Electronic-Nose as Non-destructive Tool to Discriminate “Ferrovia” Sweet Cherries Cold Stored in Air or Packed in High CO₂ Modified Atmospheres

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This study aimed to explore the applicability of electronic-nose (E-nose) as a rapid method in discriminating samples of sweet cherry cv “Ferrovia” stored in high-CO₂ (16% O₂ + 20% CO₂ + 64% N₂) or air (control) up to 21 days. Projection to Latent Structures (PLS) methods applied to E-nose data showed that fresh fruit and the packaged or unpackaged samples can be distinguished, according to both the storage condition and the storage days. Moreover, a correlation analysis between E-nose sensors and 45 volatile compounds were overall, obtained from all the investigated sweet cherry samples by Headspace Solid-Phase Microextraction (HS SPME) coupled to Gas Chromatography-Mass Spectrometry (GC-MS). These methods allowed to associate samples with a specific flavour profile to one or more E-nose sensors. Finally, quality attributes (visual quality, colour, firmness, antioxidant activity, total phenols, and sugar content) were assessed during storage. Among these, visual quality and berry deformation resulted affected by storage conditions, showing that high-CO₂ treatment better preserved the fruit quality than control.

Keywords: sweet cherry cv “Ferrovia,” electronic-nose (E-nose), volatile profiles, projection to latent structure, correlation analysis, firmness

INTRODUCTION

Cold temperatures storage and modified atmosphere (MA) packaging are well-established practises for delaying the senescence of fresh fruit and vegetables, extending their postharvest life.

Aroma and flavour, which are crucial sensory attributes for consumer acceptability, are directly influenced by the organic volatile compounds (VOCs) profiles (1). Volatile metabolites represent the final products of fruit metabolism and changes in their profiles during storage can suggest the development of spoilage (2). In the last decades, the identification and quantification of the aroma compounds by Headspace Solid-Phase Microextraction (HS SPME) sampling followed by Gas Chromatography-Mass Spectrometry (GC–MS) became a well-established method for the evaluation of the most suitable postharvest conditions to preserve the sensory quality of freshly harvested fruit and vegetables during the storage (3). However, the practical application in the food industry of HS SPME and GC–MS is limited because these techniques involve expensive instrumentations and need considerable analytical skilled manpower to handle the
complex mixture and the high number of volatiles that comprise the VOCs pattern of crops (4). In recent years, electronic nose (E-nose) technology has been demonstrated to overcome some of the drawbacks associated with the methods traditionally used for the evaluation of VOCs profile (3). Electronic nose is a device equipped with an array of partial specific and broad-spectrum electronic chemical sensors which simulate human olfactory perception and offers a digital fingerprint of the volatile components that can be investigated with appropriate statistical tools. The use of the olfactometric method for the investigation of volatiles of fruit and vegetable presents several advantages, such as low cost, easy-to-handle, fast and non-destructive analysis, no preliminary sample preparation steps, and automatic data management (5). However, there are some disadvantages of using different E-nose sensors, including their response and recovery times, sensitivities, detection range, operating restrictions, physical size, inactivation by certain poisoning agents, and other limitations that are specific to individual sensor types. As clearly reported by the study of Wilson and Baietto (6), the varieties of advantages and limitations related to each E-nose sensor type are strictly connected with the nature of the technology that regulates the principle for detection and the types of analytes that may be detected by each sensor type. This technique has already an application in the food industry, including food quality control, authenticity, and traceability studies of fresh fruit (4).

