

Isothermal Calorimetry Protocols to Monitor the Shelf-Life and After-Market follow up of Fresh Cut Vegetables

Nabil Haman^a, Marco Signorelli^a, Celia Duce^b, Laura Franzetti^a and Dimitrios Fessas^{a*}

^a Dipartimento di Scienze per gli Alimenti, la Nutrizione e l'Ambiente (DeFENS), Università Degli Studi di Milano, Via Celoria 2, 20133 Milano, Italy

^b Dipartimento di Chimica e Chimica Industriale, Università degli Studi di Pisa, Via Risorgimento 35, 56127 Pisa, Italy

* Corresponding Author: dimitrios.fessas@unimi.it;

Keywords: isothermal calorimetry; shelf life; ready-to-use vegetables, microbes

Abstract

Protocols and guidelines were assessed in order to apply Isothermal Calorimetry as a complementary/alternative method to monitoring, during the shelf life, the microbial growth/metabolism in commercial fresh cut vegetables with random initial microbial population. Moreover, the endogenous microbial population was used as a biosensor to check the modifications occurred during long storage for aftermarket characterization in the frame of vegetable waste treatments. Validation was obtained following ready-to-use carrots highlighting the effects of the different exposed surface (cylinders, sticks and à-la-julienne cut) on the overall spoiling process during shelf life and green salad stored up to 14 days as regard the aftermarket characterization.

1. Introduction

Ready-to-use fresh vegetables became so far quite appealing for consumers and food service companies thanks to the mild and quick processing treatments (trimming, peeling, washing and disinfection) required to provide commodities with sensory and nutritional properties close to those of the fresh products as defined by the International Fresh Cut Produce Association (IFPA). However, these treatments accelerate deterioration for various reasons (for instance, the cut treatment imply some cell disruption with release of enzymes that sustain production of off-flavors and browning) [1-3]. Among them, a relevant factor of early spoiling is the enhancement of microbial contamination and proliferation due to the nutrients released by wounded vegetables and the increased exposed surface area of these products [4-6]. Most of these contaminants come from machineries, environment and hand manipulations and despite washing and bland disinfection procedures, often, the commercial fresh –cut vegetables result more contaminated than the original products [7]

The microbial specie most found on in Fresh cut vegetables and responsible of alterative process are Gram negative aerobic psychrotrophic rods belonging to genus *Pseudomonas* and facultative anaerobic rods as *Erwinia carotovora*. These microbial forms are characterized by a strong pectinolytic activity that is the principal alterative phenomenon present on these products [8-10].

Microbial growth and metabolism during shelf life can be slowed by using improved packages (e.g. inert atmosphere, etc.) [11-13] which however do not avoid a still impressive food waste [14]. Fruit and vegetable waste (FVW), including pre – and after - market phases, poses environmental problems due to its high biodegradability, represents a loss of valuable biomass and an economic cost for companies. Different reduction, reuse and recycle strategies to tackle FVW have been proposed including the extraction of specific functional compounds that is one of the most studied field in the last years [15, 16]. In this frame, many efforts are devoted to the characterization and monitoring of these products as regard both the shelf life prediction and the after-market status in order to define the waste processing [14-16].

Shelf-life of fresh cut vegetables can be monitored and/or predicted either controlling the driving agents of damages (growth of microbial populations, enzymatic activities, concentration of reactive compounds etc.) or monitoring their effects, like changes in pH, color, texture, nutritional value and presence/absence of peculiar compounds. However, in these complex multi-parameter systems, there is no simple correlation between cause and effect and direct determination of the relevant parameters often is needed. Such a practice is expensive since requires repeated chemical, biochemical and microbiological tests, implies collection of several food specimens and preliminary treatments of each sample, including the simplest ones, like pH determination [17, 18]. The characterization of the wastes becomes even harder [14-16, 19-21].

As regards the microbial growth and metabolism monitoring, Isothermal Calorimetry (IC or ITC in the case of titration), represents a suitable complementary/alternative to the traditional approaches and has already been applied to the study of the metabolic activity of bacteria in opaque liquids, on surfaces and in solids in a wide range of conditions [21-36]. The instrumental output, i.e., the heat flow (HF), is a non-specific neat signal that reflects the overall energetic and kinetic picture of the bacteria activity in the real system under investigation i.e. accounting for all the chemical and physical processes in the sample [37-39].

However, many issues are still to be addressed in order to apply this technique to the case of commercial fresh cut vegetables in order to discriminate the cut treatment effects in a complex system where a number of factors and processes are occurring simultaneously and partially overlap to one another. One of the main issues is that the samples of commercial fresh products may have different initial bacterial load depending on many factors as mentioned before, precluding a straight comparison of the calorimetric data. Furthermore, the vegetable matrix may present differences even in the case of the same type of vegetable depending on the cultivation season, region etc. [40]

In order to overcome these problems, definition of some main contour conditions and initial setup/normalization IC protocols are needed. The present work addresses this issue. For this purpose, carrots were selected as an example of fresh-cut vegetable, since they allow preparation of ready-to-

use products with different exposed surface (cylinders, sticks and à-la-julienne cut) and IC normalization protocols was assessed in order to monitor the evolution of the microbial activity during the shelf life. Furthermore, IC protocols suitable for vegetable waste characterization was also assessed following the case of ready to use green salad stored up to 14 days and using the endogenous microbes as biosensors. Indeed, green salad may well represent a model of the vegetable wastes since it represents the major amount in such a category [14].

Materials and methods

Raw material and sample preparation

Carrots

Fresh carrots used in the present work were purchased from a local producer (Northern Italy), who applies a simple entrance/storage routine: the carrots are manually selected according to their size (medium-sized: 19.5 ± 1.0 cm length, 3 ± 0.1 cm diameter), washed with hydrogen peroxide (1 %), cooled to about 4 °C and finally delivered to the market (in our case to the laboratory) in large polyethylene plastic bags at 0°C and approx. 100 % relative humidity. The carrots were then peeled using a sterile manual peeler, the top and tip were removed and the remainder cut into cylinders (13 mm of diameter and 6 cm in length), sticks (2 mm of thickness, 12 mm of width and 6 cm in length) and “Julienne” slices (2 mm of thickness and 6 cm in length).

