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An experimental investigation of the composting process in an innovative home composting System: The influence of additives

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A B S T R A C T

Food-waste out of household consumption ends up in landfills resulting into huge waste of materials and energy enhancing greenhouse effect and threatening water supplies. Composting is common solution for solid organic waste management and can safely and effectively be employed in each household to produce quality compost materials. This study palpates the average composition of the Mediterranean dietary pattern food-wastes and investigates the efficiency of a novel home-composter in managing organic wastes from dish to composter to quality compost. Four different additives, low cost and easily found in the market, are addressed, (1) woodchip, (2) woodchips & zeolite, (3) woodchips & vermiculite and (4) perlite. C/N≈20 substrate's composition is investigated.

Results indicate that the composting process effectively converts food-wastes to compost within 21 days. The monitored parameters show good aeration and humidity levels of the substrate and an aerobic process. The product exhibits minor alkalinity and requires further maturing. Mineral additives help reducing TOC with vermiculite and perlite be the most promising. Zeolite and vermiculite result in higher TKN values of the product with zeolite exhibiting better performance. All minerals enchance C/N reduction when woodchips is proven inadequate as an additive if employed alone. The product can safely be used in domestic applications.

Introduction

>1.3 billion tons of food-waste are annually generated along the food chain, from agriculture to final consumption, with the highest percentage at household consumption (61%) (UN - Think, Eat, Save). They deluge the landfills and result into huge waste of materials and energy, a potential source of greenhouse gases (6% of anthropogenic greenhouse emissions) and a hazardous threat to surface and groundwater (Amicarelli et al., 2021; Ma et al., 2022; Manfredi et al., 2010; Sanjuan-Delmás et al., 2021; United Nations, 2020). This impact has been addressed by the European "Farm to Fork Strategy", aiming to reduce environmental threads, pursue food security, nutrition and public health, access to healthy, nutritious and sustainable food, and mitigate climate change via a fair and environmentally friendly food system (European Comission, 2020). Thus, food waste represents a social, financial and environmental concern, and reduction of the stream of garbage directed to dumpsites or landfills, redirecting most of its volume to the manufacturing of auspicious products, becomes of great importance to the road of a sustainable future. On top of that, scouting for innovative recycling solutions can support the low-income countries to reduce uncontrolled waste disposal and approach a recycling and circular bioeconomy.

An essential alternative, especially for regions where biowaste is intensely generated at domestic level, is undoubtedly the production of compost. Usually, particularly in low- and mid-income countries, municipal solid waste contains significant amounts of organics (50%), yet reduction of biowaste is taken lightly; small-scale compost technologies become of great importance there (Sasson and Malpica, 2018). In developing regions, home composting mitigates organic waste generation problems, actively involving local communities (Sandoval Duarte et al., 2020). In the developed world, reduction of organic waste (60% of urban) had become one of the paramount policies (Katinas et al., 2019; Phu et al., 2021).

Composting is common solution for solid organic waste management, due to cost-efficiency and nutrient-rich products (Phu et al., 2021); most common large-scale application is the Advanced Mechanical-Biological Treatment producing compost-like-outputs (CLO) and digestates (DGT). Both products are suitable sources of

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organic matter, potentially useful for amendments and fulfilling the principles of circular economy. Yet, due to great variability of sources of organic waste feed, large-scale systems' CLO products exhibit great heterogeneity in physicochemical properties, which becomes a constraint in agricultural applications (Carabassa et al., 2020).

When it comes to food waste and municipal organic waste (e.g., from gardens) collection, even in developed countries like Germany, where reduction of organic waste had become a policy of paramount importance and separate collection is mandatory since 2015, a lot of households are still not served with separated collection for the bio-bin (Sanjuan-Delmás et al., 2021). The problem becomes striking in mid- and low-income countries, where recovery rate of municipal organic solid waste is just a fraction of the generated; most of those countries have no national strategy to address sustainable management of biowaste. Same is the situation in Greece (Margaritis et al., 2018).

To mitigate the hardships of separate collection and recovery of food waste, home composting is considered a viable, sustainable alternative for household biowaste treatment. Household composting results in high-quality compost, as food waste and other bio-subproducts are separated first-handedly, at source, and treated and valorized in situ. The biowaste comes never in contact with other garbage that may contaminate it (Margaritis et al., 2018; Phu et al., 2021; Sasson and Malpica, 2018). Moreover, home composting and direct application of the product results into enhancing the soil quality at the locale, effectively diverting biowaste from landfills (Li et al., 2013). It also presents a reliable alternative for low-populated urban or rural areas, where costs of collection and transportation of separate waste-streams to central treatment facilities become a deterrent factor (Martínez-Blanco et al., 2010; Tatàno et al., 2015).

However, there are a few disadvantages regarding home composting processes. The finished product may greatly vary in composition, or be quite heterogeneous. Also, biological degradation may yield undesirable odors discouraging people from installing home-composters and employing home-composting processes. The gaseous pollutants produced during the process pose another substantial hindrance (Madrini et al., 2016). Emissions may vary from methane to ammonia and nitrous oxide, gases that contribute to the greenhouse effect (Amlinger et al., 2008; Ansorena, 2008; Martínez-Blanco et al., 2010).

