Adv. Hort. Sci., 2015 29(2-3): 65-74

Influence of edible coatings on postharvest physiology and quality of Honeydew melon fruit (*Cucumis melo L. inodorus*)

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Key words: electronic nose, ethane, ethylene, fermentative metabolites, firmness, internal oxygen, total soluble solids.

Abstract: Several techniques have been developed to preserve the quality of horticultural products throughout the supply chain. Edible coatings represent a promising technology as they can improve quality and extend shelf life of fruit and vegetables by changing gases and moisture permeabilties, enhancing fruit appearance, and reducing microbial contamination. The aim of this work was to assess the effectiveness of two kinds of novel coatings on the shelf life extension of Honeydew winter melons during retail. Sixty melons were used: 24 were uncoated as control; 18 were treated with a cellulose polymer coating (F1) and 18 with a synthetic polymer (F2) coating. Upon arrival, and after 6, 9 and 13 days at 13°C, six melons/treatment were individually analyzed for internal O_2, ethylene and ethane concentrations, fermentative metabolites, quality parameters, and aroma pattern. Already after six days, internal O_2 levels in coated fruit fell to ~1% in F1 and ~3% in F2 melons, triggering fermentative pathways as shown by the increased productions, mainly in F1 fruit, of acetaldehyde, ethanol, ethyl acetate, and ethane. This pattern caused changes in the responses of electronic nose sensors which were able to distinguish the three treatments. Coating did not influence fruit firmness and internal ethylene concentration. F1 coating reduced soluble solids content, strongly enhanced skin glossiness, and delayed yellowing, but it was not able to prevent moisture losses. In contrast, F2 coating significantly reduced weight loss and showed a slight positive effect on fruit appearance.

1. Introduction

Fresh fruit and vegetables undergo major quality and quantity losses after harvest throughout the supply chain up to consumers. The shelf life extension of a fruit depends on the control of phenomena related to ripening and senescence, water loss, and decay development. Several techniques have been developed in order to preserve the quality of horticultural products and to reduce quantity losses. They involve the management of temperatures at harvest, during transportation and storage, modification of the atmosphere composition in the storage rooms, and the application of chemical treatments.

Edible coating technology is a promising method to preserve the quality of fresh fruits and vegetables (Dahl, 2013) and meets the consumer requests to have safe food without any chemical treatments.

Edible coatings are applied in thin layers to the surface of the fresh produce and act as a semi-permeable barrier to respiratory gases and water vapor between the fruit and the surrounding atmosphere, thereby establishing a modified atmosphere around the product, which slows down respiration, senescence, and enzymatic oxidation. Edible coatings are effective in preserving food quality if they are water-resistant and stable during cold storage, do not cause excessive O_2 reduction or CO_2 accumulation, are minimally permeable to water vapor, improve fruit gloss and appearance and do not impart off-flavors and changes in aroma, taste, texture and appearance; they also must have low viscosity, be translucent and economical to use (Dhall, 2013; Mahaian *et al*., 2014).

Edible coatings are composed of polysaccharides, proteins, and lipids, alone or in combination, whose presence and abundance determine the barrier properties of the material. However, none of the three constituents can provide the needed protection by themselves and so they are usually used in a combination in order to obtain the best results (Valencia-Chamorro *et al*., 2010; Dhall, 2013; Mahaian *et al*., 2014).

They can be applied on whole or on fresh-cut fruits and vegetables. When applied on whole fruit, different and not always successful results are obtained. Arnon *et al*. (2014) found that in citrus fruit the application of edible natural biodegradable coatings enhanced fruit gloss, slightly increased fruit firmness, but was mostly not effective in preventing water loss and decreased the flavor acceptability in mandarins due to off-flavor development. Plums treated with a coating material based on carbohydrate plus sorbi-

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Received for publication 26 September 2014
Accepted for publication 9 March 2015

tol showed an extended shelf life period due to weight loss decrease and delayed changes in firmness, color, pH and acidity (Eum *et al*., 2009). Strawberries coated with edible coatings showed significant delays in the changes of weight loss, decay incidence, acidity, pH and soluble solids, and ascorbic acid contents and maintained higher concentration of total phenolics and anthocyanins in comparison to control fruit (Gol *et al.*, 2013). Positive effects of coating were also observed in mangoes treated with a nanomultilayer coating of pectin and chitosan: coated fruit presented a better external appearance, a less dehydrated surface apparently without fungal growth and lower mass loss after 45 days of storage (Medeiros *et al*., 2012). Carboxymethyl cellulose (CMC) coatings alone and in combination with gamma irradiation were tested for maintaining the storage quality and extending shelf life of pears. CMC alone was effective in extending shelf life of pears by six days, following 45 days of refrigeration, while the combinatory treatment maintained the storage quality and delayed pear decay, prolonging the shelf life period up to 12 days (Hussain *et al*., 2013). Fisk *et al*. (2008) found that coatings improved the surface appearance of kiwifruit without impairing ripening, and fruits were well liked by consumers even if no benefit was observed on weight loss.

As for melons, the majority of investigations on edible coatings have concerned their applications on fresh-cut rather than on the whole fruit (Oms-Onliu *et al*., 2008 a, b; Amaro *et al*., 2012).

Fallik *et al*. (2005) evaluated the external, internal and sensory traits of 'Galia'-type melon fruit coated with three polyethylene-based waxes. The best results were obtained by using waxes that contain no, or very low amounts, of shellac as these waxes reduced water loss, improved the general appearance, and maintained pleasant, sweet and fruity aroma notes of the fruit even after prolonged storage, while control fruit suffered from high-decay incidence and soft texture. When shellac was present in high amounts, off-flavor significantly increased in the melon fruit due to high internal levels of CO_2, ethanol, acetaldehyde and ethyl acetate. Cong *et al.* (2007) found that the bilayer coating of chitosan and polyethylene wax microemulsion containing natamycin extended the shelf life of 'Hami' melon by reducing weight loss, fruit decay, and the decrease of ascorbic acid content during storage at ambient temperature even if some doubts remained regarding the sensory quality of coated fruit.