Carrot juice was also prepared, for the preliminary assessment, from hand-peeled carrots using a household juice machine. The pH was first decreased to 4 ± 0.1 using juice lemon in order to inactivate the native microbial flora (simulating the commercial practice), and then was adjusted to 7 ± 0.1 (that is close to the native condition of carrots) for the IC measurement.

Green Salad

100 g of fresh ready-to-use green salad “**songino**” (*Valerianella locusta Laterr*) packaged in PVC bags were obtained from the same producer as for carrots. The salad bags were transported to our laboratory immediately after packaging, under refrigerated conditions at 4 °C. The products were

stored up to 14 days (the arrival time was considered as reference zero time) under controlled conditions i.e. at 10°C and relative humidity of 82%. The storage conditions were chosen to simulate an average stressed environment that a commercial product may experiencing during distribution [13, 18].

Isothermal calorimetry

The instrument used for the IC investigations was the “Calorimètre E. Calvet pour Microcalormétrie, DAM” (Setaram, Lyon, France) equipped with 10 cm³ stainless steel cells. Calibrations were performed using the Joule effect calibrator EJ2 (Setaram, Lyon, France). Measurements were performed at 30°C. Calorimetric cells were sterilized before every sample load. Typical sample mass was 5 g and 2 g for carrots and salad respectively. Constant air environment was assured in the headspace of the cell through a capillary air circulation system (Microlab 500, Hamilton Company, USA). Some measurements at 10°C were also performed using the Thermal Activity Monitor 2277 (TAM) instrument (Thermometric, Sweden) equipped with 20 ml cells. The heat flow vs time raw signal was integrated to obtain the overall thermal effect $\Delta H_{\text{overall}}$. Errors were evaluated on the basis of at least three replicates. The $\Delta H_{\text{overall}}$ error were below 6%.

Microbiological analysis

Microorganisms test and inoculum preparation for Carrots Juice:

Pseudomonas fluorescens ATCC 13525 was used as microorganism test. A fresh overnight culture of microorganism test was inoculated (10^2 - 10^3 CFU (Colony-Forming Unit) / ml) in 5 ml carrot juice incubated at 30°C for 48 hours. As control, TSB (Tryptic Soy Broth) [41] inoculated in the same conditions was used. At establish time microbial count was performed by plating on TSA (Tryptic Soy Agar) [41] and incubation for 2 days at $30 \pm 2^\circ\text{C}$.

Green Salad Total Bacterial Count

Ten grams of samples from each stored package were drawn and homogenized with 90 mL of sterile trypton salt solution at 0.85%, into a sterile Stomacher bag, by the use of a Colworth Stomacher 400 blender for 2 min. Decimal progressive dilutions were prepared and the bacteriological determination of Total Bacterial Count (TBC) was carried out according the standard procedure (ISO 4833, 2003).

All microbiological analyses were carried out in triplicate and the results were expressed as the mean of CFU / gram.

2. Results and discussion.

Shelf life monitoring. Preliminary assessment:

In order to assess the microbial growth in the selected fresh cut vegetable system (carrots in our case) and discriminate the influence of the cut treatment through IC calorimetry, a preliminary assessment had to be performed since the commercial samples may have random initial microbial load N_0 .

The main idea to overcome this problem is to take advantage of the detectability threshold of the calorimeter. Indeed, in a previous work [42] we demonstrate that, in the case of the same matrix simple systems, the initial exponential behavior of the microbial growth quickly overcomes the experimental setup peculiarities and the signal onset time mainly depends on the N_0 and more importantly, the corresponding microbial population, namely the lowest cell population, N_{onset} , that produces a detectable calorimetric signal, is constant. This last statement is not so obvious in the case of complex matrices such as fresh cut vegetables and an experimental validation in well controlled conditions is needed. For this purpose, particular microorganisms that may represent the overall microbial spoilage must be selected. In our case *Pseudomonas fluorescens* was the microbial strain selected to represent the overall endogenous microbial load of carrots [43].