Successful implementation and process's efficiency depend on a variety of factors, including the characteristics of the initial substrate, ventilation conditions, diffusion of oxygen, porosity, size, structure and texture of the substrate particles, etc (Environment Agency, 2001; Margaritis et al., 2018), which are not readily understood and fluently handled by the public. That is one of the chief reasons that, although several studies have been conducted to address the optimization of the composting process (Andraskar et al., 2021; Gabhane et al., 2012; Kurola et al., 2011; Li et al., 2012; Li et al., 2022; Pottipati et al., 2022; Song et al., 2021; Soudejani et al., 2019; Tabrika et al., 2021; Villaseñor et al., 2011; Zambrano et al., 2010), very few of them palpate the composting of kitchen waste substrates in small-scale household systems (Adhikari et al., 2010; Cox et al., 2010; Gao et al., 2022).

Control of physical properties of the substrate is usually carried out through pre-treatment, like crushing, cutting and granulation, and by addition of suitable bulking agents. Pre-treatment of food-waste requires no particular training and can be performed by any adult individual. Yet, adequate use of bulking agents, calls for a certain level of knowledge and training (Gao et al., 2022; Iqbal et al., 2010; Mohammad et al., 2021). Moving around this obstacle requires the determination of the potential food-waste composition range and the meticulous investigation of the process's performance in variable substrate compositions and C/N ratios in that range, for a selection of adequate additives.

The auspicious aim of this study is the examination of the performance of a novel home-composter designed and constructed by our team (Margaritis et al., 2018), the determination of an optimal bulking agent, and a record of "how to" directions, that would allow employment of the system in households, by untrained individuals. The study takes place and refers to Greek households and climate profiles.

Potential food-waste composition: Selection of model substrates.

Physicochemical properties and composition of different households' food-waste varies and/or changes with time. Identification of the ranges where each of the controlling factors of the composting process takes values is necessary to optimize and demonstrate the efficiency and viability of an undiversified home-composting unit, because composition and properties of the inlet pre-defines the physical, chemical and biological environment in the composter and throughout the ensuing process. Decomposition rate and product quality highly depend on the selection of biodegradable household solids that feed the composter.

The variation and statistics of composition and physicochemical properties (e.g., moisture, pH, TOC, TKN and conductivity) of the initial substrate can be deduced from the corresponding properties of certain types of foods that usually end up in a typical Greek household bin, which can be experimentally determined (Table 1). Apparently, pulses present high pH values, while the peel of citrus fruits demonstrate a low pH. High moisture content is observed in foods rich of natural fibers. Foods with high carbohydrate content exhibit low moisture. All food types are found rich in carbon. A significant variation of nitrous content is found between the different types of food; those rich in natural fibers present a low nitrous content while nourishments high in proteins are two to five times richer in nitrogen.

The C/N ratio of certain types of food is evaluated from the data in Table 1. It varies, approximately, from 5 to 28. C/N ratio is one of the key parameters of the composting process; availability of nutrients for microbial growth depends entirely on its value. All other required nutrients are met in sufficient quantities in almost all biodegradable solid wastes. It should be noted that food-waste collected at source is considered free of heavy metals, as it was meticulously prepared for consumption and is taken directly from dish to composter.

Following the establishment of the properties of the different kinds of food consumed in a typical household, food-wastes of those are mingled in various ratios producing a variety of potential substrates (Table 2) with diversified natural fiber, proteinic and carbon-hydrate content. Particular quantities were mixed considering the Mediterranean dietary pattern and the physical properties of the ingredients, to produce the model substrates required for the study. Their physical properties were again experimentally determined (Table 2). They were found in accordance to the weight average value determined by the respective values of the food-wastes (Table 1) it contained. Foods were sliced and diced in particles of dimensions between 2 and 4 cm and blended to a relatively uniform mixture.

In view of the final properties of the potential substrates and according to the average diet of Mediterranean residents (We Are What We Eat, 2015), one can safely assume that the average C/N ratio in food-waste of Mediterranean households falls between 20 and 40. Thus, of the model substrates (Table 2) prepared and assessed for the

Table 1
Physicochemical properties of a variety of foods that end up in the Greek waste bin.

Food	pH	Conductivity (mS/cm)	Moisture (%)	TOC (%)	TKN (%)	C/N
Lettuce	6.22	1.63	89.62	34.20	4.48	7.63
Spinach	6.27	1.14	88.43	34.70	4.16	8.34
Rice	6.70	0.13	61.35	44.12	4.55	9.70
Chick-peas	6.86	0.82	64.20	42.80	8.21	5.21
Beans	6.87	1.04	67.30	45.20	8.73	5.18
Bread	5.64	5.69	22.29	46.40	5.34	8.69
Potato	6.61	1.47	79.09	42.07	4.87	8.64
Orange	4.06	0.86	75.89	45.78	3.27	14.00
Lemon	2.87	1.69	81.90	44.80	2.15	20.84
Banana	5.99	3.34	90.58	46.26	1.66	27.87
Coffee	6.2	1.53	61.18	43.43	1.87	23.22

Table 2
Typical substrates coming of household food-wastes and their physicochemical properties.

No	SUBSTRATE COMPOSITION (NF / Prot / CH)	Moisture (%)	pH	% $C_{organic}$	% TKN	C/N
A	4: 0.5: 0.5	78.8	6.2	51.6	1.38	37.4
B	3: 1: 1	69.8	6	47.8	1.53	31.2
C	2: 1: 2	59.8	5.8	45.2	1.28	35.3
D	2: 2: 1	64.2	6.8	44.2	1.63	27.1
E	2.5: 1.5: 1	73.8	5.2	44.7	1.92	23.3

NF: Natural fibers content, Prot: Proteinic content, CH Carbon-hydrate content.

optimization and demonstration of the home composting process, A, B and E are chosen for exhibiting C/N ratio close to the edges and in the middle of this range.

