INTRODUCTION

Fresh-cut products can be defined as fresh fruits or vegetables that after trimming and/or peeling, are cut, washed, dried, packed in pouches or boxes and stored at chilling conditions. However, these operations may accelerate various degradation processes, such as respiration and enzymatic activities that results in the product shelf life of no more than 5-7 days. It is well know that, the reduction of the rate of ageing and the respiration are generally achieved by decreasing the concentration of oxygen and increasing the concentration of carbon dioxide in the package. This extends the usable shelf life and improves the quality of the produce. Utmost care must be taken to keep the oxygen concentration high enough to prevent anaerobic respiration and rapid spoilage from occurring. Materials for Plastics film packaging should be selected so that to achieve equilibrium between the oxygen demands of the product (oxygen consumption by respiration) and the permeability of the film to oxygen and carbon dioxide transmission.

In addition to the permeability characteristics above described, films must also satisfy other requirements such as sealability, consumer tactile appeal, slip properties that allow working on bagging machines; and clarity and printability as well.

Nowadays bi-oriented coextruded polypropylene films are widely used to pack fresh-cut vegetables.
Film structure commonly used is ABA type. The skin sealing layers are made of Terpolymer and the core is made of polypropylene Homopolymer. Generally, 30-35µm are the thicknesses with anti-fog properties commonly used, as VIBAC CTG proposal.
Due to its nature, isotactic polypropylene has a quite high oxygen and carbon dioxide permeability, see *Table 1* below.

Table 1
OTR of standard BOPP ABA structure

Thickness [µm]	**30**	**35**
OTR* [cm³/(m² d atm)]	1800	1600

(*) ASTM D3985 23°C-0% R.H.

However, due to their high respiration rate, some fresh-cut products need higher gas permeability in order to avoid anaerobic respiration.

The main technologies applied to increase OTR are: micro-perforation and breathable film.
Micro-perforation consists in a microscopic hole made on the film during the converting process.

In the breathable film, gas permeability is an intimate characteristic of the film obtained by using a specific blend of polymers during the extrusion process.
Compared to micro-perforation, breathable film has some advantages such as: less risk of rupture, tear propagation; selectivity on permeability; no external contamination.
The disadvantage is the difficulty to obtain a tailored permeability.
The purpose of our study is the identification of a correct formulation to produce a breathable polypropylene film that allows an increase of shelf life compared to standard BOPP, without sacrificing too many properties such as stiffness, water vapour permeability and anti-fog.

EXPERIMENTAL

- **Extrusion Lab Test**

Hetero-phasic Polypropylene Copolymer (HPC) and Ethylene alpha-olefin C8 (EOC) due to their nature have a lower degree of stereo-regularity and therefore more permeable to oxygen than isotactic polypropylene.
Extrusion tests are performed in pilot line by adding Hetero-phasic copolymer or Ethylene alpha-olefin C8 in the core of ABA-type BOPP film. The test target thickness was 30µm. Tests are managed at different concentrations of Hetero-phasic copolymer and Ethylene alpha-olefin C8. In *Table 2* are summarized the main film characteristics for each tested formulation.

Table 2.
Results of 30 µm tested samples

Sample N°	A – skin layer composition	B – core composition	OTR (*) ($cm^3/m^2 \cdot d$ atm)	Haze (%)	WVTR (**) (g/m^2 d)	Elastic Modulus (***) (N/mm^2)
Reference	Terpolymer ethylene, butadiene and propylene	100% PP Homoplymer	1800	1.57	6.5	1800
1	Terpolymer ethylene, butadiene and propylene	80%PP Homoplymer + 20% HPC	2800	3	9	1400
2	Terpolymer ethylene, butadiene and propylene	60%PP Homoplymer + 40% HPC	4000	4	15	1000
3	Terpolymer ethylene, butadiene and propylene	60%PP Homoplymer + 40% ethylene alpha-olefin C8	2600	2.5	8.5	1000
4	Terpolymer ethylene, butadiene and propylene	50%PP Homoplymer + 50% ethylene alpha-olefin C8	3150	2.8	10	900