The aim of the present work was to assess the effectiveness of different kinds of novel coatings (under patent) on shelf life extension of winter melon during retail by studying internal gas concentrations coupled to off-flavor development and fruit quality.

2. Materials and Methods

The experiment was carried out in 2014 on winter melons (*Cucumis melo* L. *inodorus* type Honeydew cultivar Natal) assigned for a large retail chain. Fruits were harvested in a commercial orchard in the Rio Grande do Norte Region on 21 January 2014 and arrived in Milan on 11 February, when the trial began. Natal melons are characterized by a yellow skin and white flesh. Sixty melons were selected: 24 uncoated fruits were used as control (T); 36 fruits were treated with two coatings (F1 and F2) currently under patent. F1 coating is a complex based on a cellulose polymer, it is water soluble, with a concentration of 25±2°Bx. F2 coating is a synthetic polymer, also water soluble, with a concentration of 15±1°Bx; F2 was used after dilution 1:2 (w/w) with tap water.

Fruits were dipped in the coating solutions for 30 s, dried for 24 h at room temperature and then put at 13°C together with uncoated melons. Upon arrival in the laboratory of CRA-IAA in Milan (d0), and after 6 (d6), 9 (d9) and 13 (d13) days at 13°C, six melons/treatment were individually analyzed for internal O_2, ethylene and ethane concentrations, fermentative metabolites, skin and pulp color, flesh firmness, soluble solid content (SSC), weight loss and aroma pattern by a commercial electronic nose (E-nose).

Internal oxygen

Internal oxygen was measured in the seed cavity by using a fluorescence-based optical sensor system (Neofox Fosfor-R, Ocean Optics). This Fiber Optic Oxygen Sensor uses the fluorescence of a chemical complex in a sol-gel to measure the partial pressure of oxygen. The pulsed blue LED sends light, at ~475 nm, to an optical fiber. The optical fiber carries the light to the probe. The distal end of the probe tip consists of a thin layer of a hydrophobic sol-gel material. A sensor formulation is trapped in the sol-gel matrix, effectively immobilized and protected from water. The light from the LED excites the formulation complex at the probe tip. The excited complex fluoresces, emitting energy at ~600 nm. If the excited complex encounters an oxygen molecule, the excess energy is transferred to the oxygen molecule in a non-radiative transfer, decreasing or quenching the fluorescence signal. The degree of quenching correlates to the level of oxygen concentration or to partial pressure of oxygen on the film, which is in dynamic equilibrium with the oxygen in the sample. The energy is collected by the probe and carried through the optical fiber to the spectrometer and the data are then displayed in the OOISensors Software.

Internal ethylene and ethane

Internal ethylene and ethane concentrations were measured by withdrawing 1 mL samples of internal gas from the seed cavity of each melon using a syringe equipped with 15 cm long, 15-gauge needle. The sample was injected in a DANI GS 86.10 gas chromatograph equipped with a deactivated aluminum oxide F1 (80-100 mesh) column (1/8 in. ×200 cm) and a flame ionization detector according to Rizzolo *et al*. (2005). Quantitative data were obtained by relating the peak of each hydrocarbon to that of its external standard and were expressed as ppm.

Fermentative metabolites

Fermentative metabolites (ethanol, acetaldehyde and ethyl acetate) were determined on the fruit pulp by means of static HS-GC. For each fruit, 10 g of homogenized pulp (two replications) were put into 25 mL vials tightly closed with an aluminum cap with a silicone-Teflon rubber septum; then samples were immediately frozen and kept at -20°C until analysis. After a 60 min thawing at room temperature and E-nose analysis, each vial was heated at 80°C for 30 min, and 0.5 mL of the headspace gas was sampled and injected using the automatic headspace sampler HSS 86.50 DANI fitted to a gas chromatograph DANI 8521, equipped with a PTV injector port operating in splitless mode, a FID detector, and a DB-1 column (60 m × 0.53 µm i.d., 1 µm film thickness). The following GC conditions were used: helium carrier gas flow rate, 1.6 mL min^{-1}; hydrogen flow rate, 66 mL min^{-1}; air flow rate, 146 mL min^{-1}; oven temperature program, 10 min at 50°C, 4°C min^{-1} to 100°C, injector port and detector temperatures, 200 and 250°C, respectively. Fermentative metabolites were quantified by relating the peak area of each one to that of external standards and were expressed as mg kg^{-1}.

Skin and pulp color

Skin and pulp color were measured on two opposite sides in the equatorial region of the fruit with a Spectrophotometer CM-2600d (Minolta Co, Japan), using the primary illuminant D65 and 10° observer in the *L**, *a**, *b** color space. The Gloss Index was also calculated by the SpectraMagic acquisition program by using the SCI and SCE numerical gloss control. Color readings were averaged for each fruit.

Flesh firmness

Flesh firmness was measured on the fruit flesh after having cut the melon into two parts along the longitudinal axis; measurements were carried out on one part in six opposite areas at the top, mid, and bottom positions of each fruit using an 8 mm diameter plunger mounted on an Instron Universal Testing Machine (model 4301, Instron Ltd, Great Britain) with the crosshead speed at 200 mm min^{-1}. The six measurements were averaged for each fruit.

Soluble solids content

Soluble solids content (SSC) was determined on the juice that came out during plunging at the same positions of firmness measurements; SSC was measured using an automatic refractometer (RFM81, Bellingham-Stanley Ltd., England) and the six readings were averaged for each fruit.