A comprehensive study of the composting process at C/N = 30 has been the subject of a previous work (Margaritis et al., 2018), which investigated the efficiency of an ordinary household in self-managing its kitchen waste to produce high quality compost, implementing our team's small-scale, innovative composting system and low-cost, easily found in the market, additive materials. There it has been established that the time required for completion of the process is 18–20 days, while initial ratio of C/N = 30 yielded a satisfactory progress. Additives like zeolite, vermiculite and perlite, improved the physical properties of the substrate allowing for better aeration and moisture control, without interfering with the biodegradation processes.

The present study examines the progress and efficiency of the composting process with model substrates of C/N = 20, which is the lowest value observed in household wastes, at the Mediterranean region.

Materials and methods

Household-scale composting unit

A detailed description of the prototype household-scale composter is given elsewhere (Margaritis et al., 2018; Papadopoulos et al., 2009). It is a closed type fed-batch bioreactor. Input of the feed and mechanical mixing/stirring are performed by hand. System's capacity is 60 Ls/week. The bioreactor consists of four individual and segregated compartments: (i) a feeding compartment, (ii) a composting process compartment, (iii) a compartment for collection and removal of the compost and (iv) a compartment for collection and removal of the produced leachate.

Four prototype composters were employed simultaneously to conduct four experiments with the same substrate but different additives. The process was monitored and evaluated.

Substrate

The substrate comprised of biowaste separated at source and collected from households of Kifissia Municipality, Attika, Greece. Raw biowaste materials were shredded to fragments of 3 to 4 cm, to improve the implementation of the composting process. The employed additives were zeolite, vermiculite, perlite and wood chips. Natural zeolite, vermiculite and perlite were commercially acquired. Wood chips were supplied by local carpenters, derived from natural wood and were free of chemicals. Synthetic wood (e.g., MDF, melamine, etc.) is not considered suitable as it contains chemicals. In fact, all industrial products of wood interfere with the composting process, inhibiting the microbial growth or deteriorating the quality of the end-products, rendering them unsafe for applications like soil enhancement, or fertilization as they may contain a variety of toxic substances like urea, formaldehyde, phenol formaldehyde etc. (Ntalos and Tsanaktsis, 2014).

Zeolite is a promising additive, as its affinity with ammonium ions, which bind on its active sites, makes easy their absorption and removal from the substrate. It is also capable of removing heavy metals, in the rare occasion food-waste had been contaminated by conduct.

Perlite and vermiculite modify the porosity of the substrate increasing the air pockets between the biowaste particles, aiding air diffusivity and bettering aeration. They thus favor aerobic treatment and improve the temperature profile, though the actual minerals do not actively participate in the process (Margaritis et al., 2018). All those minerals, and the wood chips, have a low-cost and can be found in the local markets. They are easily handled by untrained individuals and present no threat to them.

Selection of additives

Four different experiments in four different reactors consist the parametric study of additives. The first one palpates the physical properties of the substrate and woodchips are added alone, as they can increase the porosity and thus enchance aeration of the substrate and ensure aerobic conditions. The second and the third one addresses simultaneous physical and physicochemical properties enhancement by employment of two additives: woodchips for better aeration (physical) and a mineral additive to enchance the physicochemical properties through its ion exchange properties. Both zeolite and vermiculite are capable of absorbing NH_4^+ ions, thus improve the development of the process. Last, perlite is a light mineral that can enchance both the physical and physicochemical properties of the substrate. It is considered a promising additive and thus its relative effectiveness against zeolite and vermiculite is investigated.

Experimental and monitoring

The critical volume – an 80% load (Margaritis et al., 2018) is required to start up the composting process – consisted of the adequate quantities of household food-waste that produce the necessary 2.5:1.5:1 ratio in the substrate and a sufficient, not excessive, quantity of the studied in each reactor additive(s). Thus, each of the reactors was loaded with 10Kg of food-wastes (with the necessary composition) and 1Kg of each additive (10% w/w of the biowastes' mass), with respect of the experiment (Table 3). Loading scheme is carried out in three batches of feed, the initial 80% required for the startup, then a second batch of 10% at the end of the day, as during the first stages the reaction is too vigorous and the substrate's volume is quickly reduced, and a third one at the end of the second day.

The mixture of food-wastes was prepared to exhibit an initial C/N ratio close to 20 according to (Eq. (1)) (Rynk et al., 1992);

$$\frac{C}{N} = \frac{Q_1(C_1 \times (100 - M_1)) + Q_2(C_2 \times (100 - M_2)) + \cdots}{Q_1(N_1 \times (100 - M_1)) + Q_2(N_2 \times (100 - M_2)) + \cdots} \tag{1}$$

where Q_n is the mass (wet weight), C_n is the % percentage of carbon, N_n is the % percentage of nitrogen and M_n is the % moisture content of material n, respectively.

Four batch experiments were simultaneously initiated in the four, identical, bioreactors and the composting cycles were concluded after 21 days (residence time), for all the reactors. Initial properties of the substrate can be found in Table 2.

A number of parameters that govern the composting process, several physical, chemical and biological parameters as well, were monitored. The last were determined by direct sampling and immediate sample analysis. A summary of the monitor parameters, the stage of the process the sample was recovered and the method of measurement are presented in Table 4. Samples were recovered from the feed (when applicable), the substrate within the reactor and the final product (compost), in a daily routine during at the first 11 days (days 1 to 11th), to capture and evaluate the vigorous evolution profile of the initial composting stages. Then, sampling rate was decreased and samples were taken and analyzed only in days 15th, 18th and, finally, the 21st and last day of the experiment.

Table 3
Reactors' loading mixture and composition.

