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ORIGINAL PAPER

Co-composting of Olive Industry Wastes with Poultry Manure and Evaluation of the Obtained Compost Maturity

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Abstract

The objective of this study is to examine the viability of recycling olive industry wastes by co-composting with poultry manures, describe the evolution of the physic-chemical and microbiological composting parameters, and evaluate the maturity of the obtained compost. The co-composting process applied was a windrow composting process. A pile was prepared by mixing olive mill pomace (OMP) and olive mill solid husk (OMSH) as carbon source, poultry manure (PM) as nitrogen source, green wastes (GW) as bilking agents and olive mill wastewater (OMW) as humidifier. The mixture was prepared based on fresh weight (FW) according to the following proportions: OMP + OMSH = 51.72% FW; GW = 27.58% FW; PM = 20.68% FW and C/N ratio = 29.25. The windrow was arranged in a pile of 1.5 m height, 2 m wide and 2 m length. Results showed that during the composting process, a high microbiological activity was depicted by a quickly increase in temperature (65 °C) in 09 days. An exponential increase in the number of aerobic microorganisms in the pile with a maximum (156×10^8 CFU g^{-1} FM) after 09 days of incubation and a progressive decrease in the C/N ratio over time were recorded. The obtained compost had a homogeneous particle size with a fine majority fraction (70.41% < 2 mm), a neutral pH (6.69) and a C/N ratio close to 10. It was also rich in minerals fertilizers (P, K, Ca). Finally, the germination tests carried out on 04 different seeds (tomato (*Solanum lycopersicum*), cresson (*Lepidium sativum*), sorghum (*Sorghum bicolor*) and alfalfa (*Medicago sativa*) showed that the obtained compost allowed germination index (GI%) values that exceeded 85%, which confirms the non-phytotoxicity of the product.

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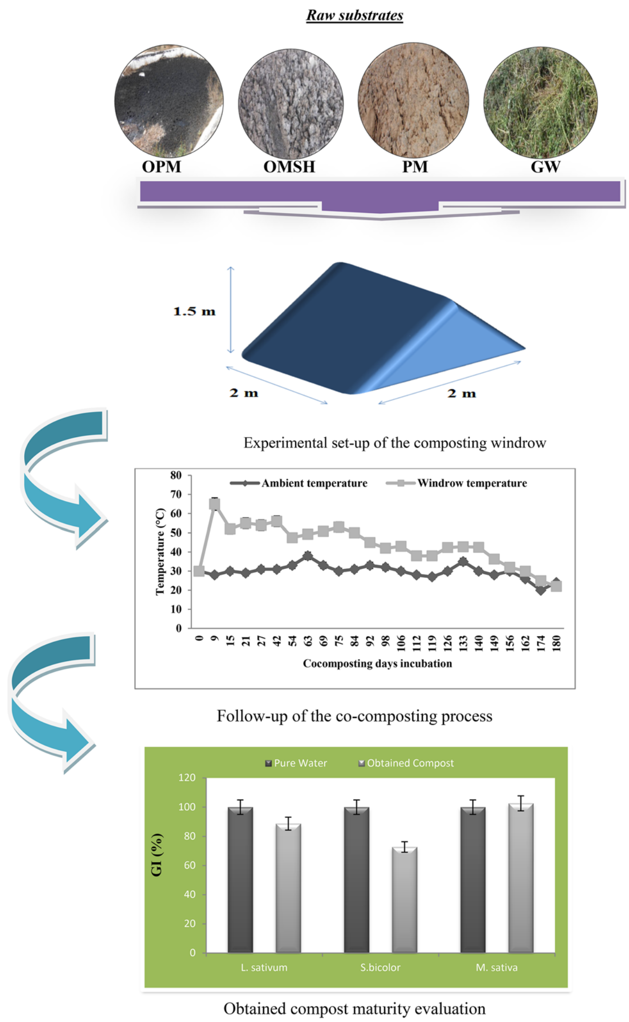
Graphic Abstract



Keywords Co-composting · Olive industry wastes · Poultry manure · Compost · Bio-fertilizer

Statement of Novelty

The olive industry biowastes constitute a serious environmental problem in Tunisia. This work aims at the valorization of the olive oil industry biowastes as well as the poultry manure.

Introduction

Olive tree (*Olea europaea* L.) is one of the most important cultivated crops in the Mediterranean basin [1]. It was considered as one of the best adapted species to the semi-arid environment, specifically due to its tolerance to drought and salinity [2].

Olive oil industry constitutes one of the most important sectors in many Mediterranean countries economies [3]. Annually, 1.8×10^6 tons of olive oil are produced worldwide, 98% of them are extracted in the Mediterranean basin with Spain, Italy, Tunisia and Greece being the four leading countries [4]. Among these, Tunisia's olive-growing potential is estimated at nearly 90 million trees, occupying an area of 1.8 million ha corresponding to about 79% of the total arboreal area [5].

Despite the economic dominance and the agricultural importance of olive growing, no one doubts that the olive-oil extraction process produces huge amounts of agro-industrial wastes [6–8]. The olive oil industry, in addition to its main product which is olive oil, generates massive amounts of bio-wastes, mainly olive mill wastewaters (OMW) and olive mill solid husk (OMSH) [9, 10]. These wastes cause diverse environmental impacts notably land degradation and wastes generation [11–13]. Thus, different remediation technologies were applied for treatment such as evaporation ponds, thermal concentration, physico-chemicals and biological processes [14–17]. However, generally, most of these methods are very expensive and unable to solve the problem completely because of the need to dispose of sludge or other by-products deriving from the treatment process [5, 18].

Alternatively, due to the increasing demand for meat and eggs in many countries like Tunisia, poultry has skyrocketed in recent decades and the industrialization of this activity has become inevitable [19, 20]. Obviously, this situation has contributed to an increase in the generation of poultry manure wastes. This agro-industry by-product is well known by its high ammonia concentration [20], which has caused significant environmental perturbations, such as water and soil pollution and atmospheric contamination [21, 22]. Thus, the need to develop new technologies to manage these wastes from the poultry industry constitutes an urgent concern. However, the richness of poultry manure in abundant nutrients such as nitrogen, phosphate and potassium make it a very potential resource for soil and plant fertilization [19, 20]. Nevertheless, many authors have observed negative effects on plants after direct manure applications, due to their high salt content and accumulation of trace metallic compounds in soil particles and plants [23, 24].

In Tunisia, the intensification of agro-food activities such as olive oil extraction and poultry generates a huge quantity of organic by-products. In fact, the first by-product of the agro industry amounts to approximately 800,000 tons of olive mill wastewaters every year and the second by-product is poultry manure with 650,000 tons yearly [18, 25]. Such generated wastes cause serious environmental problems that need to be handled. Composting is a widely used organic waste treatment process to produce organic fertilizers [26]. Indeed, this method constitutes the main biological process applied to sewage sludge treatment in Europe [27]. Sewage sludge composting is regarded as an environmental friendly technology that can effectively decompose organic matter into a stable end product [28]. Moreover, the high temperature reached due to the metabolic heat generated during the composting process thermophilic phase is effective in destroying pathogens and enhancing biological degradation of different organic micro-pollutants, allowing the final product to be safely used as fertilizer or soil conditioner [29, 30]. Using compost has important environmental benefits [31]. It is used as a field soil amendment with the primary benefit of increasing soil organic matter, stimulating soil microbial communities and thus helping to restore degraded soils [32]. In Mediterranean agroecosystems which are characterized by destructive soils very poor in organic matter [33, 34], periodic inputs of organic amendments are strongly recommended [4, 18]. According to [35], composted olive-mill pomace contains a large amount of organic matter, and thus might be useful as an amendment to agricultural soils, improving a range of soil properties, and reducing loss of agricultural crops. Hence, olive-mill pomace compost application could be considered an attractive strategy for soil carbon sequestration [36–38].