Aroma pattern

Aroma pattern was determined by a commercial E-nose on the same samples used for the fermentative metabolite analysis, soon after the 60 min thawing at room temperature. A PEN3 portable electronic nose (Win Muster Airsense Analytics Inc., Germany) was used (Rizzolo *et al.*, 2013). The PEN3 E-nose consists of a sampling section, a detector unit containing the array of sensors, and a pattern recognition software (Win Muster v. 3.0) for data recording and elaboration. The sensor array is composed of ten metal oxide semiconductor (MOS) type chemical sensors: W1C (aromatic), W5S (broad range), W3C (aromatic), W6S (hydrogen), W5C (aromatic aliphatics), W1S (broad), W1W (sulfur organic), W2S (broad alcohol), W2W (sulfur chlorinate), and W3S (methane aliphatics). The sensor response is given by the ratio of the conductivity response of the sensors to the sample gas (G) relative to the carrier gas (G_0) over time (G/G_0). The headspace gas was pumped over the sensor surfaces for 60 s (injection time) at a flow rate of 45 mL min^{-1}, and during this time the sensor signals were recorded. After sample analysis, the system was purged for 120 s with filtered air prior to the next sample injection to allow re-establishment of the instrument baseline. Each sample was evaluated three times. For each E-nose run, the conductivity G/G_0 of the 10 sensors at the time corresponding to the normalized maximum of all signals was taken as the vector of sensors signal. The average of the runs of each replicate was used for statistical analysis.

Statistical analysis

Data were submitted to analysis of variance (Statgraphics ver.7, Manugistic Inc., Rockville, MD, USA) considering coating and day at 13°C as a sources of variation, and means were compared by Tukey's test at P≤0.05%. E-nose data were also submitted to Principal component analysis. The principal component (PC) scores were then subjected to ANOVA and means were compared by Tukey's test at P≤0.05% considering as factors coating and day at 13°C. Correlations between PCs and internal O_2, ethylene and ethane concentrations and fermentative metabolites were also analyzed.

3. Results

Internal oxygen, ethylene, and ethane

Upon arrival in the laboratory, melons showed an internal O_2 amount of about 16.3%. Already after 6 days at 13°C O_2 levels fell to 1.3% in F1-coated melons and to 3.2% in F2 ones (Fig. 1) and remained at about these percentages up to 13 days. In contrast, in control fruit, internal O_2 levels decreased to about 14% at d6, slightly decreased at d9, falling to about 5% at d13. F2 melons showed higher variability in internal O_2 amounts in comparison to F1 ones, as in F2 fruit the internal O_2 ranged from 1 to 6.8%, and in F1 fruit from 0.8 to 1.8%.

Ethylene amount was 0.14±0.07 ppm at d0, increased at d6 to about 0.55 ppm and 0.78 ppm in control and F1 melons, respectively, then it decreased up to d9, to a greater extent in control fruit than in F1 ones, and remained constant up to the end of the storage period (Fig. 1). In F2 melons, ethylene was constant up to d6 and increased at d9, remaining at this level up to d13 (Fig. 1). F2 fruit showed the highest ethylene amounts from d9 to d13, while control fruit developed the least ethylene quantity in the same period.

Ethane was absent at d0; in control fruit it was produced only at d13 in very low amounts (about 8 ppm), while in F1-coated melons ethane levels steeply increased to about 60 ppm already after 6 days at 13°C, then decreased in the subsequent three days maintaining a high amount (30 ppm) up to d13 (Fig. 1). F2-coated melons showed a slight increased in ethane production, reaching about 13 ppm at d13 (Fig. 1).

Fermentative metabolites

At d0, fruit had acetaldehyde=12.3±0.6 mg kg^{-1}, ethanol=24.2±3.2 mg kg^{-1} and ethyl acetate= 1.7±0.5 mg kg^{-1}.