Reactor	Day	Lettuce	Spinach	Orange	Lemon	Chick peas	Beans	Bread	Woodchips	Zeolite	Vermiculite	Perlite	Sum	Total mass
1	1	2000	2000	500	500	1500	1500	2000	1000				11,000	
	1	400	400	100	100	300	300	400	200				2200	15,400
	2	400	400	100	100	300	300	400	200				2200	
2	1	2000	2000	500	500	1500	1500	2000	1000	1000			12,000	
	1	400	400	100	100	300	300	400	200	200				168,000
	2	400	400	100	100	300	300	400	200	200			2400	
3	1	2000	2000	500	500	1500	1500	2000	1000		1000		12,000	
	1	400	400	100	100	300	300	400	200		200		2400	16,800
	2	400	400	100	100	300	300	400	200		200		2400	
4	1	2000	2000	500	500	1500	1500	2000				1000	11,000	
	1	400	400	100	100	300	300	400				200	2200	15,400
	2	400	400	100	100	300	300	400				200	2200	

Table 4
Monitored physicochemical & biological parameters. Standard measurement methods employed.

Parameter	*Measurement instrument/ method*	*Unit*	Initial mixture of raw biomass	Substrate from bioreactor	Final product
Temperature	Digital thermometer Greisinger P410-200 + 1150	°C	√	√	√
Conductivity (dilution 1/5)	EPA 9050A	ms•cm^{-1}	√	√	√
Moisture	ISO 11465:1993	% wb	√	√	√
pH (dilution 1/5)	EPA 9045D	–	√	√	√
Volatile solids (Loss on Ignition)	TMECC Method 05.07	% dm	√	√	√
TOC	EN 13137:2002 & ISO 11465:1993	% dm	√	√	√
N-TKN	ISO 11261:1995 & ISO 11465:1993	% dm	√	√	√
N-NH_4^+	EPA 350. 1–3	mg•Kg^{-1}		√	√
N-NO_3^-	ISO 11261:1995 & ISO 11465:1993	mg•Kg^{-1}		√	√
Norg	Calculation through the determination of TN, NH_4^+, NO_3^-	% TN		√	√
C/N	Calculation through the determination of TN and TOC		√	√	√

Samples were taken simultaneously from the top, medium and bottom of the compost heap and the recovered mater was mixed, composing a sample representative of the substrate of each reactor. Then the four respective samples were dried, shredded and homogenized. Each sample was split into three portions; each portion was measured independently to improve the accuracy of the measurement; data analysis was carried out by the average of the measured values. The mass of each sample taken was about 0.120Kg, totaling to 1.4Kg extracted from each bioreactor, respectively. It is assumed that sampling did not interfere with the process.

Results and discussion

The following comparative diagrams present all the monitored parameters throughout the composting process, versus time, with respect to the additive, in all four bioreactors. The temperature profiles and the evolution of humidity, pH, conductivity and volatile solids are shown in

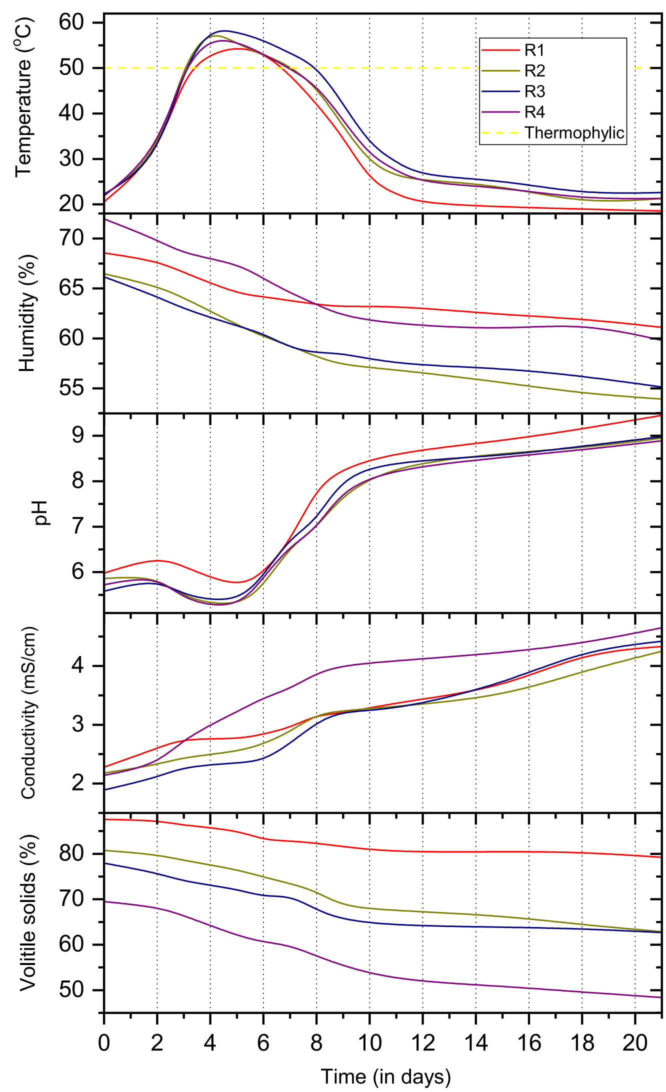

Fig. 1. Temperature, Humidity, pH, Conductivity and Volatile solids kinetics during composting process and the effect of additives on their evolution. Additives: R1 – wood chips, R2 – Zeolite & wood chips, R3 – Vermiculite & wood chips, R4 – Perlite.

Fig. 1, while Fig. 2 depicts the evolution of the total organic content (TOC), the total nitrogen content (Kjeldahl), the C/N ratio as well as the concentrations of NO_3 and NH_3.