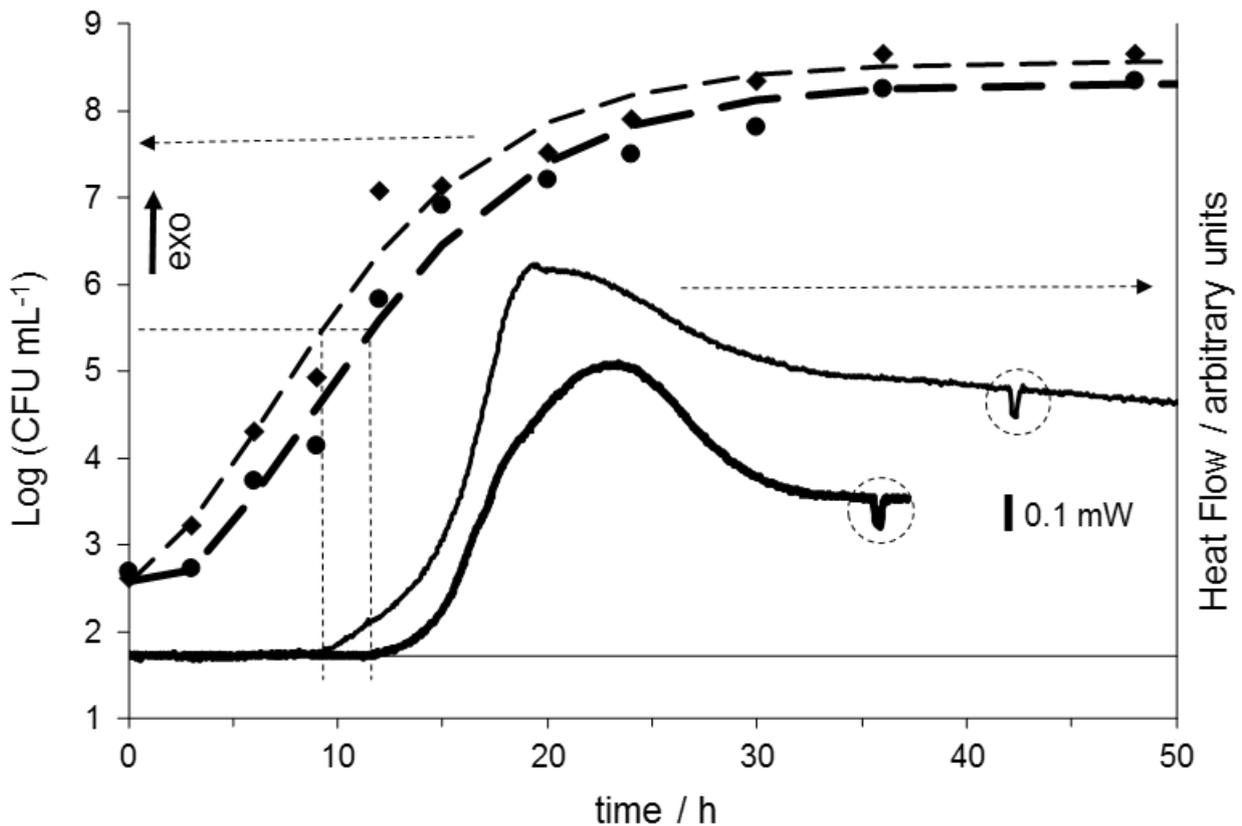


Fig. 1 In figure are reported (right side) the raw exothermic IC traces obtained from two liquid (5ml) samples of cultures of *P. fluorescens* with starting population at about 600 CFU/mL, in TSB medium (thin continuous line) and in carrot juice at pH 7 (bold continues line). Corresponding parallel microbiological plate counts are also reported (left side, thin and bold dashed lines for TSB and carrot juice respectively). In the circles the calibration signals (0.1 mW for 1200 s) are also reported

In figure 1 are reported the raw exothermic calorimetric traces obtained from two liquid samples (5ml) of cultures of *P. fluorescens* with same starting population at about 600 CFU/mL, in TSB medium and in carrot juice at pH 7, i.e. close to the native condition of carrots. The corresponding parallel plate counts are also reported. The profile of the IC signal reflects the kinetics and energetics of the overall growth/metabolism process (the end tail of the signal reflects the microbial metabolism not coupled with cell duplication), while the area beneath it represents the overall heat released, which in turn, is related to the extent of the overall process occurred.

The choice of liquid samples with the same volume and N_0 was applied to normalize as much as possible the other factors that may influence the thermogram (sample geometry, etc. [42]) in order to highlight the substrate differences due to nutrient availability and type [3, 40]. We observe that

both the onset time and the calorimetric profile, are influenced by the nutritional composition of the substrate. Nonetheless, the microbial population at the onset time, namely the lowest cell population, N_{onset} , that, in a given medium, produces a detectable calorimetric signal, remains constant and apparently independent of the specific media (about $3.2 \cdot 10^5$ CFU/mL in our experimental conditions). This observation allows to overcome any small difference of the commercial products (composition of vegetable products varies according to season, cultivation region etc. [40]) and also gives the opportunity to normalize the random initial microbiological load in the systems to be compared. Indeed, if we shift the thermograms' time axis in order to overlap the different onset times to a common virtual initial time $t_0 = 0$ we may compare the evolution of the microbial growth and metabolism at the same initial load $N_0 = N_{\text{onset}}$. Of course the reliability of this conclusion as regards the real systems depends on how much the microbiological strain/s selected to perform this preliminary test is representative of the overall microbial population (see below application range and limits).

Therefore, this t_0 normalization procedure allows the comparison of thermograms for commercial samples to take into account the other parameters that can affect the microbial growth in the fresh cut vegetables (exposed surface ratio, other cut effects etc.).

Application: Exposed surface and cut effect in commercial cutting treatments.

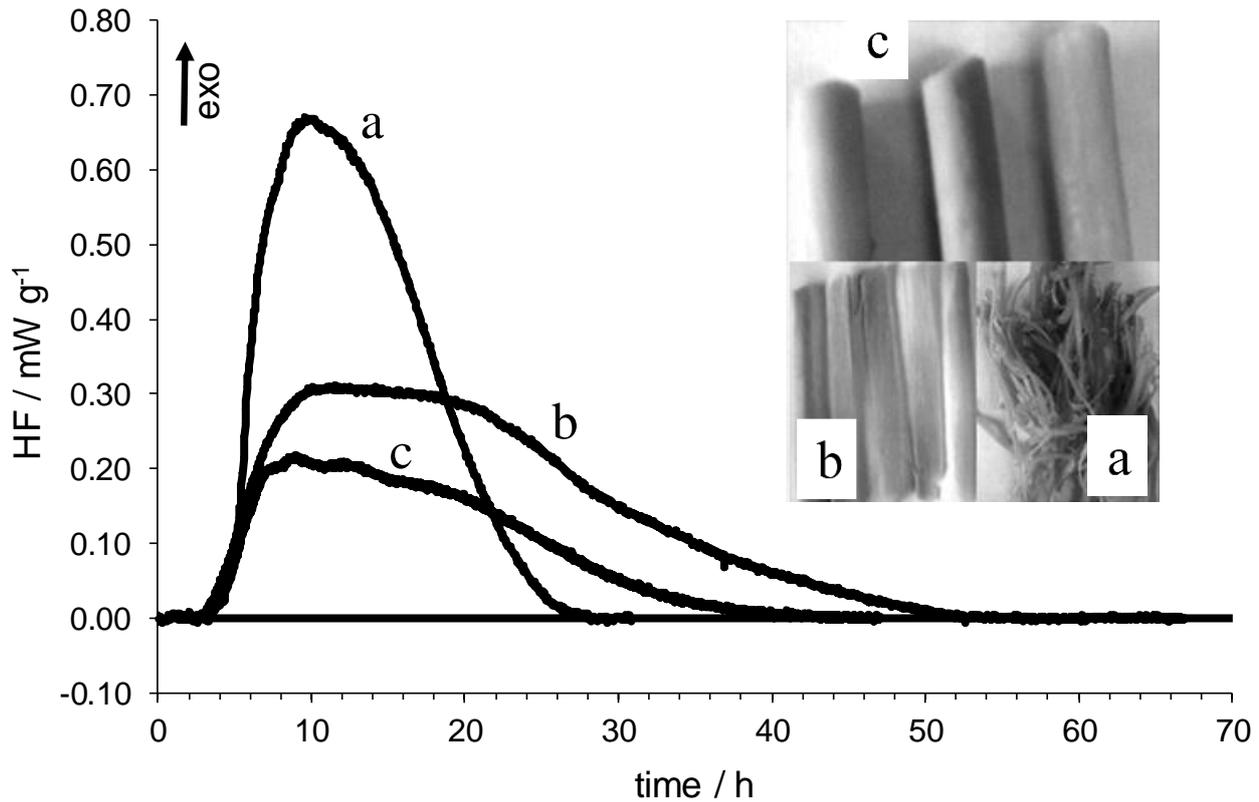


Fig. 2 Normalized IC records (exothermic) from carrots with different cut treatment (a: “Julienne”, b: sticks; c: cylinders)