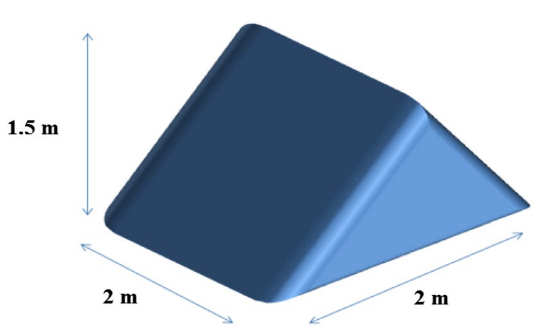


Fig. 1 Windrow dimension and raw substrates repartition (OMP + OMSH = 51.72%; GW = 27.58%; PM = 20.68%; C/N = 29.25)

The objective of this study was to investigate the application of a co-composting treatment process on two wastes abundantly generated in Tunisia, namely olive mill solid husk (OMSH) and poultry manure (PM). Also, the evolutions of the physic-chemical and microbiological composting parameters as well as the quality of the obtained compost were evaluated.

Materials and Methods

Biowastes Origin and Characterization

The olive mill solid husk (OMSH), the olive mill pomace (OMP), the olive mill wastewater (OMW), and the green wastes (GW) (as vegetable residues, leaves and branches of olives) were collected from the experimental station “Taous” of the Olive Tree Institute of Sfax, Tunisia (North latitude 34° 3′, East longitude 10° 20′). OMW were collected in an open storage basin with a capacity of 300 m^3. OMSH and OMP were stored in a ventilated shed covered at the top to avoid the effects of the precipitations. In fact, according to [18], in Tunisia alone, the olive oil extraction process generates an average annual production of 800,000 tons $year^{-1}$. Whereas, the olive mill solid sludge quantity generated after the extraction process ranges from 120,000 to 168,000 tons $year^{-1}$ depending on the extraction method [39].

Poultry manure (PM) was obtained from a commercial poultry house sited at Sfax, Tunisia. All the used biowastes were characterized before mixing in the composting windrow.

Experimental Set-Up of the Composting Windrow

The study was carried out during 06 months, from May to October 2018 at the experimental station Taous of the Olive Tree Institute of Sfax, Tunisia. The co-composting process applied was a windrow composting process. A pile was prepared by mixing olive mill pomace (OMP) and olive mill solid husk (OMSH) as carbon source, poultry manure (PM) as nitrogen source, green wastes (GW) as bulking agents and olive mill wastewater (OMW) as humidifier. The mixture was prepared based on fresh weight (FW) according to the following proportions: OMP + OMSH = 51.72% FW; GW = 27.58% FW; PM = 20.68% FW and C/N ratio = 29.25. The windrow was arranged in a pile of 1.5 m height, 2 m wide and 2 m length (Fig. 1). During composting, the windrow moisture was controlled weekly by adding the necessary OMW and water to maintain a moisture rate of 45% to 60% [40]. During the composting process, the pile was turned periodically (every 10 days) to maintain adequate moisture content and temperature. In fact, [40] showed that turning frequency affected moisture content, dry matter, total carbon and total nitrogen of composting piles.

Physicochemical Characterization

The following physicochemical parameters were determined. The temperature was measured three times a week at different levels of the pile using an automatic thermometer. The turning operation ensures better homogeneity of the pile by bringing outer, cooler layers, into the core of the pile, redistributes the intermediate decomposition molecules and optimizes the oxygen distribution in the pile.

During the composting process period, samples were taken weekly from different sides and depths in the pile. However only samples that showed significant variations on physicochemical or microbiological analyses (samples that were taken at 0, 9, 27, 42, 72, 119 and 174 days) were considered. The samples were dried, homogenized and sieved through a 0.5 mm sieve and then stored for chemical analyses. The pH and electrical conductivity (EC) was determined according to a standard method in 1:2.5 and 1:5 (w/v: compost/water) extract respectively [41]. Total organic carbon (TOC) and organic matter (OM) were estimated as the difference between dry matter and the residue after calcinations at 550 °C for 4 h and the OM rate was calculated by the equation: OM(%) = 1.725 × TOC (%) [42]. Total nitrogen was assessed by Kjeldahl method [43]. Phosphorus (P) content was assessed by Olsen and Sommers method [44]. The cation exchange capacity (CEC) was determined according to standard method [45]. Potassium (K), calcium (Ca) and sodium (Na) were evaluated by extraction with nitric acid (HNO_3) in ash after calcination of dry matter at 550 °C for 4 h and measured by flame photometry. Total phenolic compounds were determined by using the Folin–Ciocalteau method [46]. For all analyses, five repetitions were performed for each parameter.

Microbiological Analyses

Microbiological analyses consisted in measuring the countable microflora as the total aerobic microflora (TAM), fungi (yeasts and molds) (F) and heat-resistant microflora (HRM) during the co-composting process. Also the respirometric activities during co-composting were assessed.

Microbial Counting

Microbial counting was determined according to [47]. A compost sample of 10 g was suspended in 90 mL of physiological water (9 g NaCl in 100 mL distiller water). The solution was shaken at 200 rpm for 4 h. Serial decimal dilutions of each suspension (10^{-1} to 10^{-10}) were prepared. The total aerobic microflora (TAM) was enumerated on Plate Count

Table 1 Raw substrates physicochemicals characteristics (average values of five replications ± SD of each sample)

Parameters	OMP	OMSH	PM	GW
pH (25 °C) ± SD	5.69 ± 0.1	6.55 ± 0.1	7.59 ± 0.2	5.85 ± 0.1
EC (mS cm^{-1}) ± SD	3.06 ± 0.1	8.93 ± 0.2	9.14 ± 0.2	2.53 ± 0.1
MM (% DM) ± SD	6.15 ± 0.1	22.76 ± 0.3	68.82 ± 0.5	39.39 ± 0.3
OM (% DM) ± SD	93.85 ± 0.5	77.24 ± 0.5	31.18 ± 0.3	60.61 ± 0.5
TOC (% DM) ± SD	54.44 ± 0.1	44.78 ± 0.1	18.08 ± 0.02	35.15 ± 0.05
TN (% DM) ± SD	0.84 ± 0.00	1.29 ± 0.01	1.46 ± 0.00	1.2 ± 0.01
C/N ratio ± SD	64.8 ± 0.01	34.71 ± 0.01	12.38 ± 0.02	29.29 ± 0.02
P (mg kg^{-1} DM) ± SD	1.3 ± 0.00	1.68 ± 0.00	2.39 ± 0.02	1.26 ± 0.02
K (mg kg^{-1} DM) ± SD	4.45 ± 0.02	2.66 ± 0.01	3.5 ± 0.02	1.6 ± 0.01
Na (mg kg^{-1} DM) ± SD	1.15 ± 0.01	3.63 ± 0.01	5.23 ± 0.1	1.23 ± 0.00

±SD: Standard deviation ($P \leq 0.05$)

MM mineral matter, *DM* dry matter, *OM* organic matter, *TOC* total organic carbon, *TN* total nitrogen