Evolution temperature

The temperature of the substrate is an index of the microbial activity and of the final product's stability. Initially the composting process is undergoing a mesophilic phase (<40 °C), in which the soluble and easily degradable organic compounds are fractured rapidly (Manios, 2004). This mesophile microbial activity releases significant amounts of heat and the temperature of the substrate rises rapidly – compost withholds the better of the produced heat –exceeding the boundary of 40 °C past the second day, for all four studies (Fig. 1). At that temperature the thermophile microorganisms win competitiveness against the mesophile ones, become the dominant species and succeed them. Temperature keeps rising and on day 3 it exceeds 50°C, which is the upper boundary of the thermophile phase. Then the temperature curve starts leveling off as the rate of heat production drops. The rate of degradation remains high for a period of 4 days, namely 3rd to 7th day for R1, R2 and R4 and 3rd to 8th for R3; the produced heat results in temperatures between 50 and 60 °C. Maximum temperature is reached during day 4 of operation, for all reactors. Afterwards, temperature gradually decreases and during the 9th day of the process a second mesophilic phase (maturing phase) appears. Past day 12, temperature decreasing levels off as temperature approaches the environmental conditions, indicating a phase of low decomposition rate of the remaining organic matter.

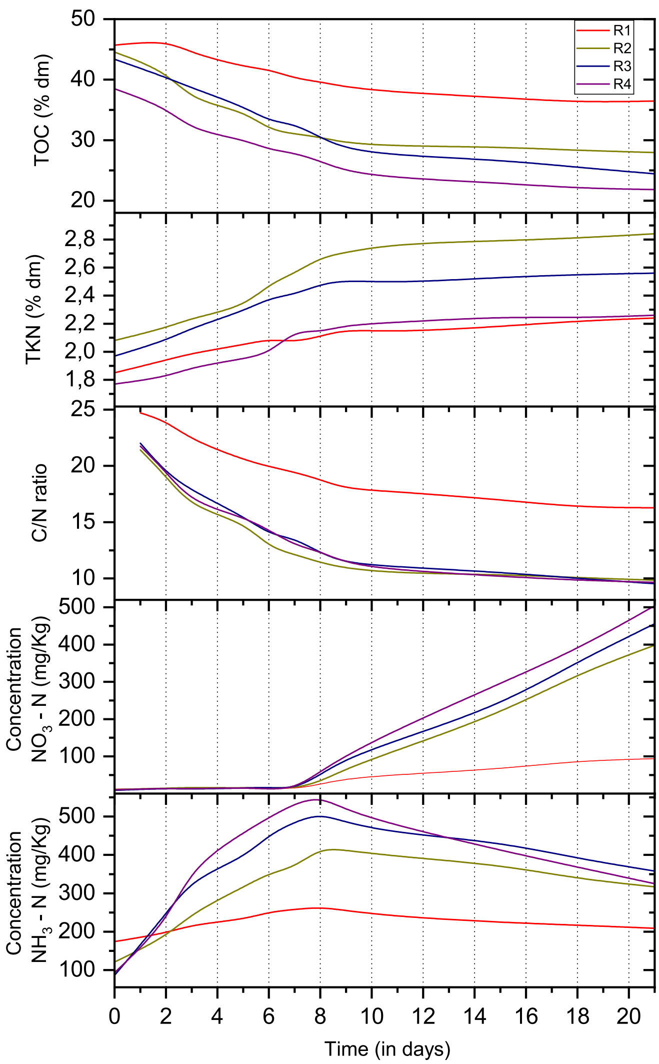

Fig. 2. TOC, TKN, C/N ratio and concentration of NO_3 and NH_3 kinetics during composting process and the effect of additives on their evolution. Additives: R1 – wood chips, R2 – Zeolite & wood chips, R3 – Vermiculite & wood chips, R4 – Perlite.

Where the additive was woodchips only (R1), maximum observed temperature was 54.72 °C. Thermophile phase was less rigorous than with mineral additives, resulting in a smoother and lower overshot above 50 °C. Here thermophile phase ended earlier than in any other study. Zeolite and woodchips together (R2) exhibited the most rigorous thermophile phase and the sharper overshot profile. Maximum observed temperature was 58.64 °C, followed by a quick drop off and a subsequent smoother approach of the 50° boundary. Thermophile's phase profile shows that the process is more rigorous than with woodchips alone and so 2nd mesophile phase is reached about 10 h later. Same are the findings concerning Perlite without woodchips (R4). The sole difference with previous (R2) is that the thermophile case begins less vigorously resulting in a smoother overshot and a maximum observed temperature of 56.57 °C; otherwise R2 and R4 present similar temperature profiles. The most rigorous thermophile phase was observed with Vermiculite and woodchips (R3). The overshoot followed the sharp incline of R2, exhibiting a maximum temperature of 58.64 °C, then a subsequent slow decline towards the boundary of 50°. Thermophile phase ended later than any other case; a day later than R1. Then the maturing phase proceeded smoothly and similarly to all other studies.

The higher temperature profiles exhibited with mineral additives concurs with the enhancement of the substrates' aeration due to the presence of minerals. Woodchips are found not to improving equally the aeration conditions, as they do not affect the porosity significantly. Yet, in all four cases, temperature remained high for an adequate period of time to eliminate any pathogens present in the food-waste.