Sweet cherries are greatly appreciated worldwide because of their appealing colour, aroma, taste, and health beneficial nutritional properties. This fruit is very perishable, and for the various cultivars, different MA treatments have been reported to preserve sweet cherry quality for the fresh market (7–10). A typical Italian sweet cherry cultivar “Ferrovia” is very appreciated for its big and bright skin berries, characterised by agreeable and middle sweetness flavour that allows this cultivar to be suitable for fresh consumption (11). In a very recent study of Cozzolino et al. (12), the changes of VOCs profiles were detected by HS SPME and GC-MS of sweet cherries cv “Ferrovia,” cold-stored in high CO2 modified atmospheres with three different compositions up to 21 days (11). Among the MA treatments, the authors observed that storage in high-CO2 (16% O2 + 20% CO2 + 64% N2) resulted in the most suitable packaging condition in preserving the sensory quality of the fruit till the end of storage (12).

The objective of the present study was to explore, for the first time, the applicability of E-nose as a rapid methodology in differentiating samples of sweet cherry cv “Ferrovia” stored in high-CO2 or air (control) for up to 21 days. Multivariate and univariate statistical data analysis have been applied to investigate the effects of storage time and storage condition on the E-nose fingerprint and VOCs profile [previously studied in (12)], while correlation analysis was performed to discover the relationships between sensors and VOCs. Moreover, some quality attributes, including visual quality (VQ), colour, deformation, antioxidant activity, total phenols, and sugar content, have also been investigated.

MATERIALS AND METHODS

Chemicals and Reagents

Sodium carbonate was purchased from Merck (Germany), while 2,2-Diphenyl-1-picrylazyl (DPPH), hydrochloric acid, potassium chloride, sodium acetate, and Folin-Ciocalteu’s phenol reagent were obtained from Fluka (Buchs, Switzerland).

Sweet Cherry Samples

Sweet cherries (Prunus avium L., cv Ferrovia) were provided by a local farm (Ermes snc, Noicattaro, Italy) in May 2017 and immediately transported to the Postharvest Laboratory of ISPA CNR. Fruits weighing 200 g were closed in 30 cm × 40 cm polyamide/polyethylene (PA/PE, 90 μm thick, Orved, Musile di Piave, Italy) plastic bags (Boxer 50, Lavizzini Vacuum Packaging

FIGURE 1 | The visual appearance of sweet cherries at harvest and stored in high-CO2 or the air (control) after 14 and 21 days at 5°C.
**TABLE 1** | Main effects of storage days and storage condition on visual quality score, \(\Delta E^*\), fruit deformation and antioxidant activity of sweet cherries (cv. Ferrovia).

| Days | Visual quality (score 5-1) | \(\Delta E^*\) | Fruit deformation (%) | Antioxidant activity (mg Trolox/100 g fw) |
|------|---------------------------|----------------|-----------------------|------------------------------------------|
| 14   | **3.0** b                 | **3.7** ab     | 12.4 b                | 69.74 b                                  |
| 21   | 2.5 c                     | 7.4 a          | 14.1 a                | 85.29 a                                  |
| Storage condition | *** ns *** ns           | *** ns         | *** ns                |                                          |
| Control | 3.0 b                 | 6.3           | 13.9 a                | 76.35                                    |
| High-CO\(_2\) | 4.5 a                 | 5.0           | 12.3 b                | 78.56                                    |

For each parameter, different letters indicate a statistical difference for \(p = 0.05\) (LSD test). Ns, not significant; \(* p \leq 0.05; ** p \leq 0.01; *** p \leq 0.001. Data are mean values of 3 replicates for each storage condition at each storage day.

System, Fiorenzuola d’Arda, Italy) in a modified atmosphere of high-CO\(_2\) (16% O\(_2\) + 20% CO\(_2\)) or were stored in open bags in air (control). All samples in triplicate were stored at 5\(^\circ\)C and were analysed, as reported below, at harvest (fresh sample) and after 14 and 21 days. The headspace gas composition (O\(_2\) and CO\(_2\)) within each high-CO\(_2\) bag was measured every day using a gas analyser (CheckPoint, PBI Dansensor, Ringsted, Denmark) and a gas chromatograph (p200 micro-GC, Agilent, CA, USA).