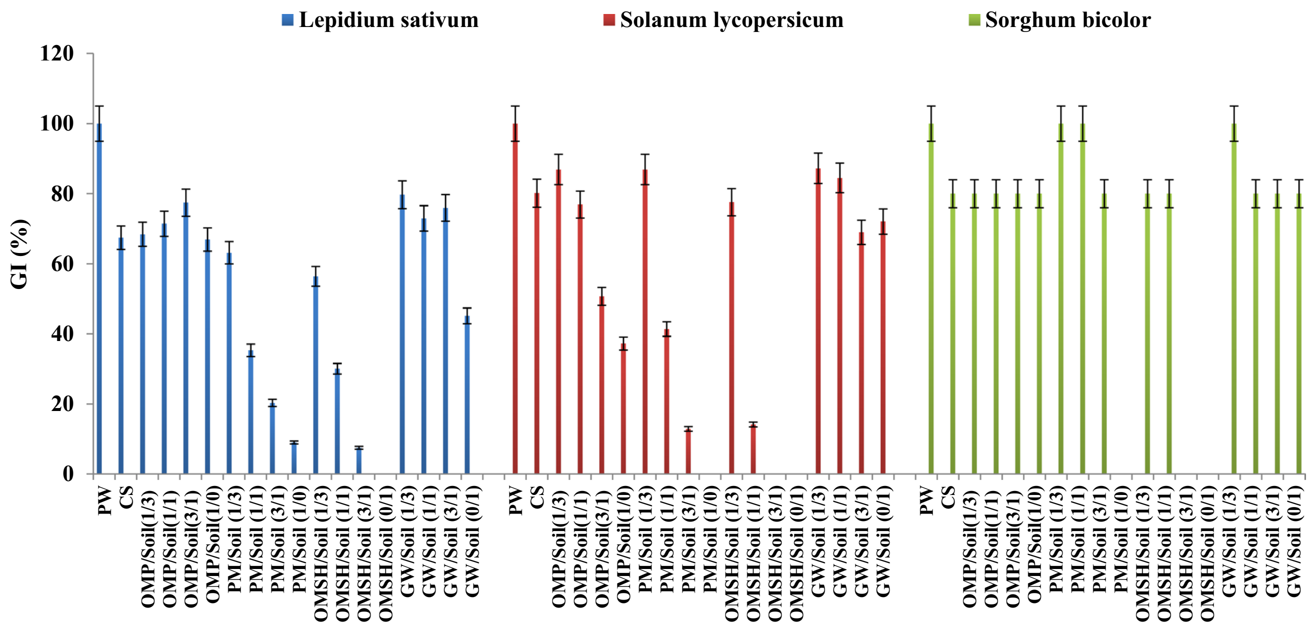


Fig. 2 Raw substrates (OMP, OMSH, PM, GW) and raw substrates/soil mixtures (1/3, 1/1, 3/1, 1/0) extracts phytotoxicity (vs. cresson (*Lepidium sativum*), tomato (*Solanum lycopersicum*) and sorghum (*Sorghum bicolor*) seeds) in comparison with soil control (Sc) extract and pure water (Pw)

Agar (PCA) for 48 h at 25 °C. For heat-resistant microflora (HRM), the suspension was heated at 80 °C for 10 min and plated on PCA for 24 h at 30 °C. Fungi were enumerated on Sabouraud solution at 25 °C for 72 h. Results were expressed as colony forming units per gram of compost fresh matter (CFU g^{-1} FM).

Respirometric Activity Assessment

Respirometric measurements were determined during the co-composting process by placing 100 g of each sample in a closed jar at constant temperature and constant moisture content. The CO_2 released is trapped in 0.1 N sodium hydroxide solution (NaOH) and titrated with hydrochloric acid HCl (0.1 N), in the presence of phenolphthalein, after precipitation of sodium carbon with 2 ml of $BaCl_2$ chloride (30 g L^{-1}) [48].

Phytotoxicity Evaluation

The phytotoxicity levels of the used raw substrates before co-composting and the obtained compost extracts were determined according to a standard method [49]. The germination tests were carried out by using four different seed species (tomato (*Solanum lycopersicum* L.), cresson (*Lepidium sativum*), sorghum (*Sorghum bicolor*) and alfalfa (*Medicago sativa*). All of these were marketed seeds and treated with preservatives for use in germination tests. The germination tests were conducted in the dark at room temperature (25 °C) during 48 h for alfalfa and during 72 h for tomato, cresson and sorghum seeds. Three repetitions were performed for each seed and mixture medium.

Statistical Analyses

All the parameters studied were carried out using SPSS software (Statistical Package for the Social Sciences, version 20). Results are expressed in mean standard deviation, using analysis of variance ANOVA.

Results and Discussion

Raw Substrates Physicochemical Characterization

Physicochemical characteristics of all the used raw substrates were determined (Table 1). The olive mill pomace (OMP) is a solid residue generated during olive oil extraction process. It has an acidic pH (pH 5.96) and a very high content of organic matter (OM = 93.85%). The OMP nitrogen content is low as micronutrients and phosphorus, so the C/N ratio is usually high (64.8). Reference [33] demonstrated that the lipid and organic phytotoxic compounds of OMP limit its use in soil amendment and their direct application could

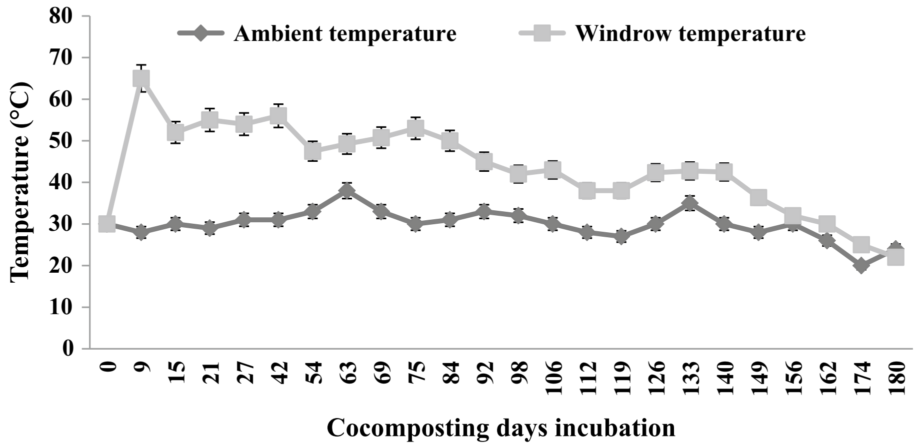


Fig. 3 Windrow temperature evolution as function of the co-composting period

cause serious environmental problems in soils and surface waters, which limits its general use in soil fertilization.

The OMSH was taken from an evaporation basin at the experimental station of the Olive Institute Tree of Sfax, Tunisia. It is an acidic solid waste (pH 6.55) with very little porosity, characterized by high salts content (EC = 8.93 mS cm^{-1}) and low nitrogen rate (TN = 1.29%). This can be explained by the accumulation of salts after water evaporation. OMSH is rich in organic matter (77.23%) comprising a relatively large amount of lignin, cellulose, hemicellulose, lipids, carbohydrates as well as phenolic compounds [12]. The GW is characterized by feeble nitrogen content (TN = 1.2%) and a relatively important C/N ratio (29.3). The used poultry manure (PM) was characterized by a high pH (7.6) and mineral matter content (68.82%). The PM nitrogen content is higher than other substrates (TN = 1.46%), which explains its low C/N ratio (12.38) (Table 1). These results are in agreement with previous studies showing that the poverty of PM in total organic carbon and its richness in nitrogen may decrease its C/N ratio [19, 20].

Raw Substrate Phytotoxicity Assessment

The raw substrate (OMP, OMSH, PM and GW) phytotoxicity potentials were assessed by the determination of the germination indexes GI (%) of three different seed crops: tomato (*Solanum lycopersicum* L.), cresson (*Lepidium sativum*) and sorghum (*Sorghum bicolor*). Various extracts from each raw substrate and in different proportions of raw substrates/soil mixtures (1/3, 1/1, 3/1 and 1/0) were used in comparison with pure water as control medium (Fig. 2).

Results showed that various mixtures of PM/water extract and OMSH/water extract had an inhibitory effect on cresson and tomato seeds germination, compared to pure water, whose germination index was 100%. Thus, the germination percentage showed gradual decrease upon increasing the OMSH proportion. For the 100% PM and 100% OMSH water extracts, tomato seeds germination was totally inhibited. For cresson seeds, GI of the order of 11% and 0% were obtained respectively. Both types of seeds are considered very sensitive to the slightest phytotoxicity of used substrates. Indeed, PM and OMSH in their raw state and mixed with soil are very phytotoxic and so they cannot be used as plant fertilizers or soil amendment. This could be due essentially to their high salinities (EC = 9.14 mS cm^{-1} and 8.93 mS cm^{-1}, respectively for PM and OMSH).