Evolution of humidity

Substrate's content of moisture is considered a parameter of significant importance for the composting process. Low moisture content (35–40%) and premature dehydration hinders the biological processes, while values below 30% eliminate them. Excessive amount of water (>65%) usually leads to anaerobic conditions, as presence of water lessens porosity (Lasaridi et al., 2006; Tiquia and Richard, 2002). Optimal moisture content values are considered those in the range of 45% to 65%. Fig. 1 presents a comparison of the moisture content of the substrate, with respect of the additive, versus composting time.

At startup, all cases exhibited a moisture content exceeding the upper optimal boundary of 65%, due to the nature of the food-waste feed. It is well established that, household food waste fraction of MSW, in South European countries, exhibits high moisture contents, up to 70% or more, as the usual food wastes there, come from fruits and vegetables (Boldrin et al., 2010; Lasaridi et al., 2006; Malamis et al., 2017; Margaritis et al., 2018). To attemper the impact of high moisture levels in the composting process, regular manual aeration (3 times/day) was performed during the first 10 days of the 21-days composting cycle in order to provide with adequate oxygen levels and allow for aerobic evolution of the process. Then, high initial rates of temperature increase and persistence of high temperature values (>50 °C) during the thermophile phase may also partly be attributed to excess aeration of the substrate. High temperatures allow for high evaporation rates and at the end of that phase (9th day) moisture content in all cases dropped below 65%; below that limit aerobic metabolism governs the composting process.

The highest initial moisture level (71.96%) was observed in R4. No woodchips were added in that bioreactor; only perlite was employed in that study. Conversely, R1 (only woodchips) also exhibited an initial moisture level (68.56%) higher that in cases R2 and R3 (66.48% and 66.15% respectively), where both woodchips and mineral, zeolite or vermiculite, respectively, were used. Consequently, zeolite and vermiculite seem to absorb a portion of the moisture but woodchips and perlite were unable to reduce the moisture level of the substrate. Yet, the increase of the substrates' porosity, due to the additives, improved aeration staving off the establishment of anaerobic conditions. In addition, the higher moisture declining rates depicted in Fig. 1 for the cases of mineral additives (R2, R3, R4), in contrast to R1, indicates that adding minerals to the substrate results in higher porosity, better aeration and thus a sharper moisture drop off, which also concurs to the higher heat rates and temperatures observed in those cases.

During the second mesophilic phase and throughout the final stages of maturing, moisture has dropped significantly, well within the aerobic process range, in all reactors. The highest moisture content was again observed in woodchips and perlite cases (R1: 61.12% and R4:59.81%, respectively) while where zeolite or vermiculite, with woodchips, were used, moisture had dropped quite lower (R2: 53,94% and R3:55,14% respectively), closer to the optimal product moisture level that is considered between 40% and 50%, for below 50% of moisture microbial activity is hindered; this is a prerequisite for the compost product to be safely applied. It is overt then, that further drying of the home-composter product is required before application.

pH profile

Acidity is also a significant parameter of the process, as it determines the microbe species able to evolve and decompose the substrate's organics. A comparison of the pH profiles, with respect to the additive, is shown in Fig. 1. A suitable pH range for aerobic fermentation is 7.0 – 9.0 (Margaritis et al., 2018).

At startup, the substrate is slightly acidic due to the particular composition of the Mediterranean food-wastes. During the initial two days pH remains almost stable, slightly rising in all cases but, maybe, R2 (zeolite-woodchips). During this startup period we may conclude that, though ammonia production due to the metabolic processes responsible for the degradation of nitrogen compounds, begins immediately (Fig. 2), decomposition of organic acids may delay and initially exhibits lower rates. Take note that new feed material is added twice during this period of time, tampering with the processes' progression and parameters' profiles. The case of woodchips (R1) presents a slightly higher rate of increase at the beginning, and the maximum pH value observed is 6.34. During cases R2, R3 and R4, pH rises only up to 5.92, 5.86 and 5.94, respectively.

After the initial two days and as the easily degradable compounds start fermenting, organic acids are rapidly produced and the pH value drops (Gajalakshmi and Abbasi, 2008). Decrease of the pH persists up to the 4th day, then starts leveling off. In case R1 it reaches a lowest value of 5.64, where in cases R2, R3 and R4 it drops to 5.22, 5.31 and 5.17, respectively. Lowest values are observed on day 5.

Past the 5th day, due to high activity of proteolytic bacteria, ammonization of the organic nitrogen becomes, again, the controlling reaction and pH starts increasing rapidly; R1 (woodchips) presents the lower initial rate. All graphs concur during day 7, then R1′s rate increases and the pH rises to higher values than the rest cases. The vigorous alkalinization of the substrate starts leveling off on day 9, as a result of the volatile nature of NH_3 and its concurrent oxidation to NO_3, which begins on day 7 (Fig. 2). Thus, day 7 the rise of NH_3 concentration starts leveling off while after the 8th it begins dropping.

After day 11 the rate of alkalization is low and the same for all cases but R1, where, as also observed in Fig. 2, decomposition of NH_3 is insufficient and its concentration drops at a low rate.

While pH of the mature compost is expected close to 7, at day 21, when the process is assumed finished, it varies between 8.89 and 9.45, indicating that the product is still unstable, requiring further maturing and stabilization.

Conductivity

Conductivity is an index of the soluble salts. It is an important factor, for high salt concentration indicates a high nutrition value of the compost but then may be harmful to the plantation (Manios, 2004). Initial conductivity values are low (Fig. 1), varying from 1.89 to 2.28mS/cm, slowly rising up to a maximum of 4.65mS/cm. This comes in agreement to the reported conductivity profiles for compost processes (Hargreaves et al., 2008). Rise in conductivity is attributed to decomposition of organic substances that increases the salts content in the substrate. The final conductivity is within the expected range for compost produced from MSW (3.69 to 7.49mS/cm) (Hargreaves et al., 2008).