Figure 2 shows the comparison of the t_0 normalized calorimetric traces obtained from fresh carrots which had undergone a different cutting treatment. We observe that major the accessible surface area major the microbial growth/metabolism rate in the systems. We may note that these thermograms represent a reliable starting point for further theoretical modelling [44, 45] to compare the cut effects since, according our normalization, all samples have the same initial contamination N_0 and also the same nutritional matrix (carrots). However, this exploitation is beyond the scope of this paper and we limit here to highlight the immediate evidences. We observe that in all cases the traces were return to the baseline. This indicates that the microbial initial random contamination of the samples was predominantly constituted of aerobic forms (like *Pseudomonas fluorescens* that is an obligate aerobe, gram negative bacillus) in line with the literature [46]. The effect observed depends, accordingly, on the accessible surface area that influence the respiration rate and consequently determine the depth of contamination in the samples. The overall enthalpy was of 28.2 Jg^{-1} , 20.9 Jg^{-1}

and 9.8 Jg^{-1} for the systems shaped as “Julienne”, stick and cylinder respectively and relatively quantify these effects that are of major importance in the packaging research sector (application of modified atmospheres, etc.) [13, 47].

After market characterization (green salads). Preliminary assessment:

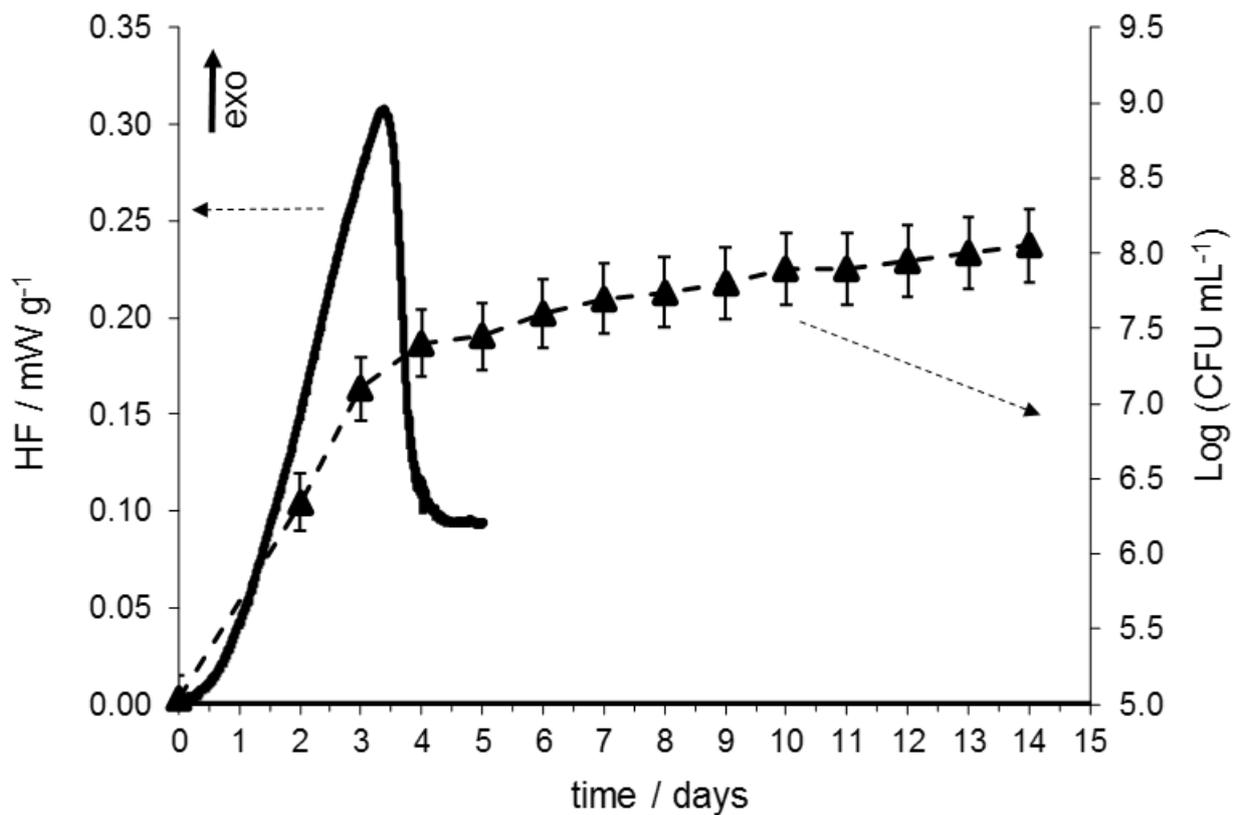


Fig. 3 IC thermogram (exothermic, bold line) obtained at 10°C from fresh green salad sample. Corresponding parallel microbiological plate counts (TBC) are also reported (full triangles)

Figure 3. shows the calorimetric traces obtained at 10°C from fresh salad samples (hosted in the TAM calorimeter). Delays in growth and microbial metabolism were observed, as expected at this low temperature and eventually the signal attains a plateau after about 4 days corresponding to when the microorganism enters the stationary phase (stationary phase is induced by- increased bacterial cell density, depletion of nutrition in media and accumulation of toxic secondary metabolic wastes). Parallel microbial assessment was performed for the samples stored at 10°C and the total

microbial count data (TBC) are also reported in the same figure to display the trend of the overall aftermarket microbial population in the system during the 14 days' storage period. We observe a good matching with the calorimetric signal at the early stage of storage. After 4 days, the total microbial count data (TBC) remains almost steady in the $10^{7.5} - 10^{8.0}$ CFU/mL range confirming the stationary phase status.