In contrast, the water extracts of various mixtures of GW/soil did not show any inhibitory effect on the germination of cresson and tomato seeds and positive effects on all seed germination were observed (Fig. 2). In line with these findings, [42] showed that the green waste was characterized by high nitrogen rate and low C/N ratio, which is necessary to seeds germination and plant growth. For OMP water extracts, a decrease of the tomato seed germinations with the increase of OMP portion in the mixture OMP/soil was observed. The germination inhibition is principally due to the phenolic compounds highly present in OMP. While OMP did not show any inhibitory effect on cresson seed germination (Fig. 2). For Sorghum bicolor seed germinations, results showed that the inhibitory effects are only noticeable for raw PM and OMSH. Thus, both substrates totally blocked the germination of Sorghum bicolor seeds and can never be a suitable medium for germination of the tested seeds. Our results are in harmony with several previous researches which have demonstrated that olive mill wastes have very phytotoxic effects when applied at large amounts [12, 13, 50].

Physicochemical Parameters' Evolution During the Co-composting Process

The evolution of the main physicochemical parameters of the co-composting process (such as temperature, pH, electrical

Table 2 Physicochemical and microbiologicals parameters evolution during co-composting process (average values of five replications ± SD of each sample)

Parameters	Co-composting time (days)						
	0	9	27	42	72	119	174
pH (25 °C) ± SD	5.85 ± 0.01	6.04 ± 0.01	6.3 ± 0.00	6.45 ± 0.00	6.75 ± 0.01	7.03 ± 0.01	6.96 ± 0.01
EC ± SD	4.98 ± 0.01	5.76 ± 0.01	6.79 ± 0.01	6.86 ± 0.00	7.1 ± 0.02	7.53 ± 0.01	7.5 ± 0.00
CEC ± SD	25 ± 0.4	31.69 ± 0.1	34.6 ± 0.00	37.33 ± 0.2	37.93 ± 0.4	41.33 ± 1	42.8 ± 0. 1
MM ± SD	24.13 ± 0.00	33.55 ± 0.3	44.33 ± 0.7	57.86 ± 0.5	59.05 ± 0.1	58.88 ± 0.2	59.2 ± 0.1
OM ± SD	75.87 ± 0.00	66.45 ± 0.3	55.67 ± 0.7	42.14 ± 0.5	40.95 ± 0.1	41.12 ± 0.2	40.8 ± 0.1
TOC ± SD	43.99 ± 0.00	38.54 ± 0.3	32.28 ± 0.7	24.44 ± 0.5	23.75 ± 0.2	23.84 ± 0.1	23.66 ± 0.1
TN ± SD	1.5 ± 0.01	2.61 ± 0.01	2.7 ± 0.00	2.81 ± 0.00	2.9 ± 0.04	2.94 ± 0.00	2.9 ± 0.04
C/N ± SD	29.25 ± 0.2	14.76 ± 0.1	11.95 ± 0.2	8.69 ± 0.2	8.18 ± 0.1	8.1 ± 0.1	8.15 ± 0.1
Na ± SD	0.22 ± 0.01	0.215 ± 0.02	0.26 ± 0.00	0.24 ± 0.01	0.28 ± 0.01	0.29 ± 0.03	0.29 ± 0.02
K ± SD	3 ± 0.1	2.97 ± 0.01	3.2 ± 0.01	3.44 ± 0.00	3.42 ± 0	3.86 ± 0.1	3.8 ± 0.01
P ± SD	0.3 ± 0.00	0.3 ± 0.00	0.29 ± 0.01	0.28 ± 0.00	0.256 ± 0.01	0.257 ± 0.01	0.258 ± 0.00
Polyphenols ± SD	1.2 ± 0.00	1.05 ± 0.1	0.99 ± 0.01	0.56 ± 0.00	0.5 ± 0.01	0.35 ± 0.00	0.3 ± 0.00
TAM ± SD	114 ± 5.00	156 ± 3.00	137 ± 3.00	149 ± 1.00	124 ± 0.2	113 ± 3.00	92 ± 2.00
HRM ± SD	48 ± 1.00	110 ± 3.00	72 ± 1.00	64 ± 0.10	41 ± 1.00	37 ± 0.05	29 ± 0.02
F ± SD	53 ± 0.50	81 ± 1.00	69 ± 0.01	57 ± 0.05	48 ± 1.00	42 ± 0.02	33 ± 0.50

±SD: Standard deviation ($P \leq 0.05$)

Units: EC (mS cm^{-1}); CEC (meq % DM); MM (%DM); OM (%DM); TOC (%DM); TN: total nitrogen (%DM); K (g kg^{-1} DM); P (g kg^{-1} DM); Na (g kg^{-1} DM); Polyphenols (mg kg^{-1} DM); TAM (10^8 CFU g^{-1} FM); HRM (10^5 CFU g^{-1} FM); F (10^5 CFU g^{-1} FM)

conductivity (EC), organic carbon content, total nitrogen and C/N ratio) were monitored along the study period.

The Temperature Evolution

The temperature constitutes a key parameter for the co-composting evolution, as it governs the microbiological and the biochemical activities of the process [19]. It is usually used as a parameter to indicate the good initiation and the end of the composting progression [51]. During the composting process, the evolution of the temperature of the material provides information about the process performance, especially at full scale [52, 53].

Figure 3 illustrates the evolution of the windrow temperature in comparison with the ambient temperature during the composting period. The temperature evolution follows a typical profile for composting with three phases: mesophilic phase, thermophilic phase and maturation phase. The first phase was characterized by heat raise from 30 to 42.5 °C observed in 5 days, showing a rapid colonization of mesophilic microbial populations. This phase was accompanied by a slight acidification of windrow due to the release and accumulation of organic acid molecules produced by the first colonizers at the beginning of the composting process [53, 54]. Then, the windrow was manually turned in order to assure both the homogeneity of the pile and the fermentation process of all parts of the decomposing material to reach the desired stability [55]. The temperature increased quickly reaching the highest level (65 °C) within 09 days and showed a rapid initiation of the composting thermophilic step. Thus, this thermophilic phase was maintained until 80 days of the incubation period, with a temperature value neighboring 55 °C (Fig. 3). In fact, [56] showed that the range of 52–60 °C is the most favorable for organic matter decomposition and the temperatures above 55 °C are required to destroy pathogenic microorganisms. However, according to other researchers, a maximum temperature of 65 °C is necessary to obliterate pathogen microorganisms, which contributes to the hygienization and sanitization of the end-product due to pathogen, weed and seed reduction [57, 58]. This rapid progress from mesophilic to thermophilic phase can be attributed to the high microbial activity generated by the presence of easily degradable organic compounds [42]. From the day 90 of incubation, the evolution of the temperature showed a progressive fall which stipulates the entry of the process in the maturation phase. Indeed, the conversion and biodegradation of the organic matter during the two previous phases (mesophilic and thermophilic) enriched the windrow in stable and hygienic mineral matter which greatly reduces the microbiological activity and consequently the decrease of the temperature of the pile [19, 50, 59]. This temperature diminution was noticeable from day 140 until day 160, when the temperature profile became stable and comparable to the ambient temperature. Our results are aligned with several previous results [60–62].

Electrical Conductivity and pH Evolution

The pH and EC evolution values during the composting process are shown in Table 2. The pH values showed an increase from 5.85 at the beginning to 6.96 at the end of the composting period. Reference [19] explained the pH increase as a consequence of the mineralization of acidic compounds, such as carboxylic and phenolic groups, and amino acids and peptides to ammonia. Indeed, the solubilization of the ammonia led to the formation of ammonium and an increase in the pH values in the composting mixtures was noted [19]. Such results are in agreement with those of [63], finding a rise in pH from the start of composting. The pH values increase indicates a good quality of the obtained compost [64]. Indeed, previous studies reported that the pH of a mature compost ranged from 6 to 8.5 [65], while [66] found that composting could be inhibited at pH below 6. Reference [63] indicated that pH is an important parameter to control the composting process. At higher pH condition, it could be faster decomposition in biowaste composting and result in a more stable compost product. Alternatively, the EC increases gradually with the co-composting time. It was probably due to the soluble salts provided from OMW and the relative increased concentration of ions, due to the mineralization of the organic material during the co-composting process [51, 67]. It should be noticed that in spite of the acidic pH of OMW used during humidification, this effluent did not have any negative impact on the composting mixture pH. These findings correlate with many other experiments about composting [19, 63, 64].

