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Fertilizing power evaluation of different mixtures of organic household waste and olive pomace

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Abstract. From the perspective of sustainable agriculture established by the Green Morocco Plan, it is interesting to direct research more towards the agronomic valorization of olive pomace, to give birth to a clean olive growing which leads to a viable economy thus respecting a pillar of sustainable development. Several studies have shown the effectiveness of using olive pomace as a soil amendment. Therefore, in this study we want to increase the agricultural performance of olive pomace by composting by mixing it with other waste.
Morocco is considered one of the major olive-producing countries with an annual production of 1.41 million tonnes (MT), part of it is dedicated to olive oil production. Morocco produces approximately 26.8 MT of waste annually, 8.3 MT are household waste, 70% are organic household waste (5.8 MT). The current production of organic household waste in urban areas is estimated at 4.8 million tonnes per year, or an average of 0.76 kg hab^{-1} day^{-1}, and in rural areas 1 million tonnes per year, or an average of 0.30 kg hab^{-1} day^{-1} (SNRVD, 2015). Agri-food industry waste is around 3 million tonnes with 600,000 to 700,000 tonnes of olive oil waste (pomace) (Agricultural Development Agency, 2018). The rejection of this waste without any prior treatment contributes to the environment deterioration. However, a large part of this waste remains recoverable, which would reduce both waste volume to be eliminated and the associated management cost. This; will contribute to reducing the negative impacts on receiving environments and the cost of restoring the environment state, and ensuring a transition towards a circular economy. Our work is part of the context of solid waste management and recovery, in particular organic waste from household and food-processing activities, and is oriented towards the pomace recovery by composting, mixing it with different percentages of organic household waste.
This work consists on composting olive pomace from the three phases system with another structural agent (organic household waste). Comparing the mixtures (6 treatments) with different concentrations in terms of composting process parameters (pH, electrical conductivity, organic matter temperature, etc.), organic matter evolution and composts quality, with manual aeration of the compost, in order to increase the agricultural yield of the olive pomace. Residues from the fermentation process can be used in agriculture. All the different mixtures of the different percentages are characterized at the initial state and at the end of the composting process in order to highlight their nutritional values.

Key words: olive pomace, compost, organic household waste, physico-chimical and bacteriological characterization.

INTRODUCTION

Morocco is one of the major olive-producing countries with an annual production of 1,414,000 tons. National production of olive oil is estimated at 142,000 t year^{-1} on average between 2015 and 2019 (Ministry of Agriculture, Maritime Fisheries, Rural Development and Waters and Forests, 2022).

Olive waste valorization represents a great source of additional income for the olive farms (Messineo et al., 2019). It can be used as fertilizer, fuel, livestock and as a thermal insulator as a contraction material (Chouchene, 2010).

In recent decades, this increase in production and the introduction of modern oil extraction technologies have placed the olive tree in a delicate position as a potential polluter. The environmental problem of olive pomace remains unresolved in the olive-growing countries, particularly in the countries on the southern coast of the Mediterranean such as Morocco, which have begun to modernize the industrial sector through vast programs with the aim of increasing and improve the quality of olive production. It is therefore necessary to find effective and feasible solutions in these developing olive countries. Olive oil production generate by-products such as olive pomace and olive mill wastewater, also known as black water. They have a significant impact on the environment such as threat to the aquatic life, odors, impenetrable film causing negative impact for oxygen transfer, discoloring of natural waters and toxicity (Yaya et al., 2012). As an example, OWW spread on the soil could increase pollution risks because of the presence of phenolic compounds and other pollutants, especially when it is not evenly distributed on the soil and the correct doses are not applied (Montemurro et al., 2004).

On the other hand, intensive agricultural practices will lead to the soil organic matter depletion. This organic matter loss will lead to a decrease of the soil structure stability and a decrease in the retention of pollutants (organic or mineral). One of the ways to solve these different soil problems is to add external organic matter. To solve these environmental and agronomic problems, there are different solutions, including composting. Indeed, the organic matter abundance in olive pomace proves that this method is reasonable, and it can establish a link between the management of these olive by-products and agriculture. Human has started using the organic amendments; he has turned to the organic farming based on fertilizing soil with organic matter, which represents a nutrients reservoir, and plays a major role in the physical soil fertility, its aeration and its resistance to erosion and degradation (Girard et al., 2005).