(*) ASTM D3985 23°C-0% R.H. (**) ASTM F1249 37.8°C 100% R.H. (***) ASTM D882 DIN EN ISO 527 1/3

It is well knows that the oxygen permeability depends on temperature according to *Arrhenius Equations* (1):

$$P = P_0 \cdot e^{\left(-\frac{E_a}{RT}\right)} \qquad (1)$$

Where:
P = permeability ($cm^3 \cdot m$ / $m^2 \cdot 24h \cdot atm$)
P_0 = pre-exponential term representing the value of P for $T \rightarrow \infty$ ($cm^3 \cdot m$/ $m^2 \cdot 24h \cdot atm$)
E_a = activation energy (J / mol)
R = universal gas constant (8,314472 J / K·mol)
T = absolute temperature (K)

Due to our equipment, it was not possible the measurement of the OTR value at temperatures below 10°C; so the barrier properties of the film at 5°C, at standard storage conditions, were obtained by linear extrapolations. The experimental data at three different temperatures are plotted by using *Arrhenius equation in logarithmic form* (2):

$$\ln P = \ln P_0 - E_a / RT \qquad (2)$$

In *Table 3* are summarized the results.

Table 3
Oxygen permeability values ($cm^3/m^2 \cdot d$ atm) refer to 30 µm tested samples

Temperature (°C)	BOPP Reference Sample	Heterophasic Polypropylene Copolymers (HPC)		Ethylene alpha-Olefin Copolymers (EOC)	
T (°C)	**Reference**	**Sample 1**	**Sample 2**	**Sample 3**	**Sample 4**
23	1800	2800	4000	2600	3150
15	890	1570	2242	1380	1564
10	600	1150	1650	915	1036
5	**376**	**784**	**1125**	**596**	**649**

(*) extrapolated data

Figure 1 showed OTR experimental data with trend line and R square values compared to standard BOPP of films containing HPC in the core.

Figure 1
OTR values of film with HPC in the core vs BOPP standard.

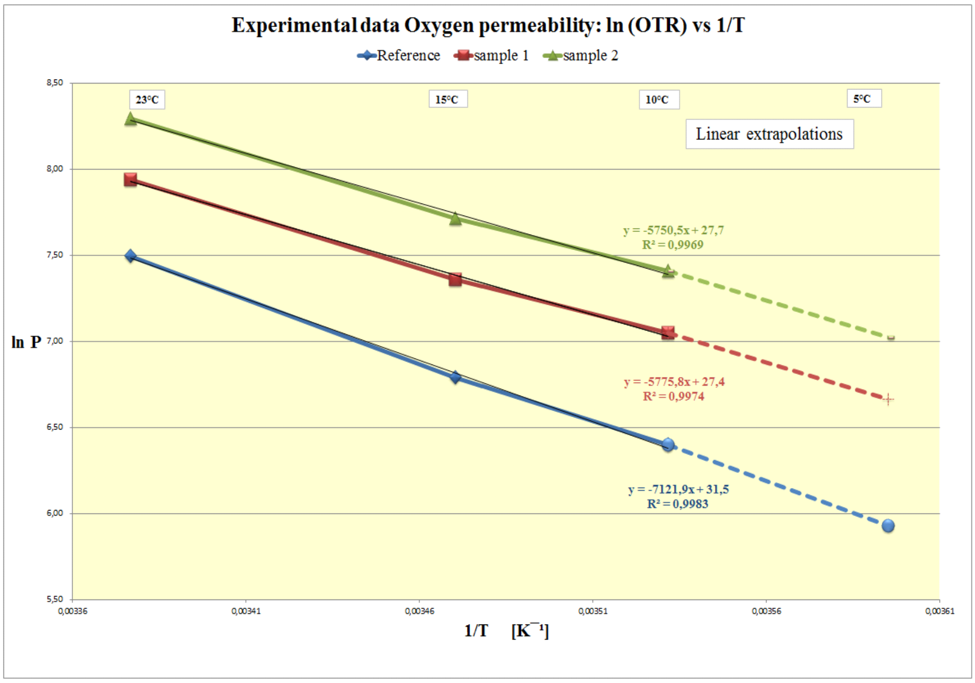
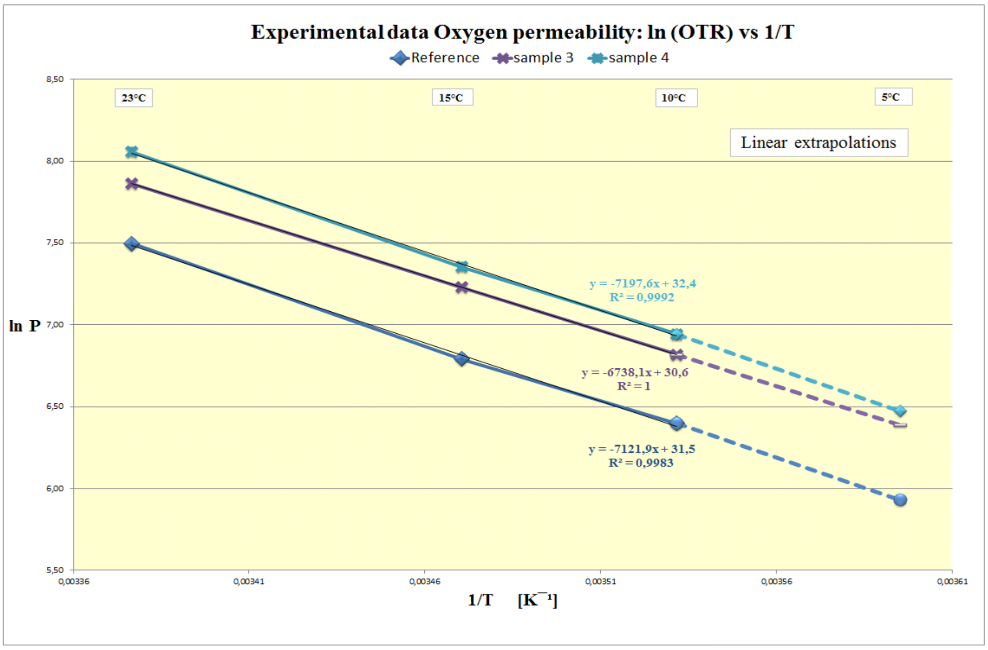