**Quality Analysis**

In order to evaluate the effect of storage on the visual quality, the fruits were scored by 10 trained panellists, using a hedonic scale of 5–1, with 5 = excellent, no defects; 4 = very good, minor defects; 3 = fair, moderate defects (limit of marketability); 2 = poor, major defects (limit of edibility) and 1 = inedible (13).

The \(L^*\) (lightness), \(a^*\) (redness), and \(b^*\) (yellowness) parameters were measured at 3 random points on 10 fruits for each replication, using a colorimeter (CR-400, Konica Minolta, Osaka, Japan), as previously described (14). The \(\Delta E^*\) was then calculated from primary \(a^*\) and \(b^*\) readings, using the following formula \(\Delta E^* = [(L_0^* - L^*)^2 + (a_0^* - a^*)^2 + (b_0^* - b^*)^2]^{1/2}\) (15).

Sweet cherry deformation was measured, on 10 fruits from each replication, as the force required to obtain a 3 mm deformation of each berry, using a texture analyser (ZwickLine Z0.5-Zwick/Roell, Ulm, Germany) equipped with a 100 mm diameter plate (16). The measure was expressed in %, normalising the diameter of the berry.

The total soluble phenolic compounds were analysed on fresh weight according to the Folin-Ciocalteu colourimetric method (17) and the concentrations were expressed in mg g\(^{-1}\) of gallic acid equivalents. The antioxidant activity was assessed on fresh weight by using the DPPH assay (18).

**Analysis of Volatile Compounds**

Volatile compounds identification and semi-quantification by HS SPME and GC-MS were previously reported in the study of Cozzolino et al. (12) which used DVB/CAR/PDMS (50/30 \(\mu\)m) fibre at 45\(^\circ\)C and 20 min as extraction temperature and time, respectively. Volatiles were analysed by using the GC device, model GC 7890A, Agilent (Agilent Technologies, CA, USA),

![Typical responses of sensors (S1–S10) to Fresh (A) and samples cold stored in Air (B) and High CO\(_2\) (C) at 21 days.](image-url)
FIGURE 3 | E-nose data. In (A), the biplot generated by PCA is reported. The points representing the E-nose sensors (black circles) are reported in the same plot of the points representing the samples of sweet cherry cv “Ferravia” investigated in our study. Fresh samples (light blue circles) spread along the vertical axis mainly influenced by sensor S10 whereas the other samples spread along the horizontal axis. Specifically, samples with the same storage days and storage conditions are represented by points close together in the plot. In (B), the biplot obtained by PLS analysis is reported. The points representing the E-nose sensors (black circles), the points representing the responses “storage days” and “storage condition” (red triangles), and the points representing the samples are reported in the same plot. Samples with the same storage days and storage conditions are represented by points close together in the plot. Moreover, responses and sensors positively correlated are represented by points close to each other while if they are inversely correlated, the points are centrosymmetric. The effect of storage condition is mainly explained by the behaviour of the S10 sensor whereas the data variation of the other sensors is mainly related to the effect of the storage days.

coupled to the mass spectrometer 5975 C (Agilent). Semi-quantitative data of each metabolite (Relative Peak Area, RPA%) were calculated with respect to the peak area of 4-methyl-2-pentanol, used as IS (12). Areas of the identified metabolites were measured from the total ion chromatogram (TIC).