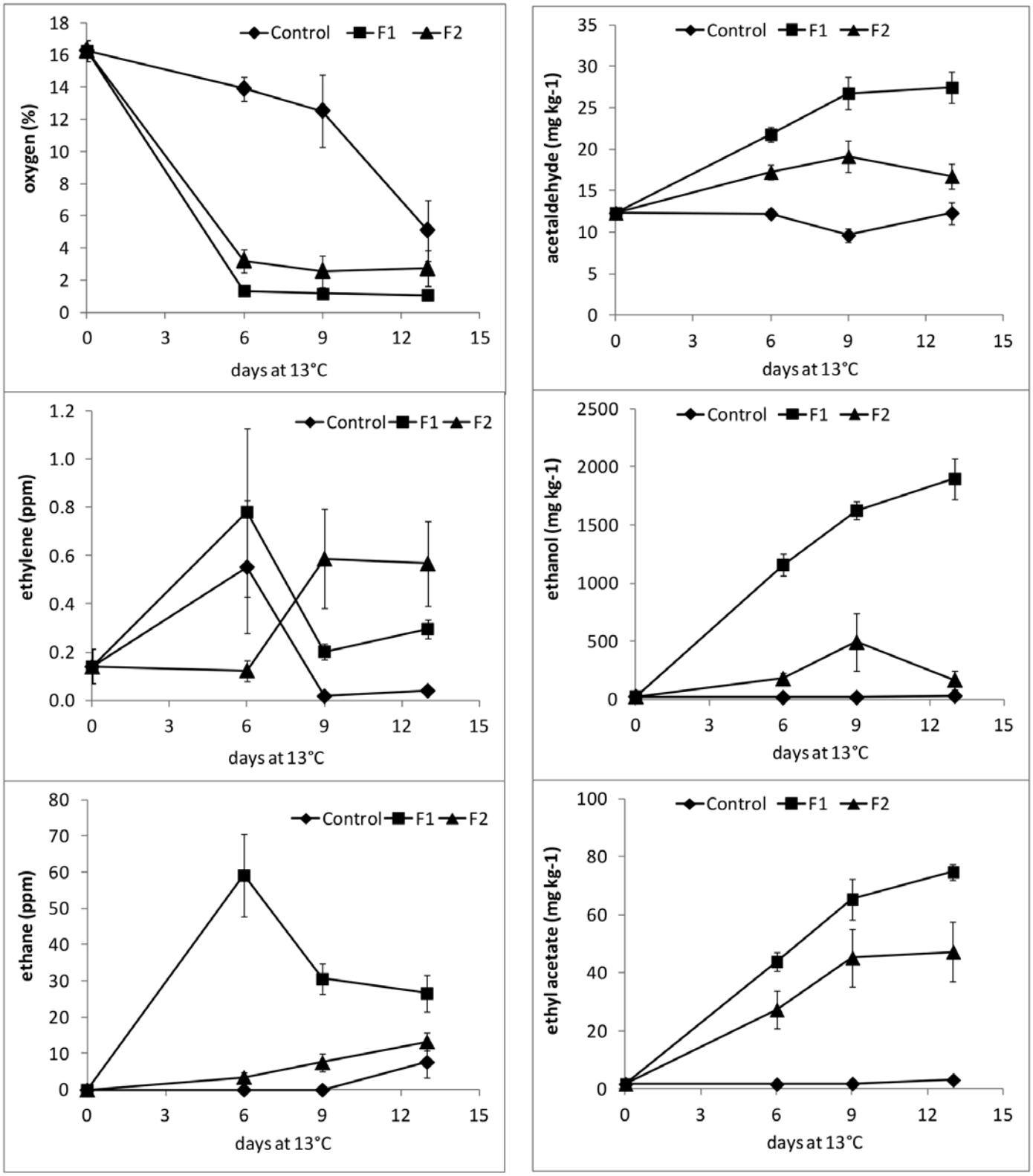

Fig. 1 - Internal oxygen, ethylene, and ethane concentrations (left) and fermentative metabolites (acetaldehyde, ethanol, ethyl acetate - right) amounts of control and coated (F1, F2) melon fruit during storage at 13°C. Bars refer to standard error of the mean (n=6).

All three fermentative metabolites dramatically increased in F1 fruit already after 6 days at 13°C (Fig. 1), increased further up to d9, showing a slight but not significant increase up to d13, with the exception of acetaldehyde which did not change from d9 to d13. Also in F2 fruit, fermentative metabolites significantly increased from d0 to d6 but to a lesser extent than in F1 melons; then they slightly increased up to d9, maintaining this amount up to 13 days. In contrast, in control melons, fermentative metabolites did not show any changes during storage at 13°C.

Skin and pulp color

The application of the coatings significantly affected *b** and Gloss Index in the fruit skin and *a** and *b** of the pulp (Table 1). Skin *b** was higher in control fruit than in coated fruit, and no difference was found between the two kinds of coating. Gloss Index showed the highest values in F1 melons, intermediate in F2 ones and the lowest in control fruit. As for pulp color, *a** was highest in control fruit and lowest in F2 melons, with F1 fruit showing intermediate values, whereas *b** had the lowest values in control fruit at d6, when F1 fruit had the highest values; no difference was found at d9 among the treatments, while at d13 control fruit still had lower *b** than both types of coated fruit. No changes were observed in skin and pulp color parameters during storage at 13°C, except for skin *L** and Gloss Index and for pulp *b** which significantly decreased during storage at 13°C.

Firmness, Soluble solids and weight loss

Firmness did not change with coating treatments and days at 13°C, while SSC, on average, were lower in F1 fruit and did not change with days at 13°C (Fig. 2).

Weight loss showed the lowest values in F2 fruit (Fig. 3). A different trend in weight loss increase during storage at 13°C was observed according to the treatment; a sharp increase was observed in F1 melon from d6 to d13, while in F2 fruit weight loss increased from d6 to d9 and then remained constant up to d13; in control melons weight loss dramatically increased up to d6, then it continued to increase but to a lesser extent up to d9 and then steeply increased up to d13.

Aroma pattern

The behavior of the signals generated by the sensor array is reported in figure 4. Each line represents the average signal variation of replicated samples for one sensor of the array, linking the conductance increase or decrease experienced by the sensors to the evolution of the coating type during the storage time. The responses of the 10 MOS sensors significantly changed with coating presence, with the exception of W1W, W2W and W3S sensors. The sensors W1C, W3C and W5C showed the lowest responses in F1 fruit and the highest in control melons; the opposite behavior was observed for W5S, W6S, W1S and W2S sensors. No sensors changed in control fruit with storage days, while the responses of W1C, W3C and W5C sensors decreased with storage time and those of W5S, W1S and

Table 1 - Skin and pulp color (mean ± standard error; n=6) of control and coated (F1, F2) melon fruit during storage at 13°C and ANOVA results