Figure 2 showed OTR experimental data with trend line and R square values compared to standard BOPP of films containing EOC in the core.

Figure 2
OTR values of film with EOC in the core vs BOPP standard.



- **Shelf – life Lab Test: Sensorial Analysis**

Shelf life tests have been carried out with each sample~~s~~ obtained to verify the improvement compared to standard BOPP.
Products chosen for the test were Romaine lettuce, curly and red radish. These kind~~s~~ of fresh-cut vegetables were selected as:

- They are widely used in the preparation of fresh-cut salads;
- Lettuce is not suitable for micro-perforated film packaging because the presence of high amounts of oxygen leads to an acceleration of browning reactions and this affects the shelf life limit;
- These types of salads have a moderate respiratory quotient.

Salad packs have been made in laboratory. About 22 grams of mixed product were packaged in a bag (12x18 cm) and each sample was sprayed with a water quantity equal to 2%. The samples were stored in a ventilated refrigerator at 4°C and 90% R.H., for about 10 days.
During storage, the sensorial analysis has been performed according to "Panel Test" DIN 10955, the following tests parameters have been monitored:

- Product status (colour, consistency, presence of marshal phenomenon);
- Pack conditions (swelling and condensation);
- Presence of off-odours.

Systematic observations on samples conducted every 2, 3, 6 and 10 days.
Parameters were scored on a 0 – 4 scale where: “0” corresponds to a high off odour, a high product degradation and swelling of the package, and “4” corresponds to slightly perceptible changes of these parameters compared to the initial storage conditions.

In *Figure 3* are showed Panel Test results.

Figure 3
Panel Test (DIN 10955) results

Product status

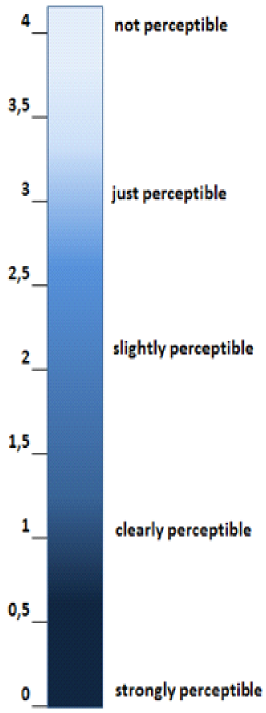
	2 days	3 days	6 days	10 days
Reference	3,2	2,9	1,8	1,8
1	3,4	3	2,4	2,9
2	3,5	3,2	2,8	2,5
3	3,2	3,1	2,4	2,2
4	3,4	3,1	2,4	2,2