Evaluation of Cherry Samples by E-Nose

The aroma profiles from the headspace of cherry samples were carried out using a commercial portable E-nose (E-nose, PEN 3, Airsense Analytics Inc., Schwerin, Germany, including the Win Muster software). The electronic nose system consists of a sampling unit and a gas detection system equipped with an array of 10 metal oxide semiconductors (MOS) sensors with different thicknesses and chemical compositions, to offer selectivity toward various volatile classes, as reported in the study of Shi et al. (20). Due to the high operative temperatures (200–500°C), VOCs transported to the surface of the sensors were completely combusted to carbon dioxide and water, causing a change in the resistance. The response of the MOS sensors, expressed as resistivity (O), was based on the variations in conductivity, due to the adsorption of gas molecules, and on the following surface reactions. For sample preparation, 4 g of each sample were put in 45 ml airtight glass vials and sealed with a screw cap with Poly (1,1,2,2-tetrafluoroethylene) (PTFE)/silicone septum. To reach the headspace equilibrium, each vial was kept at 30°C for 30 min and analysed at 22 ± 2°C and 50 ± 5% relative humidity (RH). In the course of the measurement time, the gas headspace was injected into the E-nose for 80 s at 400 ml/min. Analyses were conducted in six technical replicates for each biological sample and data were collected at each second. When the volatiles reached the measurement unit, the sensor conductivity modifies, first growing and then stabilising reaching a steady-state, causing changes of the ratio G/G0 (G and G0 are conductance of the sensors exposed to sample gas and zero gas, respectively) of each sensor. Subsequently, a second pump carries the filtered air to the sensor array for 400 s with a flow rate of 600 ml/min to clean the system between two consecutive analyses.

Electronic nose data were collected by the pattern recognition software (WinMuster, v.1.6., Airsense Analytics GmbH, Germany) and the average of each sensor response in the range from 70 to 75 s (area under the curve) was used for statistical data analysis.

Statistical Data Analysis

Quality parameters were analysed by ANOVA (Statistica 6 software, SatSoft Inc, Tulsa Oklahoma), considering factors such as storage condition (high-CO2 or air), storage days (14 and 21 days), and their interaction.

The electronic nose data and the VOCs have been investigated by ANOVA and multivariate data analysis based on projection methods. Specifically, the factors storage condition, storage days, and their interaction term have been included in the ANOVA model controlling the false discovery rate by the Benjamini-Hochberg procedure at the level δ = 0.05. Principal Component Analysis (PCA) has been applied for exploratory data analysis whereas Projection to Latent Structure (PLS) by partial least squares regression were conducted to investigate the effects of storage condition and storage days on the collected data (21).

The relationships between E-nose responses and VOCs have been explored by correlation analysis. Specifically, the Pearson
### TABLE 2 | ANOVA: p-value (p) of the effects of storage condition (High-CO$_2$ and Air), storage days (14 and 21 days at 5$^\circ$C), and their interaction on VOCs and E-nose data. Effects selected by Benjamini-Hochberg procedure assuming $\delta = 0.05$ are indicated with $^\ast$.