Organic Carbon, Total Nitrogen and C/N Ratio Evolution

The evolution of the total organic carbon (TOC) content as well as that of the total nitrogen (TN) during the composting process are important parameters considering their inference on the C/N ratio of the composted materials [64, 66].

The assessment of these parameters during the co-composting period showed a signification reduction of the TOC concentration proportionally with the progress of the co-composting period (Table 2). Indeed, the TOC amount decreased from 44% FW at the beginning to 24% FW at 72 days of incubation. After that, the TOC was stabilized until the end of the composting process. These results can be explained by the presence of easily degradable organic compounds accompanied with high microbial activity in the mesophilic and thermophilic phases [42]. Concerning the nitrogen content evolution, results showed an increase in the TN concentration from 1.7% FW to 2.9% FW at the end of process. Such nitrogen concentration augmentation can be explained by the loss of dry mass in the pile weight in terms of carbon dioxide and by water evaporation during the mineralization of organic matter [67, 68]. These results were proved by the decrease in the C/N ratio, which showed a progressive decline as a function of composting duration (Table 2). In this context, many previous studies confirmed the decrease of the C/N ratio during the composting [19, 42, 69, 70]. According to [71], the analysis of the C/N ratio in compost is one of many relative indicators of compost stability and provides information about the degree of its maturity. Reference [55] showed that the lower the C/N ratio, the more mature the compost and that the C/N ratio in mature compost should be close to 10–15.

Microbiological Parameters' Evolution During the Co-composting Process

Microbiological parameters evolutions was done by microflora counting as total aerobic microflora (TAM), fungi (F) and heat resistant microflora (HRM) during the co-composting process. Also the respirometric activities were assessed over time.

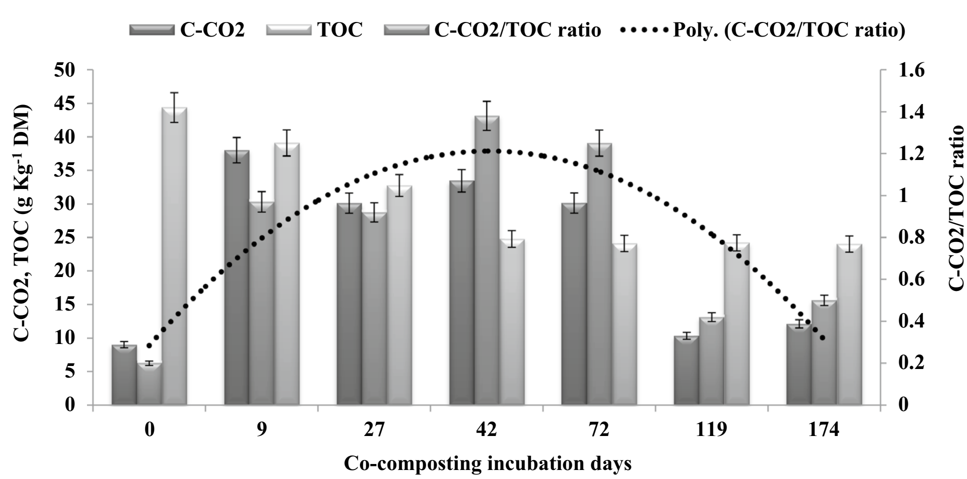


Fig. 4 Windrow respirometric activities (as cumulative C–CO_2) and specific respiration activities (as C–CO_2/TOC) evolution as function of the co-composting period

Table 3 Physicochemicals and microbiologicals characteristics of the obtained compost (average values of five replications ± SD of each sample)

Parameters	Average values ± SD
Fractions size	
> 10 mm	1.58 ± 0.01
5–10 mm	7.30 ± 0.20
2–5 mm	20.69 ± 1.00
< 2 mm	70.41 ± 3.00
Physicochemical parameters	
pH (25 °C)	6.69 ± 0.1
EC (mS cm^{-1})	7.5 ± 0.00
Water content (%)	21.2 ± 1.00
OM (%DM)	40.8 ± 0.00
MM (%DM)	59.2 ± 0.01
CEC (méq %DM)	42.8 ± 0.01
TOC (%DM)	24 ± 0.01
TN (% DM)	2.9 ± 0.04
C/N ratio	8.27 ± 0.1
K (g Kg^{-1})	3.8 ± 0.01
P (g Kg^{-1})	0.26 ± 0.01
Na (g Kg^{-1})	0.29 ± 0.02
Phenolic compounds (g Kg^{-1})	0.3 ± 0.00
Microbiological parameters	
TAM (10^8 CFU g^{-1} FM)	92 ± 3.00
HRM (10^5 CFU g^{-1} FM)	29 ± 1.00
F (10^5 CFU g^{-1} FM)	33 ± 2.00

±SD: standard deviation ($P \leq 0.05$)

Microbial Counting

The co-composting is an aerobic process involving different microbial categories able to biodegrade the organic matter present [72]. The microbiological analysis showed a variation during co-composting. This evolution depends on the stage of composting and with the variations of the physicochemical parameters (Table 2). Results showed that the evolution of the TAM, HRM and F was characterized by a peak on the 9th day, corresponding to the thermophilic phase (Table 2). In fact, the degradation of substrates generates temperature rise that allows the development of thermo-tolerant microorganisms. This group becomes the responsible for substrates degradation during the thermophilic phase [72]. Our results also showed a difference in the abundance of these types of microflora during the co-composting process. However, thermophilic microflora was more important in the beginning of the co-composting than fungi. After 30 days of the beginning, we noted a decrease of the microflora densities (Table 2). This can be explained by the variations of the windrow pH and the depletion of easy biodegradable substrates [51]. During the maturation phase, mesophilic and fungi find the optimal conditions to develop. We noted a concentration of fungi more important than thermophilic microflora. These results are consistent with previous findings [72, 73]. Overall, a decrease in the total aerobic microflora was observed in the maturation phase. This can be explained by the hygienization, the stability and the maturity of the obtained end-product after the rise of temperature and the destruction of pathogens [42, 55, 71].

Respirometric Activities Assessment

One of the most important methods for determining the composting process end product stability is the use of respirometric activities by measuring C–CO_2 production [52]. In fact, unstable compost is known by its strong demand for oxygen (O_2) and so its high C–CO_2 production rates owing to the intense development of microorganisms as a consequence of degradation of the easily biodegradable compounds in raw materials [72].

The evaluation of the respirometrics activities was assessed during the co-composting process (Fig. 4). Our results showed an optimum of the respirometric activity just 9 days after the beginning of the co-composting process. Such findings confirm previous results of physicochemical parameters and mainly the temperature evolution. In fact, at the beginning of the co-composting process the mesophilic microflora degrades the easy metabolisable molecules, which lead to an increase in the temperature promoting the development of thermophilic microflora. Then, respirometric activity decreased progressively with time incubation. In this context, previous studies confirmed that the decrease in respiration activity was attributed to the progress of the composting process and the increase of the end product maturity degree [20, 73].

Compost Quality Evaluation

The maturity of the compost is an important characteristic to be considered for the evaluation of its quality. The methods for assessing the maturity of compost are numerous because it is impossible to find a single test that can evaluate this criterion. Several authors have concluded that using a single parameter as a maturity index is insufficient and several parameters are usually needed [40, 74]. The evaluation of the quality of the compost obtained was carried out through its particle sizes, physicochemical and microbiological characterization as well as the evaluation of its phytotoxic potential.