Pack condition

	2 days	3 days	6 days	10 days
Reference	4	3,5	2	1,7
1	3,9	3,6	2,2	1,6
2	4	3,8	2,8	2,9
3	4	3,7	2,4	1,7
4	4	3,7	2,1	1,9

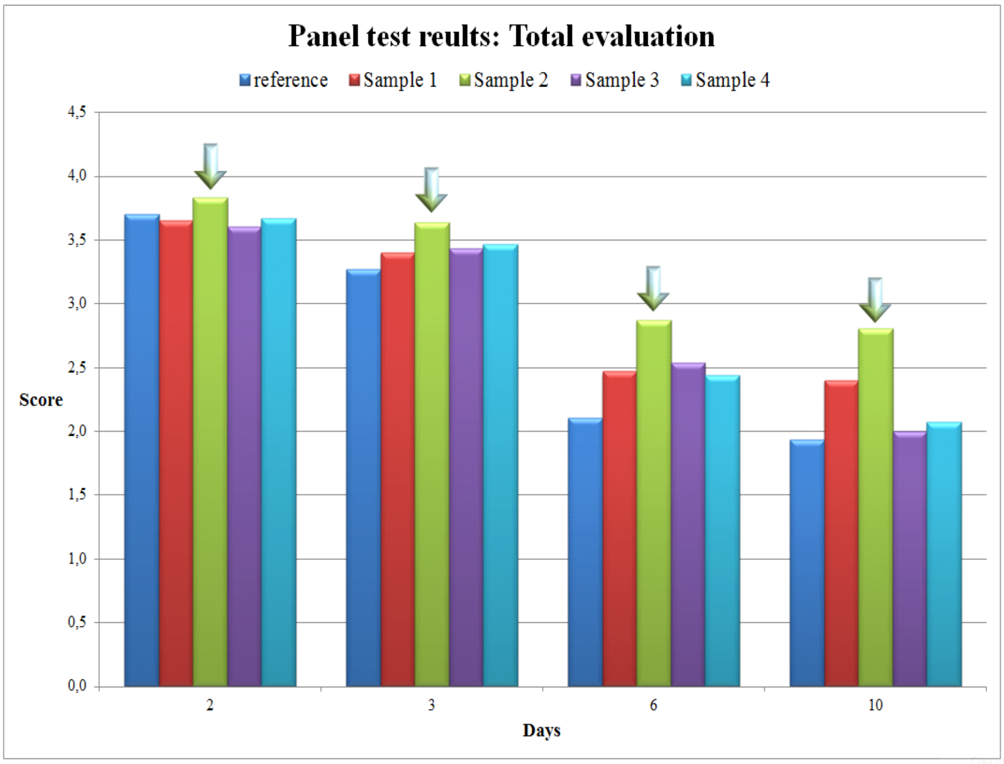
Off-odour

	2 days	3 days	6 days	10 days
Reference	3,9	3,4	2,5	2,3
1	3,9	3,6	2,8	2,7
2	4	3,9	3	3
3	3,6	3,5	2,8	2,1
4	3,6	3,6	2,8	2,1



The general conditions of each sample were evaluated through an average score of all parameters at the same stored timeframe. The average results are reviewed in the graph bar shows in *Figure 4*.

Figure 4
Panel Test general results for each sample at the same time frame.



The sensorial analysis shows a slight improvement in the shelf life performance of sample 2 compared to BOPP reference and extrusion lab test samples 1, 3 and 4.

• CONCLUSION

The sensorial analysis results confirm that the increase of OTR contributes to an improvement of fresh cut vegetable shelf life. As a next step, to support the sensory analysis results, it would be useful to perform a head space Gas Chromatographic analysis in order to verify the absence of anaerobic phenomena.
The results in *Table 2* show that the increase in value of OTR affects other film properties such as: increasing of WVTR and decreasing of the material stiffness. The stiffness reductions need to be tested for the specific end use to evaluate their influence on packaging equipment performance.

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