| Type          | Name                      | Code | $p$[storage condition] | $p$[storage days] | $p$[interaction] |
|---------------|---------------------------|------|------------------------|-------------------|------------------|
| **VOCs**      | **Esters**                |      |                        |                   |                  |
|               | Ethyl acetate             | E1   | 3.5E-05$^\ast$         | 3.5E-05$^\ast$    | 3.5E-05$^\ast$   |
|               | Ethyl 2-butenoate         | E2   | 1.1E-01                | 1.1E-01           | 1.1E-01          |
|               | Ethyl Hexanoate           | E3   | 1.2E-02                | 1.2E-02           | 1.2E-02          |
|               | 1-Hexyl acetate           | E4   | 5.3E-01                | 6.8E-01           | 6.3E-01          |
|               | 2-Hexen-1-ol acetate      | E5   | 8.5E-01                | 2.6E-01           | 6.8E-01          |
|               | 2-Hexenyl butyrate        | E6   | 6.8E-01                | 1.0E-03$^\ast$    | 3.4E-02          |
|               | Ethyl benzoate            | E7   | 2.4E-02                | 2.4E-02           | 2.4E-02          |
|               | trans-2-hexenyl hexenoate| E8   | 2.4E-01                | 2.4E-01           | 2.4E-01          |
|               | 2-Hexenyl tiglate         | E9   | 1.7E-02                | 5.1E-01           | 5.1E-01          |
|               | Isopropyl Laurate         | E10  | 2.5E-03$^\ast$         | 4.8E-01           | 4.8E-01          |
|               | **Alcohols**              |      |                        |                   |                  |
|               | 1-Penten-3-ol             | A1   | 2.8E-02                | 2.7E-02           | 7.4E-02          |
|               | 3 Hexanol                 | A2   | 1.6E-02                | 1.6E-02           | 1.6E-02          |
|               | 1 Pentanol                | A3   | 1.2E-04$^\ast$         | 3.3E-03$^\ast$    | 3.3E-03$^\ast$   |
|               | 3-Methyl-3-buten-1-ol     | A4   | 8.0E-01                | 4.3E-01           | 8.2E-01          |
|               | 3-methyl-2-Buten-1-ol     | A6   | 1.8E-01                | 4.4E-01           | 9.6E-01          |
|               | 1-Hexanol                 | A7   | 3.0E-01                | 8.4E-01           | 8.8E-01          |
|               | trans-3-Hexen-1-ol        | A8   | 1.7E-01                | 3.1E-01           | 3.9E-01          |
|               | cis 3-Hexen-1-ol          | A9   | 1.0E+00                | 1.2E-01           | 8.7E-01          |
|               | cis 2-Hexen-1-ol          | A10  | 8.5E-01                | 4.7E-01           | 9.8E-01          |
|               | 1-Octanol                 | A11  | 6.6E-01                | 3.0E-01           | 7.0E-01          |
|               | Nonanol                   | A12  | 8.1E-01                | 1.3E-01           | 1.8E-01          |
|               | Benzene methanol          | A13  | 7.4E-01                | 3.2E-01           | 6.4E-01          |
|               | 1-Dodecanol               | A14  | 7.8E-01                | 5.4E-02           | 7.9E-01          |
|               | **Aldehydes**             |      |                        |                   |                  |
|               | Butanal 3-methyl          | Ald1 | 1.7E-01                | 1.7E-01           | 1.7E-01          |
|               | Hexanal                   | Ald2 | 4.1E-01                | 3.6E-01           | 8.3E-01          |
|               | 2-Hexenal                 | Ald3 | 4.0E-01                | 4.4E-01           | 8.0E-01          |
|               | Octanal                   | Ald4 | 1.1E-01                | 3.9E-02           | 3.9E-01          |
|               | Nonanal                   | Ald5 | 7.4E-01                | 7.4E-02           | 8.0E-01          |
|               | Decanal                   | Ald6 | 3.0E-02                | 7.1E-01           | 7.1E-01          |
|               | Benzaldehyde              | Ald7 | 1.4E-01                | 8.3E-01           | 8.6E-01          |
|               | Dodecanal                 | Ald8 | 4.8E-01                | 5.6E-01           | 8.8E-01          |
|               | Tetradecanal              | Ald9 | 4.5E-02                | 1.8E-01           | 1.2E-01          |
|               | **Ketones**               |      |                        |                   |                  |
|               | 2 pentanone 4 methyl      | K2   | 4.9E-02                | 1.6E-01           | 5.8E-01          |
|               | 3 Butyrolactone           | K4   | 6.4E-07$^\ast$         | 6.4E-07$^\ast$    | 6.4E-07$^\ast$   |
|               | 2-Dodecanone              | K5   | 7.4E-03$^\ast$         | 5.6E-01           | 5.6E-01          |
|               | **Terpenes**              |      |                        |                   |                  |
|               | dl-Limonene               | T1   | 3.5E-03$^\ast$         | 8.9E-01           | 8.9E-01          |
|               | Linalool                  | T3   | 8.3E-01                | 2.9E-01           | 3.1E-01          |
|               | α Terpineol               | T4   | 6.0E-01                | 4.7E-02           | 2.1E-02          |
|               | **Others**                |      |                        |                   |                  |
|               | Formamide N,N-dibutyl     | O2   | 7.2E-01                | 5.5E-01           | 7.4E-01          |
|               | Benzothiazole             | O3   | 3.3E-01                | 5.5E-01           | 8.9E-02          |

(Continued)
correlation coefficient has been calculated for all pairs of E-nose data and VOCs and the resulting correlation matrix has been investigated by heatmap using a clustering procedure based on Euclidean distance and Ward’s method.