Particle Size Determination

Despite its importance in determining the quality of the compost, particles size constitutes an important parameter

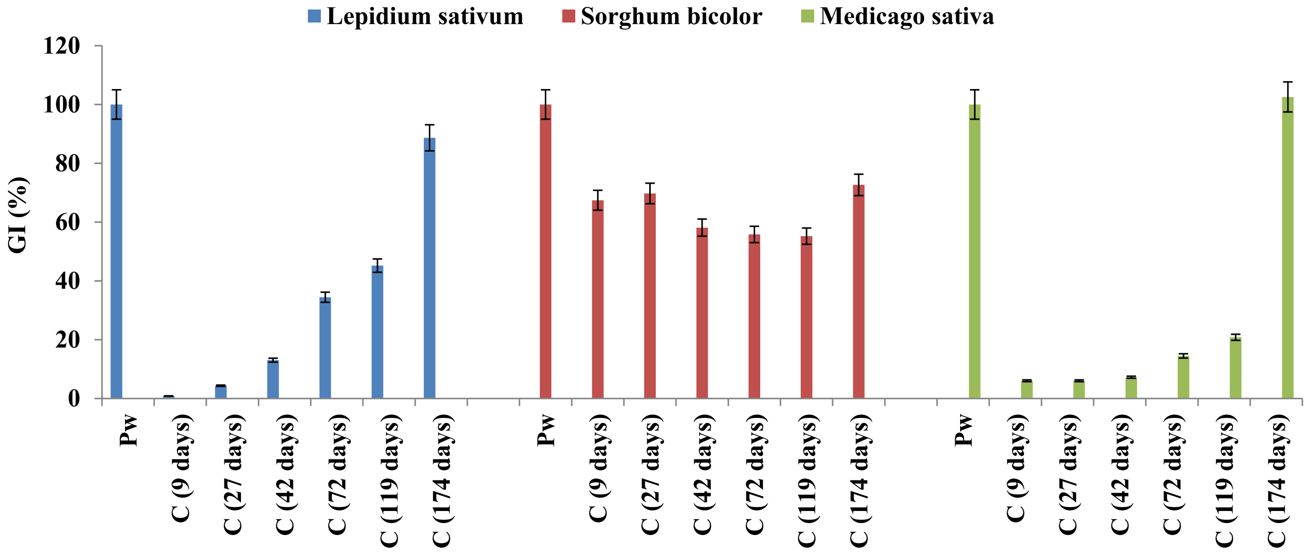


Fig. 5 Phytotoxic potential evolution as function of the co-composting period (C_9–C_{27}–C_{42}–C_{72}–C_{119} and obtained compost (C_{174}) (vs. cresson (*Lepidium sativum*), sorghum (*Sorghum bicolor*) and alfalfa (*Medicago sativa*)) seeds in comparison with pure water (Pw)

in composting, although it is not often measured. This parameter influences the porosity, aeration and the water holding capacity in co-composting process [27]. Fine elements in compost facilitate its integration in soil and then its use as biofertilizer. Table 3 illustrates the percentage of different fractions in the obtained compost. Results showed that the obtained compost has a homogeneous texture. The different fractions are divided as follows: fractions > 10 mm (1.58%), 5 < fractions < 10 mm (7.30), 2 < fractions < 5 mm (20.69) and fractions ≤ 2 mm (70.41%). The high proportion of fine particles testifies the good quality of the final compost. Indeed, according to international standards (AFNOR) concerning the appreciation of organic substances, good and rich compost has greater than 60% of fine particles (< 10 mm). Moreover, our results are in agreement with previous works [75].

Physicochemical and Microbiological Characteristics

Various physical, biological and chemical parameters were assessed to monitor the quality and maturity of the obtained compost. The end product characteristics are presented in Table 3. The compost produced has a pH (6.69) close to neutrality with a C/N ratio around 8.5 exhibiting their stability. The C/N ratio is widely used as an indicator of compost maturity [51]. Reference [76] showed that a C/N ratio of about 10 is the ideal ratio for well-matured compost. Reference [77] recorded higher values of the C/N ratio (18) in the compost obtained from manure and straw.

According to French standards (NF U 44-051, 1981), specifying and defining organic conditioners, our prepared compost could be specified as vegetal compost since their total nitrogen expressed in percentage on a dry matter basis did not exceed 3%, and their organic matter content over organic nitrogen was inferior to 55 (Table 3). Indeed, the comparison to the French standards, the composition of minerals and fertilizing confirmed the beneficial effect of this product as organic fertilizer. These results are in accordance with other previous studies valorizing olive mill wastes by co-composting [19, 20, 42, 64].

Phytotoxicity Potential Evaluation

The phytotoxicity test is one of the key indicators of the compost maturity. In order to evaluate the obtained compost phytotoxic potential, the germination indexes (GI%) of three seed species as cresson (*Lepidium sativum*), sorghum (*Sorghum bicolor*) and alfalfa (*Medicago sativa*) were determined [49]. The compost extracts were obtained from mature compost samples at the end of the composting process. Figure 5 shows the effects of the compost extracts in all used seeds germination.

The results showed GI values of 88.69%, 102% and 112% for cresson seeds, alfalfa seeds and sorghum bicolor seeds respectively, indicating the non phytotoxicity and so the maturity of the obtained compost. In fact, a GI value of 80% was used as an indicator of disappearance of phytotoxicity in compost [19, 69]. The difference between seed germination indexes values can be explained by the high resistance of alfalfa and sorghum seeds to residual toxic elements in comparison with cresson seeds, which are considerate as sensible seeds. These results are aligned with those mentioned in previous studies [78, 79].

Conclusion

This work aims at the valorization of the olive oil industry biowastes as well as the poultry manure. Such agro-wastes constitute a serious environmental problem for all olive oil producing countries such as Tunisia. The co-composting process was applied as an ecological and safety technology used for recycling biodegradable organic materials.

From the first week of the composting process, a high microbiological activity was revealed by a quick increase in temperature indicating the entry of the windrow in the thermophilic phase. Such thermophilic step was accompanied by an exponential increase in the aerobic microorganisms' number in the pile and a progressive decrease in the C/N ratio over time.

The initial biowastes mass value mixed in windrow pile was estimated to 1100 kg. After 6 months of incubation, a loss of mass about 36% from the initial mass was recorded. During the composting process the humidification was maintained by the addition of OMW. The amount of OMW added was changeable as it varies regularly depending on the windrow pile moisture. However, a quantity of 1 m^3 of OMW was used throughout the composting process. The final mass of the produced compost was around 700 kg.

The obtained compost was characterized by homogeneous particles size with a fine majority fraction, a neutral pH and a C/N ratio close to 10. It is also rich in mineral fertilizers (P, K, Ca). The evaluation of the end product phytotoxic potential was realized by the germination test measurements. Results showed that the compost extracts stimulated all the used seeds in comparison with control medium. Such findings confirm the success of the use of co-composting process to stabilize and transform the various used raw substrates in mature and hygienic compost which can be used as soil and plant biofertilizer.

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Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