The use of olive pomace in the agriculture as an organic amendment has shown some problems in plant growth, because of their high organic matter, mineral salts, the acidic pH and the presence of phytotoxic compounds (Del Buono et al., 2011; Gigliotti et al., 2012; Proietti et al., 2015). Therefore, composting is a better way to stabilize the high organic content and benefit from the pomace fertilizing power (Gómez-Muñoz et al., 2012). Nevertheless, no negative effects were observed when raw pomace was used as an amendment on soil fertility parameters (Ameziane et al., 2019). Similar studies have shown that composting olive pomace improves the physical and chemical characteristics of the soil, and provides the necessary nutrients for plant growth (nitrogen, potassium and phosphorus) (Sellami et al., 2008; Del Buono et al., 2011).

Composting is one of the solutions proposed to recycle waste (particularly pomace) from olive oil factories. Composting olive waste has been proven to produce very good quality compost. Composting aims to aerobically converting organic matter into humus while destroying pests and pathogenic microorganisms (Hay et al., 1996).

In addition, the use of compost in agriculture helps protect the soil by reducing the use of chemical fertilizers. Organic materials are increasingly used in agriculture as a fertilizer but also as a soil conditioner. Organic matter is a key component of soil, which affects its physical, chemical and biological properties (Hassink et al., 1997; Herold et al., 2014). Several studies showed the positive effect of organic product amendment or along with mineral fertilizer to cultivated soils (Alvarez et al., 1998; Goyal et al. 1999; Blair et al., 2006; Gong et al., 2009; Butler & Hooper, 2010; Evans et al., 2012; Zhou et al., 2013; Cannavo et al., 2014). It is in this context that this work focuses on the valorization of olive by-products. OP compost could be used as suitable soil amendment, ensuring at the same time an eco-friendly recycling of waste materials. It can optimize organic emmer yield production, sustain soil fertility, and reduce pollution risks linked to the landfill disposal (Diacono & Montemurro, 2019).

The objective is to valorize by composting the olive pomace; resulting from the three phases system to evaluate the agronomic quality of the pomace as a soil amendment; with organic household wastes in order to evaluate the composts quality.

For this, we made six mixtures of different composition based on olive pomace associated with different percentages of organic household waste. Physicochemical and bacteriological characterization of the different mixtures at the initial state called time zero (T_0) and once the compost is mature (T_f).

MATERIALS AND METHODS

Sampling

The pomace used in this study was collected from a crushing unit with a three phases extraction system located in Tiflet city (Tiflet, Morocco, latitude: 33°53′40″ North, longitude: 6°18′23″ West, altitude above sea level: 340 m), it is a city in the province of Khemisset, in the Rabat Salé Kénitra region (Fig. 1). For organic household waste, was generated from the wholesale market in the city of Salé (Salé, Morocco, latitude: 34° 1' 54.476" North, longitude: 6° 46' 17.494" West, altitude above sea level: 34 m). Organic household waste were cut into small pieces between 1 and 2 cm before starting the composting process (Fig. 2).

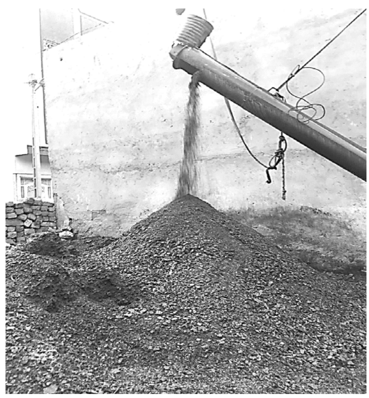


Figure 1. Olive pomace in the olive oil extraction unit (raw material).

The composting experiment consists on mixing olive pomace with another structural agent, which is organic household waste. Composting is carried out in 30 liters barrels (Ameziane et al., 2020), perforated to ensure a good aeration and placed in a sunny place (Manu et al., 2016). For the mechanical aeration, it had been performed many times, at the beginning of the composting process (the mesophilic phase) and at the end of the thermophilic phase and at the beginning of the cooling phase. Piles were supplied with air and turned periodically to ensure good aeration in order to promote aerobic fermentation and the humidity was monitored and adjusted.

Figure 2. Organic household waste from the wholesale market (raw material).