Data analysis has been performed by in house R-function implemented using the R 4.0.4 platform (R Foundation for Statistical Computing, Vienna, Austria).

RESULTS AND DISCUSSION

Changes in Quality Parameters of Sweet Cherries Cold Stored in High-CO₂ or Air

Fruit stored in high-CO₂ reported a mean value of the visual quality significantly higher than control, with a quality decrease during storage from 5 to roughly 2.5 at the end of the storage (Figure 1, Table 1). Changes in visual quality during storage can be mainly related to the browning of the skin and a significant increase in berry deformation (Table 1). This last parameter resulted higher in air than in high-CO₂ fruit, influencing the sensory evaluation of the visual quality. This result confirmed the positive effect of high-CO₂ MA storage in the preservation of quality of sweet cherry cv. “Ferrovia,” as previously reported in the study by Cozzolino et al. (12).

For fresh fruit the initial mean values of antioxidant activity, total phenols and total sugar content were 63.6 ± 7.2 mg Trolox 100 g⁻¹ fw, 130.3 ± 6.2 mg gallic acid 100 g⁻¹, and 21.04 ± 2.0 g glucose 100 g⁻¹, respectively. Except for the antioxidant activity that significantly increased during the storage of about

| Type      | Name | Code | p[storage condition] | p[storage days] | p[interaction] |
|-----------|------|------|----------------------|-----------------|----------------|
| E-nose sensors |      |      |                      |                 |                |
| S1        |      | 2.3E-07* | 2.3E-12*          | 4.7E-11*        |                |
| S2        |      | 8.5E-10* | 9.8E-13*          | 1.2E-11*        |                |
| S3        |      | 1.9E-06* | 9.2E-13*          | 3.5E-11*        |                |
| S4        |      | 4.4E-09* | 3.2E-10*          | 5.2E-09*        |                |
| S5        |      | 1.4E-05* | 8.2E-13*          | 1.1E-10*        |                |
| S6        |      | 2.4E-07* | 1.7E-13*          | 5.2E-09*        |                |
| S7        |      | 7.3E-03* | 1.3E-09*          | 2.4E-09*        |                |
| S8        |      | 8.5E-07* | 2.9E-13*          | 2.1E-09*        |                |
| S9        |      | 1.9E-08* | 1.4E-13*          | 3.2E-10*        |                |
| S10       |      | 5.3E-03* | 1.6E-01           | 8.2E-01         |                |

FIGURE 4 | VOCs data. In (A), the biplot generated by PCA is reported. The points representing the VOCs (black circles) are reported in the same plot of the points representing the samples of sweet cherry cv “Ferrovia.” Fresh fruits (light blue circles) and samples packed in high-CO₂ for 21 days (yellow circles) are evidently separated from the other samples. When VOCs and points representing samples are close, VOCs show high levels for those samples or if their images obtained by inversion in the origin are close to the points representing the samples, low levels. In (B), the biplot obtained by PLS analysis is reported. The points representing the VOCs (black circles), the points representing the responses “storage days” and “storage condition” (red triangles), and the points representing the samples are reported in the same plot. Samples with the same storage days and storage conditions are represented by points close together in the plot. Moreover, responses and VOCs positively correlated are represented by points close to each other while if they are inversely correlated, the points are centrosymmetric.
Changes in E-Nose Responses of Sweet Cherries Cold Stored in High-CO\textsubscript{2} or Air

Five biological samples have been collected for fresh produce and each combination of storage condition (air or high-CO\textsubscript{2}) and storage days (14 and 21 days at 5\textdegree C). Since six technical replicates have been considered for each biological sample, a data set composed of 150 observations was obtained.

