, for proper preservation of foodstuffs, it is necessary to maintain the correct gas composition within the package, and that this objective can be achieved using the correct packaging materials.

Modified atmosphere packaging (MAP) technology gives the advantage of packaging perishable products after harvest allowing for extension of their shelf-life, thereby restraining distribution costs with minimal effect on the nutritional value or organoleptic quality of the product (Mastromatteo et al., 2010).

MAP technology basically consists of the substitution of the surrounding atmosphere of a packaged product with a modified atmosphere. The gases mainly used in MAP are CO_2, N_2 and/or O_2 (Rutherford et al., 2007). In addition, MAP, in combination with low-temperature storage, is an effective tool to prolong shelf-life of food products because, generally, low O_2 or high CO_2 concentrations decrease produce respiration, postharvest pathogens and the rate of deterioration (Kader et al., 1989). Therefore, product deterioration processes are slowed down, respiration decreases and shelf-life is prolonged.

However, to prevent anaerobic conditions as a result of oxygen consumption, it is necessary to use permeable materials so that oxygen can freely flow from external air into the package. The choice of packaging material is related to the required barrier effect against gases and water vapour, depending on the desired residual amount of each gas to be exchanged over time with the outside environment at steady-state (Agar et al., 1999). Therefore, the packaging material is very important, and it represents a strategic choice as it affects the final characteristics of the product and a significant part of production costs