Storage		Skin color				Pulp color		
		*L**	*a**	*b**	Gloss Index	*L**	*a**	*b**
day 0		75.1±1.0	3.8±0.8	75.1±0.9	3.7±1.0	73.1±1.1	-3.0±0.3	15.3±0.6
day 6	Control	74.5±1.1	5.7±1.4	76.6±1.1	5.0±0.5	74.7±0.9	-1.9±0.4	12.7±0.4
	F1	74.6±0.8	3.7±1.3	72.8±1.2	21.5±4.5	76.4±0.6	-2.2±0.2	14.0±0.3
	F2	74.0±0.8	4.7±0.9	73.2±1.3	12.8±2.2	72.9±0.4	-3.3±0.2	15.5±0.2
day 9	Control	75.7±0.5	4.2±1.2	77.3±0.8	1.7±0.6	73.7±0.8	-1.9±0.8	14.6±1.1
	F1	73.6±0.2	7.1±0.7	73.7±0.4	20.5±4.5	74.1±0.8	-2.2±0.2	13.8±0.1
	F2	73.5±0.3	6.6±0.5	73.9±0.5	14.7±2.6	75.1±0.7	-2.4±0.3	13.2±0.4
day 13	Control	73.9±0.8	5.8±0.6	75.4±1.2	0.0±0.0	73.5±1.2	-1.6±0.2	12.0±0.5
	F1	72.3±0.5	6.9±0.9	71.7±0.6	10.5±3.3	74.7±0.3	-2.1±0.1	13.4±0.3
	F2	72.9±0.7	6.8±0.8	73.3±0.4	5.8±1.1	72.5±1.2	-2.5±0.2	13.6±0.8
					ANOVA			
coating (A)		NS	NS	***	***	NS	**	NS
days at 13°C (B)		*	NS	NS	**	NS	NS	*
A x B		NS	NS	NS	NS	NS	NS	**

***, P<0.001; **, P<0.01; *, P<0.05. NS= not significant.

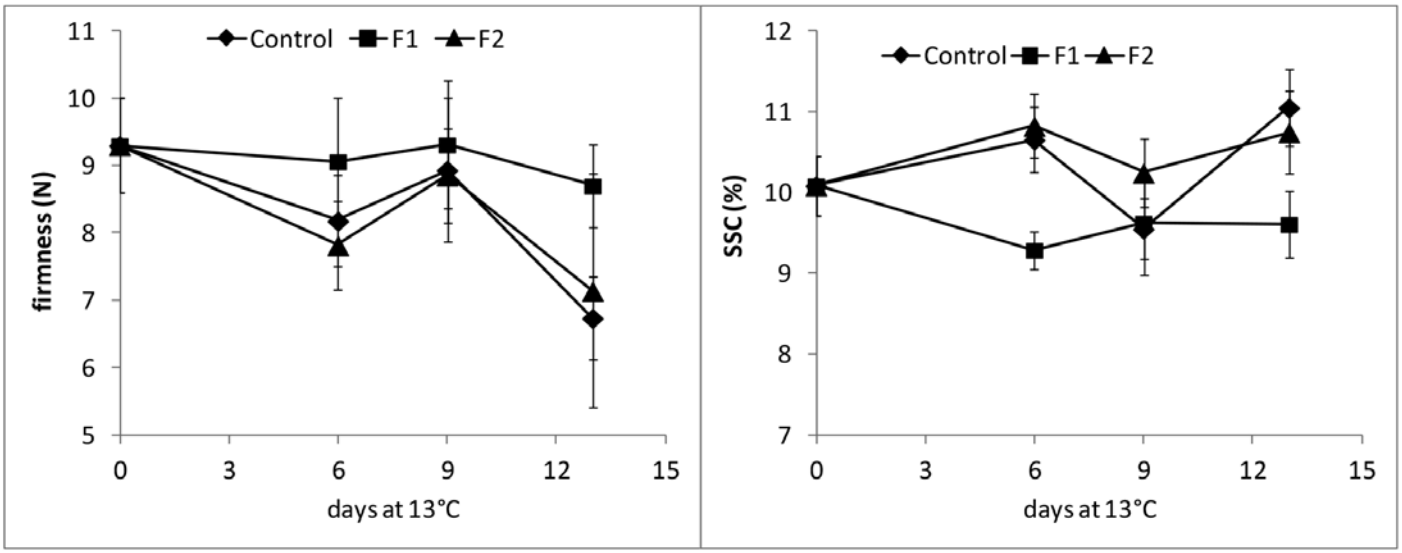

Fig. 2 - Firmness (left) and soluble solids content (SSC, right) of control and coated (F1, F2) melon fruit during storage at 13°C. Bars refer to standard error of the mean (n=6).

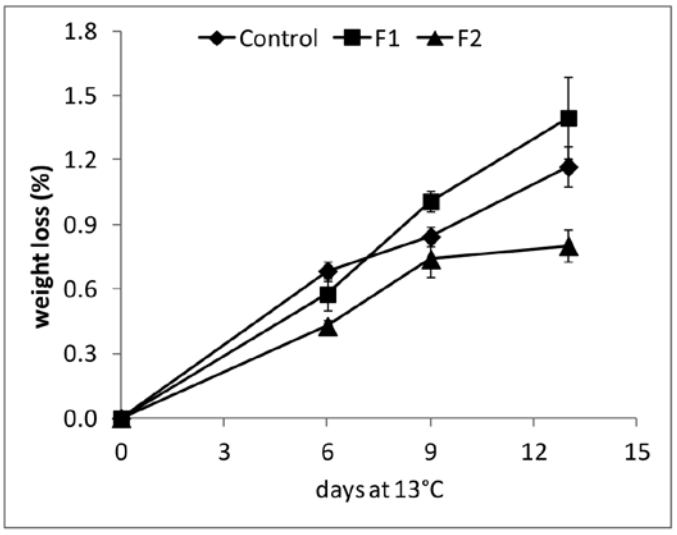

Fig. 3 - Weight loss of control and coated (F1, F2) melon fruit during storage at 13 °C. Bars refer to standard error of the mean (n=6).

W2S decreased in coated fruit. In F2 melons, the E-nose sensor responses were always intermediate between control and F1 melons.