During such a long storage the fresh cut salad undergoes some deterioration not necessarily correlated directly with microbial activity (chemical, textural, etc. [48, 49]) that eventually compromise the aftermarket recovery possibilities. [14-16]

In order to evaluate the overall status of the product during such a long storage through IC calorimetry, the basic hypothesis is that the food spoilage, i.e. the vegetable cellular damages, produces a release of microbial nutrients that become easily accessible [8, 50]. Considering the almost steady level attained by the endogenous microbial population we may use this population as a biosensor to check the modifications occurred in the salad leaves during long storage. In other words, the hypothesis is that if we stimulate a further microbial activity in such systems, for example by rising the temperature, the rate of this activity will depend on the matrix nutrients availability that, in turn, maybe correlated with the damage and waste status [50].

Application

To this aim, the salad samples that had been stored for different time lapses at 10 °C, were calorimetrically investigated in isothermal conditions at 30 °C. These samples undergoing the IC run with an initial microbial load in almost steady condition in the $10^{7.5} - 10^{8.0}$ CFU/mL range that is well above the 10^5 CFU/mL signal detection threshold. The temperature rise stimulates the overall microbial activity, which however would be re-activated in different matrices according to the extent of deterioration experienced during the previous storage. The time of this re-activation to produce a detectable IC signal was not taken into account because it is difficult to discriminate between environmental factors and microbe peculiarities (lag time, initial load small differences etc.) [51].

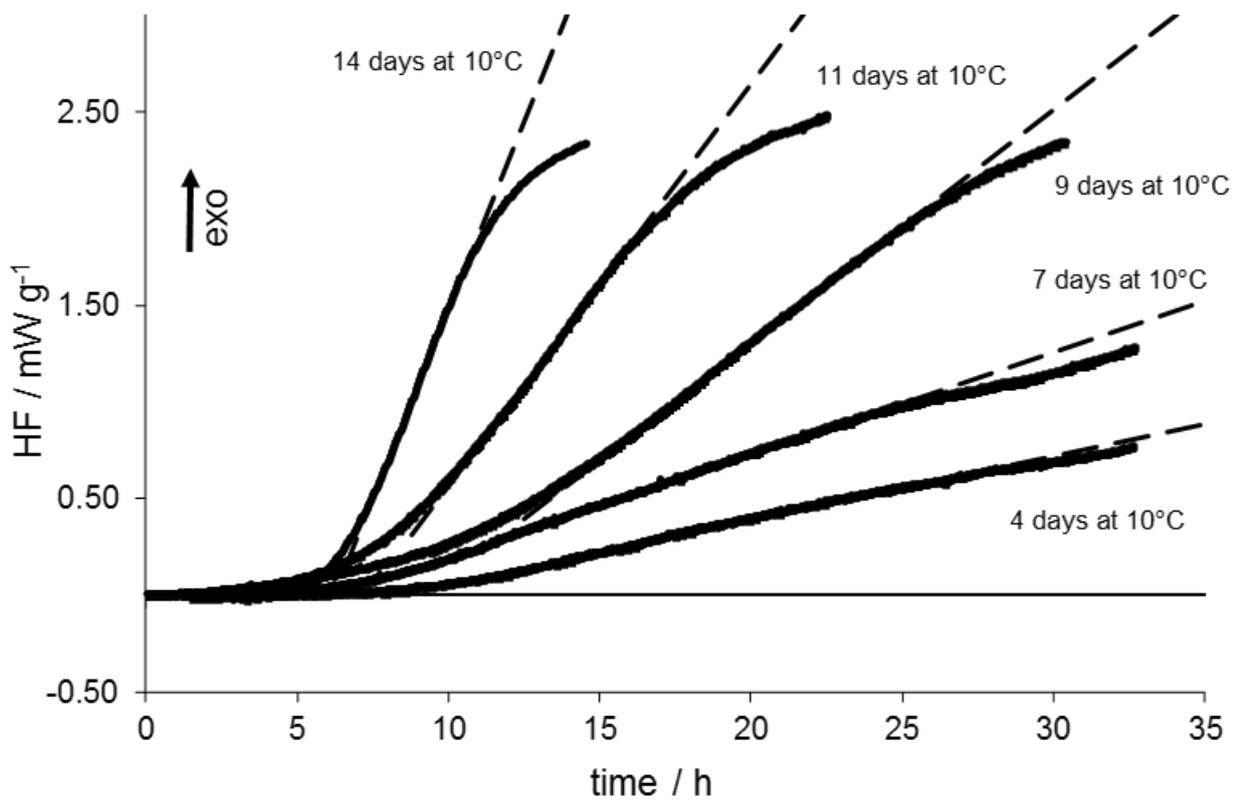


Fig. 4 IC traces at 30°C from salad samples that had been stored at 10 °C for 4, 7, 9, 11 and 14 days

Figure 4 shows the calorimetric traces at 30°C relevant to salad samples that had been stored at 10 °C for 4, 7, 9, 11 and 14 days. We observe that the initial heat flow rate indicates an increasing trend which follows the age of the samples i.e. it is in line with our hypothesis that the overall microbial activity may depend on the matrix nutrients availability which increases during the storage period of time.