In Figure 2, the typical E-nose responses to Fresh (A) and cold-stored sweet cherry samples in air (B) or high-CO\textsubscript{2} (C) at 21 days are represented. Each curve displayed the response values, expressed as the ratio G/G\textsubscript{0} (vertical axis) of the relative sensor which changed with time (horizontal axis). The signals trend in all samples was almost similar. The response values of S8 (sensitive to broad-alcohol) appeared significantly increased, followed by S6 (sensitive broad-methane) and S2 (broad range). On the contrary, the signals of the sensors S4, S6, and S10 were sensitive to hydrogen, broad-methane, and methane-aliph, respectively. They did not show significant variations, keeping the value of G/G\textsubscript{0} around or less than one. Finally, the sensors S1, S3, S5, and S9, which were all responsive to aromatic components, regularly declined slightly. Comparing the three panels of Figure 2, the values of S8, S6, and S2 were different and indicate that sweet cherries stored in high-CO\textsubscript{2} (C) could produce more aroma components than fresh (A) and air (B) samples.

The data set composed of 150 observations and 10 features has been autoscaled and investigated by PCA. A model with two principal components explaining 97\% of the total variance has been obtained. The biplot of the model is reported in Figure 3A.

Changes in VOCs of Sweet Cherries Cold Stored in High-CO\textsubscript{2} or Air

Three biological samples have been collected for fresh fruit and each combination of storage condition (air or high-CO\textsubscript{2})
and storage days (14 and 21 days at 5°C) obtaining a data set composed of 12 observations and 45 VOCs.

Applying autoscaling to the data, a PCA model with two principal components has been obtained. The model explained 54% of the total variance. The biplot is reported in Figure 4A. Fresh fruits and samples packed in high-CO₂ for 21 days were evidently separated from the other samples being characterised by specific VOCs. Sweet cherries stored in air or high-CO₂ for 14 days were located in the centre of the plot and are not characterised by specific VOCs.

The effects of storage condition and storage days on the VOCs have been investigated by PLS analogously to the case of E-nose data. Considering autoscaled data, a PLS model with two latent variables, \( R^2_Y = 0.81 \) and \( Q^2_Y = 0.62 \), has been obtained. The effects of storage condition resulted better explained than in the case of E-nose (\( R^2_Y = 0.84 \) and \( Q^2_Y = 0.67 \) for VOCs and \( R^2_Y = 0.55 \) and \( Q^2_Y = 0.43 \) for E-nose data). The model passed the

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**FIGURE 6** Heatmap representing the correlation between VOCs and E-nose data sensors. In the heatmap, the colour of each cell depends on the value of the Pearson correlation coefficient between the VOC and E-nose data sensor. VOCs and E-nose data have been clustered based on the Euclidean distance and Ward’s method. As a result, specific groups of VOCs positively or negatively correlated to specific groups of E-nose sensors can be visually discovered, searching the regions of the map with the highest intensity (red or blue, respectively).
The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS
RC and MC designed experiments. BP, CL, and MP carried out the experiments. RC, MC, and MP analysed the experimental results and wrote the manuscript. MC and MS performed the statistical analysis. All authors contributed to the article and approved the submitted version.

FUNDING
The project Prin 2017 Multi Functional polymer cOmposites based on groWn matERials (MI-FLOWER) (Grant Number: 2017B7MMJ5_001) from the Italian Ministry of Education University and Research Project High-Performing Advanced Material Platform for Active and Intelligent Food Packaging is kindly acknowledged.
ACKNOWLEDGMENTS

The authors thank Mr. Massimo Franchi and Dr. Mariella Quarto of ISPA-CNR for providing technical and administrative assistance.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fnut.2021.720092/full#supplementary-material

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