To see whether the sensor array was able to distinguish the different kinds of coating, PCA was applied to the E-nose measurements. Two functions were extracted, explaining about 89% of the variability (Fig. 5). PC1 grouped W1S, W2S and W5S sensors opposite to W1C, W3C and W5 ones, while in PC2 W1W and W2W sensors were opposed to W3S ones. PC1 scores showed the lowest values for control melons, intermediate for F1 ones and highest for F2 (Fig. 6). The PC1 score was also lower at d0 in comparison to the other days at 13°C. PC2 scores didn't change, neither with coating nor with storage time (Fig. 6).

To compare the E-nose patterns with composition data, the correlations between PC1 and PC2 scores with internal O_2, ethylene, ethane, and fermentative metabolites were studied (Table 2). High and positive correlations were found between PC1 fermentative metabolites and ethane while a negative correlation was observed between PC1 and internal O_2 levels. No correlation was found for PC1 with ethylene amount and for PC2 with all compounds.

4. Discussion and Conclusions

Edible coatings have been used in order to retain quality and to extend shelf life of fresh fruits and vegetables. Most fruits and vegetables possess a natural waxy layer on the surface (cuticle) which generally has a low permeability to water vapor. Applying an external coating could enhance this natural barrier as a semi-permeable membrane is formed on the fruit surface and thus it will be possible to obtain a better control of gas diffusion and moisture loss, delaying ripening and senescence.

Table 2 - Linear correlation coefficients (r) of PC1 and PC2 scores, obtained from Principal Component Analysis, with oxygen level, ethylene, and ethane amounts and fermentative metabolites

Correlation coefficient	PC1	PC2
Oxygen	- 0.668***	- 0.040
Ethylene	0.211	- 0.090
Ethane	0.702***	0.034
Acetaldehyde	0.844***	- 0.034
Ethanol	0.836***	- 0.059
Ethyl acetate	0.882***	- 0.101

Significance of *r*: *, P ≤ 0.05; **, P ≤ 0.01; and ***, P ≤ 0.001)

The quality of fruits and vegetables depends on their internal O_2 and CO_2 concentrations which in turn are affected by the environmental concentrations of these gases (Hagenmaier, 2005). A reduced O_2 level is desirable for slowing down respiration and preventing exchange of food aroma and flavor compounds with the environment. The coatings applied to fruit form barriers to the diffusion of O_2 and CO_2 through the fruit peel. When the supply of O_2 needed for respiration or the release of CO_2 is blocked, fruit and vegetables quickly become inedible and rotten. Such blockage lowers and raises the interior O_2 and CO_2 concentrations, respectively, causing off-flavor development due to anaerobic fermentation. Thus, the selection of appropriate coating materials and formulations with a proper gas permeability represents a crucial point to obtain successful results.

Our results showed that already after 6 days at 13 °C, internal O_2 levels in coated fruit fell to about 1% in F1 melons and to 3% in F2 ones. This O_2 drop led to a remarkable increase in ethane, acetaldehyde, ethanol, and ethyl acetate amounts, mainly in F1 fruit. This means that F1

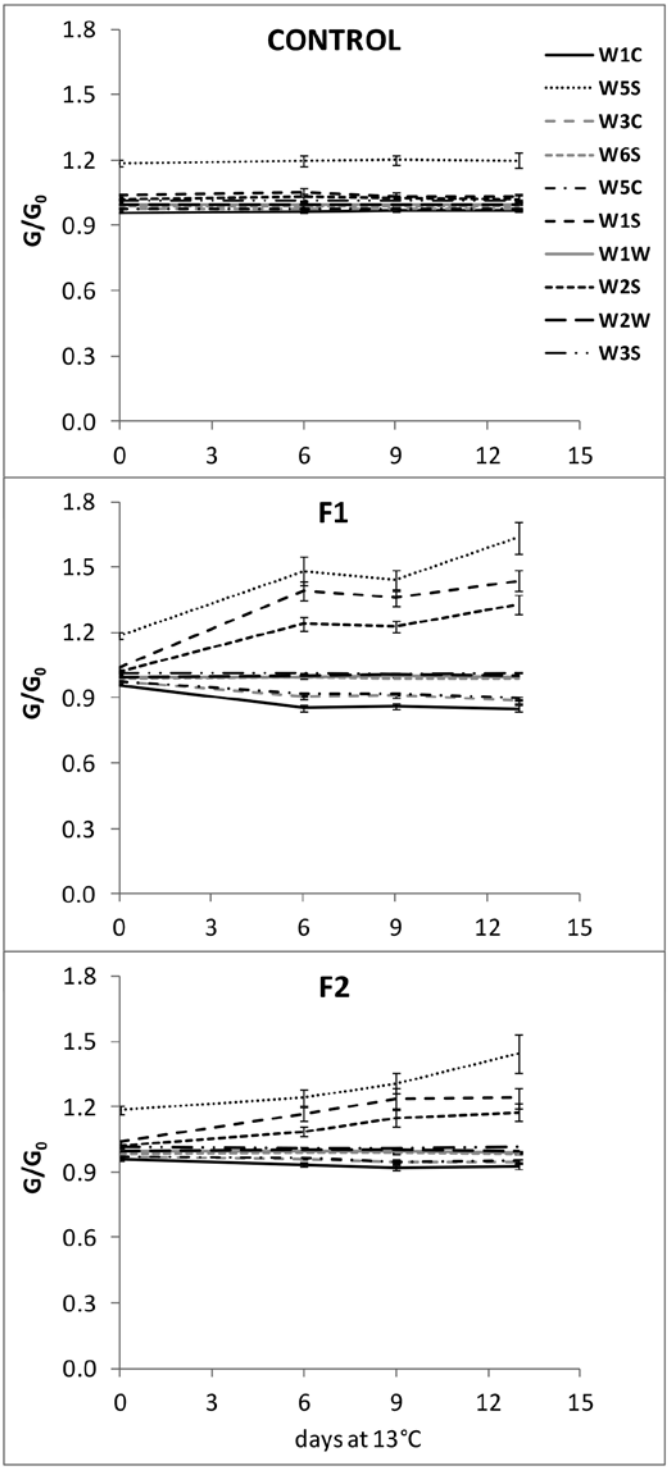

Fig. 4 - Relative conductivity (G/G_0) of each sensor in control and coated (F1, F2) melon fruit during storage at 13°C. Bars refer to standard error of the mean (n=6).