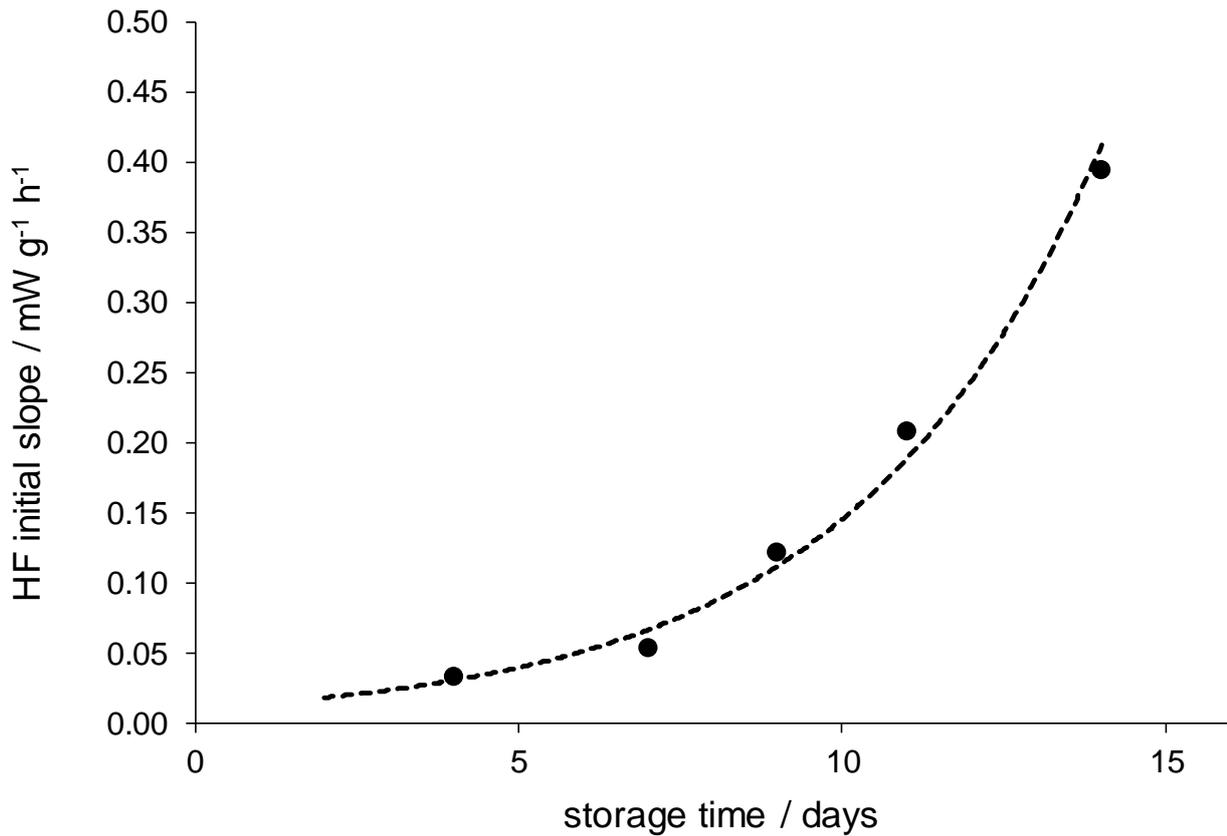


Fig. 5 HF initial slope obtained from the thermograms presented in fig. 4 vs storage time

Indeed, the trend of the IC trace slope vs storage time, presented in figure 5, follows an exponential law that is in line with the increase of substrate availability in stochastic microbial activity [52].

In summary, this function, obtained using the IC method, may be used as a phenomenological relative index of the fresh cut vegetable overall spoilage. However, correlation with the other complementary indexes is needed, depending on the peculiar case, in order to be integrated in a control protocol [53-56].

Overall application range and limits

- a) The onset time normalization implies that the initial contamination is under the detectability of the instrument. However, the procedure of time normalization may be applied also taking

into account another reference point of the HF signal (higher than zero) if the corresponded $N_{\text{reference}}$ is proved constant at the initial assessment.

- b) In our case we used, for demonstration purposes, a selected microorganism to represent the overall vegetable microbial population. Fresh vegetables are mainly contaminated by the same or few general classes of microorganisms as regard the calorimetric point of view i.e. the energetic behavior of these microbes [9, 57]. However, depending on the system and the research purposes, other choices and/or the overall load method may be applied without changing the concept of the initial assessment i.e. to prove that the corresponded N_{onset} is constant.
- c) The effects of cut treatment (carrots) was monitored through IC measurements performed at 30°C accelerate regime in order to avoid deterioration side effects by a long stay of the samples in the calorimetry. We may note, however, that temperature is a relevant factor in the microbial growth and metabolism kinetics and a more accurate inspection is necessary if we intend recognize the combined effect of temperature and time of conservation on the microbial activity [5, 13, 58].
- d) The long time storage of the green salad product was performed with the samples in the original sealed bags, under standard microbiology laboratory controlled conditions and the Total Bacterial Count (TBC) was regularly monitored to confirm the microbial stationary status. In these conditions seems unlikely the contamination and proliferation of external microbial contaminants at a relevant level to strongly influence the IC thermograms at the early stage.

However, for application in real systems, this issue has to be taken into account applying more severe microbiological control in the method setup phase to assess experimentally how external microbial contamination, during storage, may influence the IC trace.

4. CONCLUSIONS

Protocols and guidelines were assessed in order to apply Isothermal Calorimetry as a complementary/alternative method to monitor, during the shelf life, the microbial growth/metabolism in commercial fresh cut vegetables with random initial microbial population. Moreover, the endogenous microbial population was used as a biosensor to check the modifications occurred during long storage for aftermarket characterization in the frame of waste treatments. Validation was obtained following ready-to-use carrots highlighting the effects of the different exposed surface (cylinders, sticks and à-la-julienne cut) on the overall spoiling process during shelf life and green salad stored up to 14 days for the aftermarket characterization.

Acknowledgements

This research was supported by Ministero dell'Istruzione, dell'Università e della Ricerca (Prot. 957/ric, 28/12/2012), through the Project 2012ZN3KJL "Long Life, High Sustainability".

References

1. Aked J. Fruits and vegetables. In: Kilcast D, Subramanian P, editors. The stability and shelf life of food. Cambridge: Woodhead publishing; 2000. pp. 250-275.
2. Singh RP. Scientific principles of shelf life evaluation. In: Man CMD, Jones AA, editors. Shelf Life Evaluation of Foods. London: Blackie Academic and Professionals; 1994. pp. 3-26.
3. Barry-Ryan C, O'Beirne D. Quality and shelf life of fresh cut slices as affected by slicing method. *Journal of food science* 1998;63:851-856.

4. Carlin F, Nguyen-the C, Cudennec P, Reich M. Microbiological spoilage of ready-to-use grated carrots. *Sci Alim.* 1989;9:371-386.
5. Willocx F, Hendrickx M, Tobback P. The Influence of Temperature and Gas Composition on the Evolution of Microbial and Visual Quality of Minimally Processed Endive. In: *Minimally Processing of Foods and Process Optimization: An Interface.* Singh RP, Oliveira, FAR, editors. Boca Raton, USA: CRC Press; 1994. pp. 475-492.
6. Garg N, Churey JJ, Splittstoesser DF. Effect of processing conditions on the microflora of fresh cut vegetables. *J Food Prot.* 1990;53:701-703.
7. Marchetti R, Casadei MA, Guerzoni ME. 'Microbial Population Dynamics in Ready-to-use Vegetable Salads' in Italy. *Food Sci.* 1992;2:97-108.
8. Singh RP, Anderson BA, The major types of food spoilage: an overview. In: Steele R, editor. *Understanding and Measuring the Shelf-Life of Food.* CRC Press LLC; 2004. pp. 3-23. doi:10.1533/9781855739024.1.3
9. Nguyen-the C., Carlin F. The microbiology of minimally processed fresh fruits and vegetables. *Crit Rev Food Sci Nutr.* 1994;34:371-401
10. Fro der H, Martins CG, De Souza KL, Landgraf M, Franco BD, Destro MT. Minimally processed vegetable salads: microbial quality evaluation. *J Food Prot.* 2007;70:1277–1280
11. Izumi H, Watada AE, Ko NP, Douglas W. Controlled atmosphere storage of carrot slices, sticks and shreds. *Postharvest Biol and Technol.* 1996;9:165-172.