Volatile solids

Percentage of volatile solids is an index of the organic content of the substrate. Volatile solids are easily absorbed and digested by microbial flora and thus are responsible for the development of microbial activity and the progress of the process. Thus, the volatile solids graph (Fig. 1) shows the progress of decomposition throughout the process and indicates its ending.

Volatile solids reduction becomes vigorous between days 3 and 10, concurring with the thermophilic phase of the process deduced by the temperature profile. Highest initial values of volatile solids are observed in R1 (only woodchips), whereas lowest values are found in R4 where no woodchips were added. It is apparent that adding only woodchips in the substrate leads to deficient reduction of volatile solids, concurring with the TOC profile (Fig. 2). In contrast, all studies involving mineral additives, particularly R4 (perlite, no woodchips), exhibit a vigorous reduction of volatile solids and better stabilization of the product. Thus woodchips, alone, may not suffice for an effectual development of the composting processes, whereas addition of minerals enhances the operation. Perlite is indicated as a uniquely promising additive.

Total organic carbon

Total organic carbon is reduced due to the bio-oxidative processes that take place in the substrate and decompose the organic mass, converting its C to CO_2. The greater slant in the TOC curves, in all studies, (Fig. 2) is observed between days 2 and 10, indicating that higher consumption rates of organic carbon is achieved during thermophilic phase and concurring with the volatile solids reduction curve, due to the intense microbial activity and the readily available organic compounds. Initial TOC values of R1, R2, R3 and R4 are 45.70%, 44.55%, 43.37%, 38.50% w/w respectively. At the end TOC is reduced by 20.21%, 37.23%, 43.67% and 43.27% with respect to the additive.

Results indicate that addition of minerals enhance the process and result in higher biodegradation. It also accelerates the rates of TOC reduction during thermophile period, as suggested by the higher initial slope of the R2, R3 and R4 TOC curves, in contrast with R1 where no mineral is present. This may be attributed to the improved the aeration and moisture absorption, because of the higher porosity of the substrate due to the mineral additive. In case R1, (only woodchips), the product's TOC is high, in accordance with the volatile solids profile (&4.5), indicating that microbe population did not develop adequately, so the compost process did not proceed efficaciously. In conclusion, mineral additives are important for the home compost process; vermiculite and perlite are the most promising of the studied ones.

Total Kjeldahl nitrogen (TKN)

The TKN profile of all studied cases is shown in Fig. 2. To the greater extend, N content of food waste is metabolized to NH_3 while non-soluble N compounds are transformed to soluble salts. N losses are chiefly due to NH_3 emissions, whereas a small fraction may get away via $^{-}NO_3$ salts or acids drainage.

Yet in spite of N losses, TKN value increases throughout the process due to the decreasing of dry mass, as organic C is transformed to CO_2.

The greater increment takes place at thermophile phase, where C is vigorously transformed as shown by TOC profile. Past day 10, as the rate of composting decreases and consumption of organic mass lessens, slant of TKN tends to zero. Yet TKN value continues rising, at a small degree, as N is partially recovered due to free-living nitrogen-fixing bacteria (Beauchamp et al., 2006; Insam and de Bertoldi, 2007).

Initial values of TKN are 1.85%, 2.08%, 1.97% and 1.77% for R1, R2, R3 and R4, respectively, while the respective final values are 2.24%, 2.84%, 2.56% and 2.26%. Results indicate that in the case of a single additive (woodchips, R1, or vermiculite, R4), the TKN curve follows the same profile. But when both mineral and woodchips were added (R2, R4), the TKN curves exhibited higher values. With zeolite in particular (R2), N uptake was higher. This might be accounted to high NH_3 absorption capacity of zeolite that reduces NH_3 emissions.

C/N ratio

C is a source of energy and principal a structural block of organisms, while N is a principal element when it comes to building proteins and accounts for 50% of microbes dry mass. Doth elements belong to the chief nutrients for the microbes that carry out the aerobic biodegradation; Ph and K be the rest principal nutrients (Gajalakshmi and Abbasi, 2008). All those elements are usually found in excess in food waste, but the composition ratio of C/N is of profound importance for the composting process (Environment Agency, 2001) and nutritional evaluation of the feed is ascertained through it (Bernal et al., 2009). C/N ratio of microorganisms' structure fall between 9 and 12 (Zucconi and de Bertoldi, 1987) while during degradation process the microorganisms assimilate about a third of the metabolized carbon, releasing the rest via CO_2 emissions (Alexander, 1977). The theoretically optimal initial value for C/N in the substrate is between 27 and 36 which comes in agreement with the experimentally reported values (Bishop and Godfrey, 1983; Gaur and Tandon, 2000; Golueke, 1992). Achieving an adequate initial C/N requires proper combination of the different kinds of food-waste. During aerobic biodegradation loss of C is usually higher than loss of N, resulting in a reduced C/N ratio in the final product (Goyal et al., 2005).

Reduction of C/N for each study is shown in Fig. 2. Additive included, the initial C/N value for R2, R3 and R4 are found about 22 while R1 exhibits a value of 25. During initial stages and throughout thermophile phase, in accordance to TOC profiles, the ratio is rapidly reduced reaching a value of about 10 for R2, R3 and R4. In R1, reduction of C/N ratio is significantly lower; day 10 it retains a value of 17. Past day 10, due to low oxidation rates of the residual organic mass, reduction of C/N is insubstantial. At the end, cases with mineral exhibit a value close to 10 while R1′s C/N≈16.