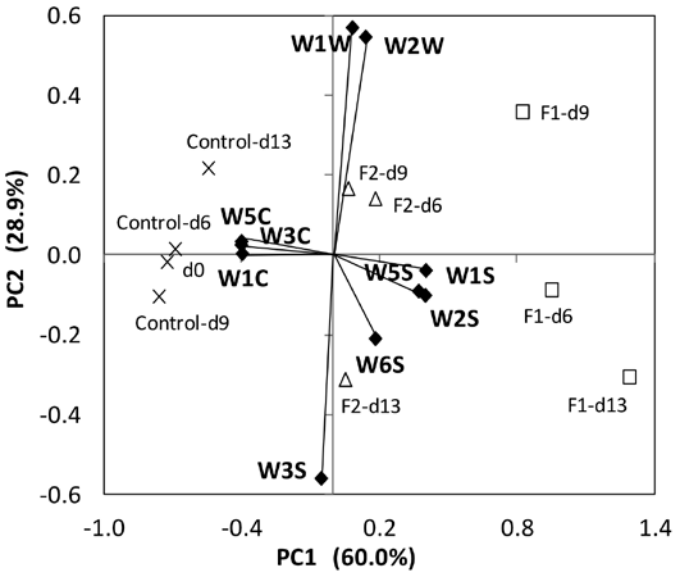

Fig. 5 - PCA of E-nose data: loadings and scores of PC1 versus PC2 according to coating treatment (control; coated=F1, F2) and day at 13°C (d0, d6, d9, d13 refers to arrival, after 6, 9 and 13 days at 13°C, respectively).

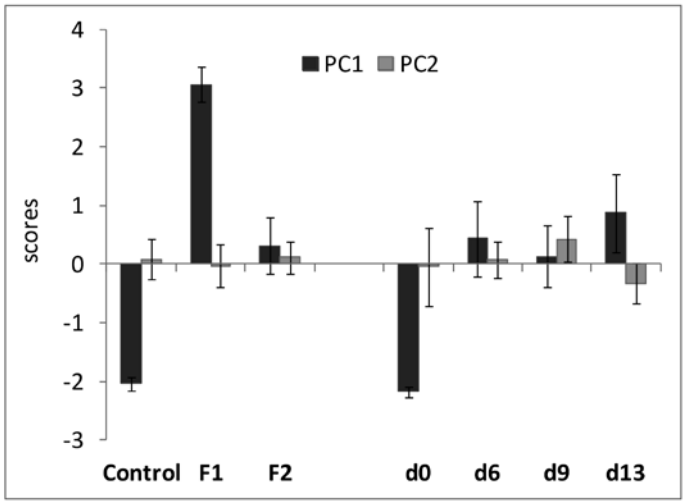

Fig. 6 - PCA scores of PC1 and PC2 according to coating treatment (control; coated=F1, F2) and days at 13°C (d0, d6, d9, d13 refers to arrival, after 6, 9 and 13 days at 13°C, respectively). Bars refer to standard error of the mean (n=18).

melons initiated anaerobic respiration, by which glucose is converted to pyruvate by glycolysis and then, pyruvate metabolized to acetaldehyde and acetaldehyde to ethanol.

The recommended percentage of O_2 in a modified atmosphere for fruits and vegetables for both safety and quality falls between 1 and 5% (Sandhya, 2010). It has been established that at a 2% O_2 level anaerobic respiration may result in the development of off-flavors and off-odors. Fruits exposed to such low O_2 levels may also lose their ability to attain uniform ripeness upon removal from the modified atmosphere packaging. The minimum O_2 concentration tolerated in controlled atmosphere storage of whole cantaloupe melons is 2% and impaired ripening, off-flavors and odors could develop when O_2 falls to 1% and CO_2 goes up to 20% (Kader *et al*., 1989).

Oms-Oliu *et al.* (2008 a, b), studying low oxygen modified atmospheres on shelf life extension of fresh-cut melons, found that fermentative pathways were triggered under a 2.5 kPa O_2 + 7 kPa CO_2 atmosphere. This atmosphere caused a rapid reduction in the O_2 levels below 1 kPa and an accumulation of CO_2 so the initial respiratory quotient (RQ-ratio of CO_2 produced to O_2 consumed) of 1.2 increased above 1.3 after 10-14 days of storage. When RQ is higher than 1, anaerobic respiration takes place and fermentative products are developed (Fonseca *et al*., 2002). In fact, fresh-cut melons produced acetaldehyde and ethanol mainly inside package when O_2 concentrations drop below 2 kPa level (Oms-Oliu *et al.*, 2008 a, b).

Whole melon fruit coated with waxes characterized by high amounts of shellac developed off-flavors when internal O_2 and CO_2 levels reached about 3% and 20%, respectively. These fruits developed higher amounts of acetaldehyde, ethanol, and ethyl acetate than uncoated ones and were characterized by a 'bad flavor' as fruity-pleasant notes (due to butyl acetate and 2-methyl-propyl acetate) were very low, while 'ethyl acetate note' (which causes a solvent like smell) and the 'ethanol-like' note were high.