12. Manzano M, Citterio B, Maifreni M, Paganessi M, Comi C. Microbial and Sensory Quality of Vegetables for Soup Packaged in Different Atmospheres. *Sci Food Agric*. 1995;67:521-529.
13. Jacxsens L, Devlieghere F, Debevere J. Temperature dependence of shelf-life as affected by microbial proliferation and sensory quality of equilibrium modified atmosphere packaged fresh produce. *Postharvest Biology and Technology*. 2002;26:59–73
14. Plazzotta S, Manzocco L, Nicoli MC. Fruit and vegetable waste management and the challenge of fresh-cut salad. *Trends in Food Science & Technology*. 2017;63:51-59
15. Arvanitoyannis I, Varzakas T. Vegetable Waste Management: Treatment Methods and Potential Uses of Treated Waste. In: Arvanitoyannis I, editor. *Waste Management for the Food Industries. A volume in Food Science and Technology*. Elsevier Academic Press; 2008. p.p. 703-761. ISBN: 978-0-12-373654-3
16. San Martin D, Ramos S, Zufía J. Valorisation of food waste to produce new raw materials for animal feed. *Food Chemistry*. 2016;198:68-74. doi: 10.1016/j.foodchem.2015.11.035
17. Ansorena MR, Goñi MG, Aguëro MV, Roura SI, Di Scala KC. Application of the General Stability Index method to assess the quality of butter lettuce during postharvest storage using a multi-quality indices analysis. *Journal of Food Engineering*. 2009;92:317–323
18. Giovenzana V, Beghi R, Buratti S, Civelli R, Guidetti R. Monitoring of fresh-cut *Valerianella locusta* Laterr. Shelf life by electronic nose and VIS–NIR spectroscopy. *Talanta*. 2014;120:368–375

19. Malakar PK, Brocklehurst TF, Mackie AR, Wilson PDG, Zwietering MH, van't Riet K. Microgradients in bacterial colonies: use of fluorescence ratio imaging, a non-invasive technique. *International Journal of Food Microbiology*. 2000;56:71-80.
20. Nicoli MC. *Shelf Life Assessment of Food*. CRC Press; 2016. ISBN 9781138199347
21. Mitchell DA, von Meien OF, Krieger N, Dalsenter FDH. A review of recent developments in modelling of microbial growth kinetics and intraparticle phenomena in solid-state fermentation. *Biochemical Engineering Journal*. 2004;17:15-26.
22. Boe I, Lovrien R. Cell counting and carbon utilization velocities via microbial calorimetry. *Biotechnology and Bioengineering*. 1990;35:1-7.
23. Menert A, Liiders M, Kurisoo T, Vilu R. Microcalorimetric monitoring of anaerobic digestion processes. *Journal of Thermal Analysis and Calorimetry*. 2001;64:281-291.
24. Wadsö L, Galindo FG. Isothermal calorimetry for biological applications in food science and technology. *Food Control*. 2009;20:956-961.
25. Braissant O, Wirz D, Goepfert B, Daniels AU. Use of isothermal microcalorimetry to monitor microbial activities. *FEMS Microbiology Letters*. 2010;303:1-8.
26. Mihhalevski A, Sarand I, Viiard E, Salumets A, Paalme T. Growth characterization of individual rye sourdough bacteria by isothermal microcalorimetry. *Journal of Applied Microbiology*. 2011;110: 529-540.

27. Riva M, Fessas D, Schiraldi A. Isothermal calorimetry approach to evaluate shelf life of foods. *Thermochimica Acta*. 2001;370:73-81.
28. Wilson RDG, Brocklehurst TF, Arino S, Thuault D, Jakobsen M, Lange M, Farkas J, Wimpenny JWT, van Impe JF. Modelling microbial growth in structured foods: towards a unified approach. *International Journal of Food Microbiology* 2002;73:275-289.
29. Antwi M, Geeraerd AH, Vereecken KM, Jenne R, Bernaerts K, Van Impe JF. Influence of a gel microstructure as modified by gelatin concentration on *Listeria innocua* growth. *Innovative Food Science and Emerging Technologies*. 2006;7:124-131.
30. Lago N, Legido JL, Paz Andrade MI, Arias I, Casas LM. Microcalorimetric study on the growth and metabolism of *Pseudomonas aeruginosa*. *Journal of Thermal Analysis and Calorimetry*. 2011; 105:651-655.
31. Liu J-S, Marison IW, von Stockar U. Anaerobic calorimetry of the growth of *Lactobacillus helveticus* using a highly sensitive BIO-RCI. *Journal of Thermal Analysis and Calorimetry*. 1999;56: 1191-1195.
32. Stulova I, Kabanova N, Kriščiunaite T, Laht T-M, Vilu R. The effect of milk heat treatment on the growth characteristics of lactic acid bacteria. *Agronomy Research*. 2011;9:473-478.
33. Pu S, Ma Z, Wang Q. Anti-*Staphylococcus aureus* evaluation of gallic acid by isothermal microcalorimetry and principle component analysis. *Journal of Thermal Analysis and Calorimetry*. Published on line 2018; <https://doi.org/10.1007/s10973-018-7726-5>