References

1. Chatzistathis, T., Koutsos, T.: Olive mill wastewater as a source of organic matter, water and nutrients for restoration of degraded soils and for crops managed with sustainable systems. Agric. Water Manag. **190**, 55–64 (2017)
2. Koubouris, G.C., Tzortzakis, N., Kourgialas, N., Darioti, M., Metzidakis, I.T.: Growth, photosynthesis and pollen performance in saline water treated olive (*Olea europaea* L.) plants under high temperature. Int. J. Plant Biol. **6**, 28–32 (2015)
3. IOC.: International Olive Council, *Olivae*. No: 124 (2017)
4. Bargougui, L., Guergueb, Z., Chaieb, M., Braham, M., Mekki, A.: Agro-physiological and biochemical responses of Sorghum bicolor in soil amended by olive mill wastewater. Agric. Water Manag. **212**, 60–67 (2018)
5. Meftah, O., Guergueb, Z., Braham, M., Sayadi, S., Mekki, A.: Long term effects of olive mill wastewaters application on soil properties and phenolic compounds migration under arid climate. Agric Water Manag. **212**, 119–125 (2018)
6. Ayoub, S., Al-Absi, K., Al-Shdiefat, S., Al-Majali, D., Hijazean, D.: Effect of olive mill wastewater land-spreading on soil properties, olive tree performance andoil quality. Sci. Hortic. **175**, 160–166 (2014)
7. Rusan Munir, J.M., Albalasmeh Ammar, A., Malkawi Hanan, I.: Treated olive mill wastewater effects on soil properties and plant growth. Water Air Soil Pollut. **227**, 135–143 (2016)
8. Al-Imoor, H., Raed, I., Husam, H.Z., Oday, Z., Motasem, Z.: Germination of seeds grown on medium from olive mill liquid waste, olive mill pomace, and stone sludge waste. Chem. Mater. Res. **9**, 10 (2017)
9. Barbera, A.C., Maucieri, C., Ioppolo, C., Milani, A., Cavallaro, V.: Effects of olive mill wastewater physicochemical treatments on polyphenol abatement and Italian ryegrass (*Lolium multiflorum* Lam.) germinability. Water Res. **52**, 275–281 (2014)
10. Buchmann, C., Felten, A., Peikert, B., Munoz, K., Bandow, N., Dag, A., Schaumann, G.E.: Development of phtotoxicity and composition of soil treated with olive mill wastewater (OMW): an incubation study. Plant Soil **386**, 99–112 (2015)
11. Peri, C., Proietti, P.: Olive mill waste and by-products. In: Peri, C. (ed.) The Extra-Virgin Olive Oil Handbook, pp. 283–302. Wiley, Chichester (2014)
12. Chaari, L., Elloumi, N., Mmseddi, S., Gargougri, K., Benrouina, B., Mechichi, T., Kallel, M.: Changes in soil macronutrients after a long-term application of olive mill wastewater. J. Agric. Chem. Environ. **4**, 1–13 (2015)
13. Magdich, S., Abid, W., Boukhris, M., Ben Rouina, B., Ammar, E.: Effects of longterm olive mill wastewater spreading on the physiological and biochemical responses of adult Chemlali olive trees (*Olea europaea* L.). Ecol. Eng. **97**, 122–129 (2016)
14. Roig, A., Cayuela, M.L., Sánchez-Monedero, M.A.: An overview on olive mill wastes and their valorisation methods. Waste Manag. **26**, 960–969 (2006)
15. Khoufi, S., Feki, F., Sayadi, S.: Detoxification of olive mill wastewater by electrocoagulation and sedimentation processes. J. Hazard. Mater. **142**, 58–67 (2007)
16. Kappekalis, I.E., Tsagarakis, K.P., Crowth, J.C.: Olive oil history, production by product management. Rev. Environ. Sci. Biotechnol. **7**, 1–26 (2008)
17. Mekki, A., Dhouib, A., Feki, F., Sayadi, S.: Review: effects of olive mill wastewater application on soil properties and plants growth. Int. J. Recycl. Org. Waste Agric. **2**, 15 (2013)
18. Mekki, A., Aloui, A., Guergueb, Z., Braham, M.: Agronomic valorization of olive mill wasteswaters: effects on medicago sativa growth and soil characteristics. CLEAN-Soil Air Water **46**, 9 (2018)
19. Hachicha, S., Chtourou, M., Medhioub, K., Ammar, E.: Compost of poultry manure and olive mill wastes as an alternative fertilizer. Agron. Sustain. Dev. **26**, 135–142 (2006)
20. Mekki, A., Arous, F., Aloui, F., Sayadi, S.: Treatment and valorization of agro-wastes as biofertilizers. Waste Biomass Valor. **8**, 1877–2641 (2016)

21. Bustamante, M.A., Restrepo, A.P., Alburquerque, J.A., Bernal, M.P., Murcia, P., Paredes, C., Moral, R.: Recycling of anaerobic digestates by composting: effects of the bulking agent used. J. Cleaner Prod. **47**, 61–69 (2013)
22. Dennehy, C., Lawlor, P.G., Jiang, Y., Gardiner, G.E., Xie, S., Nghiem, L.D., Zhan, X.: Greenhouse gas emissions from different pig manure management techniques: a critical analysis. Front. Environ. Sci. Eng. **11**, 11–16 (2017)
23. Nicholson, F.A., Chambers, B.J., Smith, K.A.: Nutrient composition of poultry manures in England and Wales. Bioresour. Technol. **58**, 279–284 (1996)
24. Wong, J.W.C., Ma, K., Fang, K.M., Cheung, C.: Utilization of manure compost for organic farming in Hong Kong. Bioresour. Technol. **67**, 43–46 (1999)
25. GDAP.: General Directorate of Agricultural Production, Tunisia. Statistics (2015)
26. Dhyani, V., Awasthib, M.K., Wang, Q., Kumara, J., Ren, X., Zhao, J., Chen, H., Wang, M., Bhaskara, T.H., Zhang, Z.: Effect of composting on the thermal decomposition behavior and kinetic parameters of pig manure-derived solid waste. Bioresour. Technol. **252**, 59–65 (2018)
27. Colon, J., Ponsá, S., Álvarez, C., Vinot, M., Lafuente, F., Gabriel, D., Sánchez, A.: Analysis of MSW full scale facilities based on anaerobic digestion and/or composting using respiration indices as performance indicators. Bioresour. Technol. **236**, 87–96 (2017)
28. Sánchez- Garcia, M., Alburquerque, J.A., Sánchez-Monedero, M.A., Roig, A., Cayuela, M.L.: Biochar accelerates organic matter degradation and enhances N mineralization during composting of poultry manure without a relevant impact on gas emissions. Bioresour. Technol. **192**, 272–279 (2015)
29. Bernal, M.P., Alburquerque, J.A., Moral, R.: Composting of animal manures and chemical criteria of compost maturity assessment. Bioresour. Technol. **100**, 544–553 (2009)
30. Sadef, Y., Bester, K., Poulsen, T.: Modeling organic micro pollutant degradation kinetics during sewage sludge composting. Waste Manage **34**, 11 (2014)
31. Vázquez, M.A., Soto, M.: The efficiency of home composting programs and compost quality. Waste Manage. **64**, 39–50 (2015)
32. Sullivan, D.M., Bary, A.I., Miller, R.O., Brewer, L.J.: Interpreting compost analyses. In: Proceedings of the International Conference on Soils Across latitudes. San Diego, California (2018)
33. Aranda, V., Macci, C., Peruzzi, E., Masciandaro, G.: Biochemical activity and chemical-structural properties of soil organic matter after 17 years of amendments with olive-mill pomace co-compost. J. Environ. Manage. **147**, 278–285 (2014)
34. Gargouri, K., Masmoudi, M., Rhouma, A.: Influence of olive mill wastewater (OMW) spread on carbon and nitrogen dynamics and biology of an arid sandy soil. Commun. Soil Sci. Plant Anal. **45**, 1–14 (2014)
35. García-Ruiz, R., Ochoa, M.V., Hinojosa, M.B., Gomez, B.: Improved soil quality after 16 years of olive mill pomace application in olive oil groves. Agron. Sustain. Dev. **32**, 803–810 (2012)
36. Sánchez, M., González, J.L., Díez, M.A., Guimarães, A.C., Navas, L.M.: Treatment of animal carcasses in poultry farms using sealed ditches. Bioresour. Technol. **99**, 7369–7376 (2008)
37. Lozano-García, B., Parras, L.: Short-term effects of olive mill byproducts on soil organic carbon, total N, C:N ratio and stratification ratios in a Mediterranean olive grove. Agric. Ecosyst. Environ. **165**, 68–73 (2013)
38. Gomez, B., Hatch, D.J., Bol, R., García-Ruiz, R.: Agrochemical characterization, net N mineralization, and potential N leaching of composted olive mill pomace currently produced in southern Spain. J. Plant Nutr. Soil Sci. **176**, 655–664 (2013)
39. Wafi, T., Ben Othman, A., Besbes, M.: Qualitative and quantitative characterization of municipal solid waste and the unexploited potential of green energy in Tunisia. Bioresour. Bioprocess. **6**, 39 (2019)
40. Zhang, L., Sun, X.: Improving green waste composting by addition of sugarcane bagasse and exhausted grape marc. Bioresour. Technol. **218**, 335–343 (2016)
41. Sierra, J., Marti, E., Garau, M.A., Cruanas, R.: Effects of the agronomic use of olive oil mill wastewater: field experiment. Sci. Tot. Environ. **378**, 90–94 (2007)
42. Majbar, Z., Rais, Z., El Haji, M., Ben Abbou, M., Bouka, H., Nawdali, M.: Olive mill wastewater and wine by-products valorization by co-composting. JMES **8**(9), 3162–3167 (2017)
43. Kandeler, E.: Total nitrogen. In: Shinner, F., Ohlinger, R., Kandeler, E., Margesin, R. (eds.) Methods in Soil Biology, pp. 406–408. Springer, Berlin (1995)
44. Olsen, S.R., Sommers, L.E.: Phosphorus. In A.L. Page et al., (ed) Methods of soil analysis. Agronomy **9**, 403–430 (1982)
45. Ohlinger, R.: Soil respiration by titration. In: Schinner, F., Kandeler, E., Ohlinger, R., Margesin, R. (eds.) Methods in Soil Biology, pp. 95–98. Springer, Berlin (1995)
46. Box, J.D.: Investigation of the Folin-Ciocalteau phenol reagent for the determination of polyphenolic substances in natural waters. Water Res. **17**, 511–522 (1983)
47. Mekki, A., Dhouib, A., Sayadi, S.: Changes in microbial and soil properties following amendment with treated and untreated olive mill wastewater. Microbiol. Res. **161**, 93–101 (2006)
48. Mekki, A., Aloui, F., Dhouib, A., Sayadi, S.: Effects of Phanerochaete chrysosporium on biologic activity of soil amended with olive mill wastewaters. J. Soil Sci. Environ. Manag. **3**, 1–8 (2012)
49. Zucconi, F., Forte, M., Monaco, M., De Bertoldi, M.: Biological evaluation of compost maturity. Biocycle **22**, 27–29 (1981)
50. Belaqziz, M., El-Abbassi, A., Lakhal, E., Agrafioti, E., Galanakis, C.: Agronomic application of olive mill wastewater: effects on maize production and soil properties. J. Environ. Manag. **171**, 158–165 (2016)
51. Sellami, F., Hachicha, S., Chtourou, M., Medhioub, K., Ammar, E.: Maturity assessment of composted olive mill wastes using UV spectra and humification parameters. Bioresour. Technol. **99**, 690–706 (2007)
52. Komilis, D., Kletsas, C.: Static respiration indices to investigate compost stability: effect of sample weight and temperature and comparison with dynamic respiration indices. Bioresour. Technol. **121**, 467–470 (2012)
53. Sellami, F., Jarboui, R., Hachicha, S., Medhioub, K., Ammar, E.: Co-composting of oil exhausted olive-cake, poultry manure and industrial residues of agro-food activity for soil amendment. Bioresour. Technol. **99**(5), 1177–1188 (2008)
54. Rigane, H.: Valorization of organic discharges through the composting process for soil amendment: agronomic and environmental interests. Sci. Compost. **33**, 12–57 (2014)
55. Kopeć, M., Gonde, K., Mierzwa-Hersztek, M., Zaleski, T.: Effect of the composting process on physical and energetic changes in compost. Acta Agrophys. **23**, 607–619 (2016)
56. Katheem, S., Kiyasudeen, M.H., Ibrahim, S., Quaik, S., Ismail, A.: Prospects of Organic Waste Management and the Significance of Earthworms. Springer, Berlin (2015)
57. Li, Z., Lu, H., Ren, L., He, L.: Experimental and modeling approaches for food waste composting: a review. Chemosphere **93**, 1247–1257 (2013)
58. Yuan, J., Chadwick, D., Zhang, D., Li, G., Chen, S., Luo, W., Du, L., He, S., Peng, S.: Effects of aeration rate on maturity and gaseous emissions during sewage sludge composting. Waste Manag. **56**, 403–410 (2016)
59. Soudi, B.: Composting of household waste and valorisation of compost: the case of small and medium towns in Morocco. Actes, 104 (2001)