In our work, when melons were cut for analysis, a fermentative smell was perceived for F1-coated fruit, as the amounts of acetaldehyde and ethanol were higher than their detection thresholds of 25 μg L^{-1} and 990.000 μg L^{-1}, respectively (Czerny *et al.,* 2008). Flores *et al.* (2004) considered inedible a melon fruit when ethanol was about 64 μmol kg^{-1}, as found in fruit packed in modified atmospheres due to higher CO_2 levels.

In contrast, when oxygen levels remained at about 4% and CO_2 levels at about 10%, fresh-cut cantaloupe cubes retained salable quality for 9 days at 5 °C and fruit showed better color retention, reduced translucency, respiration rate and microbial populations (Bai *et al.*, 2001).

Hagenmaier (2005) found a rather wide range of internal CO_2 and O_2 values when individual coated oranges and apples were considered, in comparison with uncoated fruit showing a rather tight cluster of values. The internal gas values were particularly scattered for fruit with shellac and resin coatings, which caused the greatest reduction in peel permeance. This means that low-permeance coatings result in fruit with higher variation in product quality. On the contrary, in our work a large variation in internal O_2 levels was found for uncoated fruit followed by F2-coated fruit, while F1 melons which had the lowest O_2 levels also had the lowest variability in O_2 levels.

F1 melons also exhibited a dramatic increase in ethane levels already after 6 days at 13°C when O_2 fell from 16% to 1%. Similarly, Rizzolo *et al.* (2008) found that ethane production was maximum in pears under 0.1 kPa O_2 and absent in fruit stored at $O_2 \geq 2$ kPa. In our work a slight ethane production was also detected in F2-coated fruit where the O_2 level was about 3%. Ethane production depends also on CO_2 levels, as it was high in pears stored under 5 kPa CO_2 whatever the pO_2 (Rizzolo *et al*., 2008). Ethane is usually considered as a marker of lipid peroxidation in the cell membranes and it is released in pears affected by core browning while it was not detectable in healthy fruit (Veltman *et al*., 1999; Larrigaudière *et al*., 2001).

The aroma pattern as revealed by E-nose reflected the different O_2 and ethane levels as well as the different amounts of fermentative metabolites found in melon fruit according to coating treatment.

By using an E-nose it was possible to distinguish control fruit from F1- and F2-coated ones. W1S, W2S, W5S and W6S sensors showed higher responses for coated melons in comparison with control fruit, which in turn had the highest responses for W1C, W3C and W5C sensors. W1S, W2S, W5S and W6S sensors were grouped in PC1 and were positively related to acetaldehyde, ethanol, ethyl acetate, and ethane and negatively related to O_2 levels. PC1 had the highest scores in F1 fruit which were characterized by the lowest O_2 levels and by the highest production of ethane and fermentative metabolites and showed the lowest values in control fruit at day 0 when no fermentative metabolism occurred. The same relationships between MOS sensors and fermentative metabolites were found by Riva *et al.* (2005) in strawberries as a consequence of the formation of a peripheral layer of sugar with reduction of tissue porosity occurring during the osmodehydration process. Differently from that found for cold-stored peaches for which a high and significant correlation was found between ethylene production and E-nose pattern (Rizzolo *et al*., 2013), no correlation was found between E-nose pattern and internal ethylene. Ethylene production was very low as expected for a honeydew-type melon and slight changes were observed in relation to coating treatments and to days at 13°C in agreement with Barreiro *et al.* (2001).

Considering quality parameters, coating treatments had no influence on fruit firmness, while reduced SSC content was found when F1 coating was applied on fruit, and this decrease may be due to the fermentative pathway of accumulations of acetaldehyde and ethanol catalyzed by the enzymes pyruvate decarboxylase and alcohol dehydrogenase, respectively (Kader, 1995). Coating also affected skin and pulp color of melon fruit as F1 coating enhanced skin glossiness and delayed skin yellowing in compari-

son both to control and F2-coated fruit, while F2 melons showed a white-slightly greener pulp than control fruit.

In our experiment, weight loss was quite low, reaching the maximum values of about 1.5 % in F1-coated fruit and was lower in F2 fruit than in control and F1 ones. The inability of F1 coating to control weight loss could be due to the fact that this type of coating is based on a cellulose polymer and it is well known that the hydrophilicity of this material does not provide a sufficient moisture barrier (Lin and Zhao, 2007; Falguera *et al*., 2011; Dhall, 2013).

Application of coating to whole winter melons caused the onset of fermentation processes especially in fruit coated with the cellulose-based polymer (F1) where the O_2 level dropped to 1% which is the threshold value causing anaerobic metabolism and development of off-flavors and off-odors. Probably this kind of coating strongly decreased permeance of the skin to gas exchanges while it had no effect on water loss. The coating (F2) based on a water-soluble synthetic polymer showed a higher permeance to O_2 exchanges as O_2 levels were maintained at about 3% and therefore the development of fermentative metabolites was limited; this coating was also able to prevent fruit weight loss but no other positive effect was observed on fruit quality as firmness and soluble solids content were similar to those of uncoated melons. However, the cellulose based polymer coating improved fruit appearance, strongly enhancing fruit gloss and delaying skin yellowing, but these positive effects are of secondary importance in comparison to the anaerobic metabolism induced by this kind of coating.

Acknowledgements

Research carried out within the project "Utilizzo di prodotti innovativi derivanti da polimeri organici di interesse per il settore agro-industriale (PRO-INN)" of the Italian Ministry of Agriculture.

The work reported in this paper was presented at the "POSTHARVEST2014 Reducing Postharvest Losses to Feed the World Congress" held in Barletta, Italy, on 22-23 May 2014.

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