34. Vazquez C, Lago N, Mato MM, Esarte L, Legido JL. Study of the growth of *Enterococcus faecalis*, *Escherichia coli* and their mixtures by microcalorimetry. *J Therm Anal Calorim.* 2016;125:739–744; DOI 10.1007/s10973-015-5203-y
35. Jiangbing Xu J, Feng Y, Barros N, Zhong L, Chen R, Lin X. Exploring the potential of microcalorimetry to study soil microbial metabolic diversity. *J Therm Anal Calorim.* 2017;127:1457–1465; DOI 10.1007/s10973-016-5952-2
36. Yao J, Wang F, Tian L, Zhou Y, Chen HL, Chen K, Gai N, Zhuang RS, Maskow T, Ceccanti B, Zaray G. Studying the toxic effect of cadmium and hexavalent chromium on microbial activity of a soil and pure microbe. A microcalorimetric method. *J Therm Anal Calorim.* 2009;95:517–524
37. Gardikis K, Signorelli M, Ferrario M, Schiraldi A, Fortina MG, Hatziantoniou S, Demetzos C, Fessas D. Microbial biosensors to monitor the encapsulation effectiveness of Doxorubicin in chimeric advanced Drug Delivery Nano Systems: A calorimetric approach. *International Journal of Pharmaceutics.* 2017;516:178–184.
38. Perry BF, Beezer AE, Miles HJV. Flow microcalorimetry studies of yeast growth: fundamental aspects. *J Appl Bacteriol.* 1979;47:527-537.
39. Schiraldi A. Microbial growth and metabolism: Modelling and calorimetric characterization. *Pure Appl Chem.* 1995;67:1873-1878.
40. Singh G, Kawatra A, Sehgal S. Nutritional composition of selected green leafy vegetables, herbs and carrots. *Plant Foods for Human Nutrition.* 2001;56:359-364.

41. R.M. Atlas. Handbook of Microbiological Media. 3rd ed. Boca Raton, FL: CRC Press, Inc.; 2004. ISBN 0-8493-1818-1
42. Fessas D, Schiraldi A. Isothermal calorimetry and microbial growth: beyond modeling. *J Therm Anal Calorim.* 2017;130: 567–572; doi: 10.1007/s10973-017-6515-x.
43. Franzetti L, Galli A. Microbial quality indicators of minimally processed stick carrots. *Ann Microbiol Enzimol.* 1999;49:137–144.
44. Zwietering, M.H. Jongenburger I., Rombouts F M., and Van 't riet K. Modelling of the bacterial growth curve. *Appl Envir Microbiology.* 1990;56:875-1881.
45. Surjadinata BB, Cisneros-Zevallos L. Modelling wound induced respiration of fresh cut carrots (*Daucus carota* L.). *Food Engineering and Physical Properties.* 2003;68:2735-2740.
46. Barry-Ryan C, O'Beirne D. Effects of peeling methods on the quality of ready-to-use carrot slices. *Journal of Food Science Technology.* 2000;35:243–254.
47. Buick RK, Damoglou AP. The effect of vacuum packaging on the microbial spoilage and shelf-life of ready-to-use sliced carrots. *J Sci Food Agri.* 1987;38:167-175.
48. Varoquaux, P., Wiley, R.C. Biological and Biochemical Changes in Minimally Processed Refrigerated Fruits and Vegetables. In: Willey RC, editor. *Minimally Processed Refrigerated Fruits and Vegetables.* New York, USA: Chapman & Hall; 1994. pp. 226-268.
49. Ferrante A, Martinetti L, Maggiore T. Biochemical changes in cut vs. intact lamb's lettuce (*Valerianella olitoria*) leaves during storage. *Int J Food Sci Technol.* 2009;44:1050–1056

50. Negi PS, Handa AK. Structural deterioration of the produce: the breakdown of cell wall components. In: Paliyath G, Murr DP, Handa AK, Lurie S, editors. Postharvest biology and technology of fruits, vegetables, and flowers. 1st ed. Usa: Wiley- Blackwell. 2008. pp.162-194. ISBN 978-0-8138-0408-8/2008
51. Swinnen IAM, Bernaerts K, Gysemans K, van Impe JF. Quantifying microbial lag phenomena due to a sudden rise in temperature: a systematic macroscopic study. *International Journal of Food Microbiology*. 2005;100:85-96.
52. Wang G, Mayes MA, Gu L, Schadt CW. Representation of Dormant and Active Microbial Dynamics for Ecosystem Modeling. *PLoS ONE*. 2014;9: e89252; doi:10.1371/journal.pone.0089252
53. De Giusti M, Aurigemma C, Marinelli L, Tufi D, De Medici D, Di Pasquale S, De Vito C, Boccia A. The evaluation of microbiological safety of fresh ready-to-eat vegetables produced by different technologies in Italy. *J Applied Microbiol*. 2010;109:996–1006
54. Lavelli, V., Pagliarini, E., Ambrosoli, R., Minati, JL, Zanoni, B. Physicochemical, microbial, and sensory parameters as indices to evaluate the quality of minimally processed carrots. *Postharvest Biol Technol*. 2006;40:34–40.
55. Ferrante A, Maggiore T. Chlorophyll a fluorescence measurements to evaluate storage time and temperature of Valeriana leafy vegetables. *Postharvest Biol Technol*. 2007;45:73–80
56. Ferrante A, Incrocci L, Maggini R, Serra G, Tognoni F. Colour changes of fresh-cut leafy vegetables during storage. *J Food Agric Environ*. 2004;2:40–44

57. Abadias M, Usall J, Anguera M, Solsona C. Microbiological quality of fresh, minimally-processed fruit and vegetables, and sprouts from retail. *Int J Food Microbiol.* 2008;123:121-129.

58. Caldera L., Franzetti L. Effect of storage temperature on the microbial composition of ready-to-use vegetables. *Curr Microbiol.* 2014;68:133–139.

Figure Captions

Fig. 1 In figure are reported (right side) the raw exothermic IC traces obtained from two liquid (5ml) samples of cultures of *P. fluorescens* with starting population at about 600 CFU/mL, in TSB medium (thin continuous line) and in carrot juice at pH 7 (bold continues line). Corresponding parallel microbiological plate counts are also reported (left side, thin and bold dashed lines for TSB and carrot juice respectively). In the circles the calibration signals (0.1 mW for 1200 s) are also reported

Fig. 2 Normalized IC records (exothermic) from carrots with different cut treatment (a: “Julienne”, b: sticks: c: cylinders)

Fig. 3 IC thermogram (exothermic, bold line) obtained at 10°C from fresh green salad sample. Corresponding parallel microbiological plate counts (TBC) are also reported (full triangles)

Fig. 4 IC traces at 30°C from salad samples that had been stored at 10 °C for 4, 7, 9, 11 and 14 days

Fig. 5 HF initial slope obtained from the thermograms presented in fig. 4 vs storage time