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Nomenclature

Indices in vector and subscripts

1	is O_2
2	is CO_2
3	is N_2
μ	Gas viscosity (Pa s)
ΔC	Vector of ΔC_i
ΔC_i	$C_{i,out}$-C_i, differential molar concentration of gas "i" across the device (mol m^{-3})
ΔP_P	P_{out}-P_P, differential pressure across the device (Pa)
ΔP_i	$P_{i,out}$-P_i, differential pressure of gas "i" across the device
ΔP_{P0}	P_{out}-P_{P0}: differential pressure across the device (Pa) at time t = 0
$\Sigma\nu_i$	"diffusion volume" of gas "i" (Fuller et al., 1966)
$\Sigma\nu_m$	"diffusion volume" of the gas mixture (Fuller et al., 1966)
ac	Model coefficient of CO_2 respiration rate eq. (3)
ao	Model coefficient of O_2 respiration rate eq. (2)
A	Device active cross-sectional area (m^2)
C_i	N_i/V, molar concentration of gas "i" in the package (mol m^{-3})
$C_{i,out}$	Molar concentration of gas "i" external to the package (mol m^{-3})
C_{out}	Molar concentration of gas mixture external to the package (mol m^{-3})
C_x	Vector of $C_{i,x}$
$C_{i,x}$	$=C_i$ if $\Delta P_P < 0$, $=C_{i,out}$ if $\Delta P_P \geq 0$ (mol m^{-3})
C_P	N_P/V, molar concentration of gas mixture in the package (mol m^{-3})
d	Device active cross-sectional area diameter (m)
D_{ij}	Diffusivity coefficient of gas "i" into gas "j" (m^2 s^{-1})
D_{im}	Diffusivity coefficient of gas "i" into gas mixture (m^2 s^{-1})
dc	Model coefficient of CO_2 respiration rate eq. (3)
do	Model coefficient of O_2 respiration rate eq. (2)
F_{im}	Diffusion parameter of the device with regard to gas "i" (m^3 s^{-1})
G	Mass matrix of the differential equations set
H	Hydro-dynamic parameter of the device (m^3 Pa^{-1} s^{-1})
HPVR	Headspace to product volume ratio
J	Vector of J_i
J_i	Molar flow of gas "i" (mol m^{-2} s^{-1})
J_i^F	Molar flow of gas "i" (mol m^{-2} s^{-1}) due to diffusion and hydro-dynamical mechanism
J^F	Vector of J_i^F
kc	Model coefficient of CO_2 respiration rate eq. (3)
ko	Model coefficient of O_2 respiration rate eq. (2)
L	Device active length (m)
L-MMAD	Long type device
M_i	Molar mass of gas "i" (kg mol^{-1})
M_m	Molar mass of gas mixture (kg mol^{-1})
MAP	Modified atmosphere packaging
mc	Model coefficient of CO_2 respiration rate eq. (3)
mo	Model coefficient of O_2 respiration rate eq. (2)
MMAD	Micro-machined adhesive device
N	Vector of N_i
N_i	Moles of gas "i" in package (mol)
N_P	Overall moles of gas in the package (mol)
N^F	Vector of N_i^F
N_i^F	Moles of gas "i" in the package (mol) due to diffusion and hydro-dynamical mechanism
nc	Model coefficient of CO_2 respiration rate eq. (3)
no	Model coefficient of O_2 respiration rate eq. (2)
P_i	Partial pressure of gas "i" in the package (Pa)
P_P	Pressure in the package (Pa)
P_{P0}	Pressure in the package (Pa) at time t = 0
$P_{i,0}$	Partial pressure of gas "i" in the package (Pa) at time t = 0
$P_{i,out}$	Partial pressure of gas "i" external to the package (Pa)
$P_{i,x}$	$=P_i$ if $\Delta P_P < 0$, $=P_{i,out}$ if $\Delta P_P \geq 0$
P_{out}	Pressure external to the package (Pa)
RRO_2	Respiration rate expressed as consumption of O_2 (mol kg^{-1} s^{-1})
$RRCO_2$	Respiration rate expressed as production of CO_2 (mol kg^{-1} s^{-1})
RR	Vector of respiration rates RR_i
RR_i	Component related to gas "i" of vector of respiration rates (mol kg^{-1} s^{-1})
RQ	Respiratory quotient ($RRCO_2/RRO_2$)
PO_2	Partial pressure of O_2 (Pa)
PCO_2	Partial pressure of CO_2 (Pa)
R	Gas constant (8.314 J mol^{-1} K^{-1})
S-MMAD	Short type device
STP	Standard temperature and pressure (0 °C and 10^5 Pa)
T	Constant temperature (K)
V	Constant container volume (m^3)
Vo	Measuring apparatus internal volume (m^3)
zc	Model coefficient of CO_2 respiration rate eq. (3)
zo	Model coefficient of O_2 respiration rate eq. (2)
w	Mass of product in the container (kg)
X_i	$N_i/N_P = P_i/P_P$, molar fraction of gas "i" in the package
$X_{i,out}$	$P_{i,out}/P_{out}$, molar fraction of gas "i" external to the package
$X_{i,x}$	$=X_i$ if $\Delta P_P<0$, $=X_{i,out}$ if $\Delta P_P \geq 0$
$X_{i,out}$	$P_{i,out}/P_{out}$, molar fraction of gas "i" external to the package
XO_2	Molar fraction of O_2
XCO_2	Molar fraction of CO_2

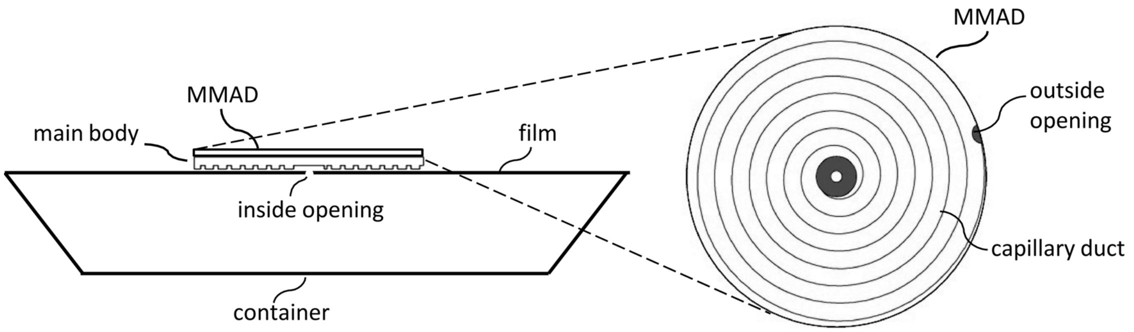

Fig. 1. Working principle of the MMAD and its application to a container.