Thus, mineral additives result in, more or less, a 55% reduction of C/N, with or without the use of woodchips, while sole employment of woodchips results in a 34% reduction.

Nitrate and ammonium

Amounts of NH_3^+ and NO_3^- in the product are of critical importance; ratio $(NH_4^+ - N)/(NO_3^- - N)$ is an index of compost's maturity. Evolution of their concentration with the process, in all cases, is presented in Fig. 2. Metabolization of the food-waste's N begins immediately as proteolytic bacteria converts a portion to NH_3. During the first days and along the thermophile phase NH_3 concentration rises quickly in R2, R3 and R4, with R4 exhibiting the greatest slope and R2 the lesser, as zeolite additive absorbs higher amounts of NH_3 than the other minerals. In contrast, R1 depicts a meagre rise indicating that woodchips do not favor N conversion. The sharp increase of NH_3 concurs with the sharp increase of the substrate's pH.

At the end of the thermophile phase starts the nitrification of NH_4^+ and its concentration reduces; NO_3^- concentration rises. Two different types of nitrification occur: (1) via heterotrophic nitrifying bacteria that convert NH_4^+ to NO_3^- at the initial stages and along the thermophile phase (Alexander, 1977; Insam and de Bertoldi, 2007), where nitrification rate is significantly slow and (2) autotrophic nitrification, during the latter stages, which governs the process but is hindered by high temperatures (de Bertoldi et al., 1983; Insam and de Bertoldi, 2007). High increase of NO_3^- concentration past day 11, where temperature drops below 30°, indicates the aerobic conditions existing in the substrate, as autotrophic nitrobacteria require oxygen rich environments. R4, R3 and R2 show higher nitrification rates than R1, their slopes reducing with the respective order. R1 exhibits both lower NH_3 concentration and nitrification rate; woodchips show no enhancement of any of the N conversions.

At the end, R2, R3 and R4 exhibit high concentrations of NH_4^+ and NO_3^-, where R1 exhibits low concentration of both ions; woodchips do not favor organic N conversion at all and compost process does not proceed satisfactory.

Conclusions

The present study indicates that households in Mediterranean region can efficiently manage and exploit their food wastes through home composting, by an innovative compost unit (Margaritis et al., 2018; Papadopoulos et al., 2009), even if the substrate presents a low C/N ratio. It demonstrates that the addition of low-cost additive materials enhances and makes possible the implementation of this small-scale process, at home, at environmental temperature, to produce compost for domestic use, even yet for exploitation. Findings referring to food-waste with low C/N, concur with those concerning substrates with mid-C/N ratio (e.g., C/N = 30) (Margaritis et al., 2018).

In all studies the process starts vigorously due to the absence of temperature control and as environmental conditions have little effect on the substrate, entering the thermophilic phase on day 3. The process gets more vigorous as the porosity of the substrate increases with respect to the additive. All woodchips and mineral additives add to the porosity; cases R2 and R3 overtly present higher porosity than the R1, thus addition of minerals together with woodchips improves aeration. Perlite seems to increase the porosity of the substrate to the same level, as with woodchips and zeolite or woodchips and vermiculite, as the sharpness of the T curve is also increased accordingly, but holds down the overshot. Then during the maturing phase, the T profile of R4 still indicates better aeration and porosity, as T remains at the same levels with R2 and R3.

The better of organic C is reduced during that, high temperature, phase, which ends about day 10. pH increases considerably during the thermophile phase, as the organic acids are consumed quickly and concentration of ammonia rises due to decomposition of organic nitrogen. TKN approaches its final value about day 10. C/N decrease ratio starts leveling off after the thermophile phase ends, where conversion of NH_3^+ to NO_3^- begins. After day 11 the rate of alkalization slows as decomposition of NH_3 is scarce and its concentration starts dropping slowly.

Concludingly, the required period for completion of the process is 18 to 20 days. Values of all the main parameters, in particular C/N, remain almost stable after day 18, signifying the end of the process. Thereon, the final product can be diverted for maturation.

The amounts of additives employed in this study are proven adequate to regulate the moisture of the substrate to acceptable levels for microorganisms' growth. O_2 is also maintained at an optimum level for the desired aerobic process. Frequent agitation (2–3 times/day, by hand) of the substrate helps control humidity and O_2 levels while mineral additives induce the required porosity to maintain adequate aeration and moisture.

Minerals, due to their ion-exchange properties and NH_4^+ selectivity, reduce N losses and help regulating NH_3 and NO_3^- concentrations in the substrate. Both zeolite/woodchips (R2) and vermiculite/woodchips (R3) mixtures kept lower moisture levels than cases R1 and R4, where woodchips or perlite were applied as single additives. Then, cases R2, R3 and R4 present an enhanced NH_4^+ retaining capability, due to the mineral additive. Perlite, though added alone (R4), presents the higher NH_4^+ absorption, due to its higher affinity.

Better aeration of the substrate due to minerals leads to enchance TOC removal, while perlite reduces TOC significantly, a fact also associated to its enhanced performance in absence of woodchips. TKN in the product is increased for the cases R3 and R3 and zeolite exhibits better performance.

The raised moisture content of the finished product and its alkalinity are satisfactory, but the compost derived from the process require a period of maturation before exploitation. Total concentration of heavy metals is considered negligible as the feed of the process comes out of human meals and is free of heavy metals.

Conversely, to process appears to progressing well with substrates of the lowest C/N values observed at the Mediterranean household wastes, while perlite shows better efficiency in reducing TOC and volatile solids values while presenting a high affinity to the NH_4^+ ions. It enhances the process without the need of woodchips addition and thus is assumed a most promising mineral for the in-situ composting process.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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