60. Osada, T., Sommer, S.G., Dahl, P., Rom, H.B.: Gaseous emission and changes in nutrient composition during deep litter composting. Soil Plant Sci. **51**, 137–142 (2001)
61. Karolina, M., Mária, K.: Influence of compost covers on the efficiency of biowaste composting process. Waste Manag. **30**, 2469–2474 (2010)
62. Jusoh, M.L., AdbelManaf, L., Abdullatiff, P.: Composting of rice straw with effective microorganisms (EM) and its influence on compost quality. Environ. Health Sci. Eng. **10**, 17 (2013)
63. Sundberg, C., Jonsson, H.: Higher pH and faster decomposition in biowaste composting by increased aeration. Waste Manag. **28**, 518–526 (2008)
64. Abid, N., Sayadi, S.: Detrimental effects of olive mill wastewater on the composting process of agricultural wastes. Waste Manag. **26**, 1099–1107 (2007)
65. Fogarty, A.M., Tuovinen, O.H.: Microbiological degradation of pesticides in yard waste composting. Micobiol Rev. **55**, 225–233 (1991)
66. Smars, S., Gustafsson, L., Beck-Friis, B., Jonsson, H.: Improvement of the composting time for household waste during an initial pH phase by mesophilic temperature control. Bioresour. Technol. **84**, 237–241 (2002)
67. Paredes, C., Cegarra, J., Bernal, M.P., Roig, A.: Influence of olive mill wastewater in composting and impact of the compost on a Swiss chard crop and soil properties. Environ Int. **31**, 305–312 (2005)
68. Chaari, L., Elloumi, N., Mmseddi, S., Gargougri, K., Benrouina, B., Mechichi, T., Kallel, M.: Effects of olive mill wastewater on soil nutrients availability. Int. J. Interdiscip. Multidiscip. Stud. **2**, 175–183 (2014)
69. Francou, C.: Stabilization of organic matter during composting of urban waste: Influence of the nature of the waste and the composting process, Search for relevant indicators. **18**, (2003)
70. Ieshita, P., Dam, B., Sen, S.K.: Composting of common organic wastes using microbial inoculants. 3Biotech **2**, 127–134 (2012)
71. Cerda, A., Artola, A., Font, X., Barrena, R., Gea, T., Antoni Sánchez, A.: Composting of food wastes: status and challenges. Bioresour. Technol. **248**, 57–67 (2017)
72. Chroni, C., Kyriacou, A., Manio, T., Lasaridi, K.-E.: Investigation of the microbial community structure and activity as indicators of compost stability and composting process evolution. Bioresour. Technol. **100**, 3745–3750 (2009)
73. Adani, F., Ubbiali, P., Genevini, P.: The determination of biological stability of composts using the dynamic respiration index: the results of experience after 2 years. Waste Manag. **26**, 41–48 (2006)
74. Aparna, P., Shanthi Priya, M., Mohan Reddy, D., Latha, P.: Estimation of genetic parameters in groundnut (*Arachis hypogaea* L.) for yield and it's contributing characters under inorganic fertilizer managements. Int. J. Curr. Microbiol. Appl. Sci. **7**, 1559–1565 (2018)
75. Compaoré, E., Nanéma, L.S.: Composting and compost quality of solid urban waste in the city of Bobo-Dioulasso, Burkina Faso. Tropicultura **28**, 232–237 (2010)
76. Pathak, A.K., Singh, M., Kumar, V.: Composting of municipal solid waste: a sustainable waste management technique in Indian cities—a review. Int. J. Curr. Res. **3**, 246–339 (2011)
77. Wang, X., Pan, S., Zhang, Z., Lin, X., Zhang, Y., Chen, S.: Effects of the feeding ratio of food waste on fed-batch aerobic composting and its microbial community. Bioresour. Technol. **224**, 397–404 (2017)
78. Antil, R.S., Raj, D., Inubushi, K.: Physical, chemical and biological parameters for compost maturity assessment: a review. Compost. Sustain. Agric. **83**, 101 (2014)
79. Temgoua, E., Ngnikam, E., Dameni, H., Kameni, G.S.: Valorization of garbage by composting in the city of Dschang, Cameroun. Tropicultura **32**, 28–36 (2014)