This method is based on forced aeration and mechanical turning devices, which aim to speed up the composting process. We chose to compost a sample well mixed and homogenized and then put into barrels in order to determine a better concentration at the level of the fertilizing elements (Manu et al., 2017). Then, the best concentration will be destined for application with large quantities. As a result, these results obtained at the laboratory scale can be reproduced in full-scale installations by adjusting the forced aeration according to the available equipment.

From the two raw materials, pomace (Gr) and organic household waste (D), four mixtures with different percentages were prepared: GD1; GD2; GD3 and GD4, ranging from 15% to 50% pomace and 85% to 50% organic household waste (Table 1). The composts stability and maturity are achieved after almost 120 days.

Table 1. Mixtures percentages

Mixtures	Percentages
Gr	100% olive pomace
D	100% household organic waste
GD1	15% olive pomace + 85% household organic waste
GD2	25% olive pomace + 75% household organic waste
GD3	43% olive pomace + 57% household organic waste
GD4	50% olive pomace + 50% household organic waste

Physico chemical characterization

In order to characterize the mixtures (raw materials and composts) from a physico-chemical perspective, a representative sample is dried in an oven in a temperature between 40 °C and 60 °C, ground and sieved to 2 mm to determine the pH and EC, and to 0.2 mm to determine the other mineral elements.

The pH is measured by a pH meter (Orion Star A111), while the electrical conductivity (EC) is measured by a conductivity meter (Orion Star A212). pH and EC are measured in the aqueous extract using the ratio 2:5 (w/v) for pH (Rodier et al., 2009), and the ratio 1:5 (w/v) for EC (ISO 11265, 1994).

The moisture content is determined by drying the sample at 105 °C until a constant mass is obtained (Rodier et al., 2009). Organic matter was characterized by ignition loss at 525 °C for 4 hours (Rodier et al., 2009). The measurement of Nitrate (NO_3^-), Ortophosphate (PO_4^{3-}) and Sulfate (SO_4^{2-}) were measured by the molecular absorption spectrometry method (Rodier et al., 2009).

However, the other minerals were obtained by calcination in the oven at 500 °C for 2 hours to 3 hours; the obtained ashes were dissolved to determine the other mineral elements (Pinta, 1979).

Total nitrogen and ammoniacal nitrogen were measured by the Kjeldahl method (Rodier et al., 2009), total organic carbon (Dabin, 1970). The macroelements (P_2O_5, K_2O, Na_2O, CaO, MgO, Cl^-…) were determined in the Research Unit on Environment and Natural Resource Conservation at the Institut National de Recherche Agronomique Rabat laboratory. P_2O_5 was obtained by the Olsen method (Olsen, 1954). Whereas for assimilable potassium (K_2O) and sodium (Na_2O) were measured by flame spectrometry (Bower et al., 1952). CaO and MgO were obtained by the atomic absorption spectrometry (Pinta, 1979).

The results of the physico-chemical analyses of the raw materials to be composted are presented in table (Table 2).

Table 2. Physical-chemical characterization of the raw materials used for the composting process (pomace and organic household waste)

Raw materials in the beginning of composting process (T_0)	Olive pomace	Organic household waste
pH	5.05 ± 0.53	6.18 ± 0.33
Electrical conductivity (EC) mS cm^{-1}	1.77 ± 0.10	0.72 ± 0.04
Moisture, %	26.52 ± 3.46	91.10 ± 3.16
Organic matter (OM), %	92.35 ± 2.46	89.87 ± 2.38
Ash, %	7.65 ± 2.46	10.13 ± 2.38
Total organic carbon (TOC), %	53.57 ± 1.43	52.13 ± 1.38
Total nitrogen (NTK) %	1.27 ± 0.04	1.57 ± 0.02
C/N ratio	42.23 ± 1.40	33.28 ± 0.46
Orthophosphate (PO_4^{3-}), %	0.0187 ± 0.0013	0.0655 ± 0.0044
Available phosphorus (P_2O_5), %	0.007 ± 0.001	0.014 ± 0.002
Calcium (CaO), %	0.22 ± 0.007	0.12 ± 0.005
Magnesium (MgO), %	0.08 ± 0.005	0.14 ± 0.005
Potassium (K_2O), %	0.46 ± 0.001	1.52 ± 0.002
Sodium (Na_2O), %	0.05 ± 0.001	0.27 ± 0.002
Chloride (Cl^-), %	0.0185 ± 0.001	0.0235 ± 0.001
Sulfate (SO_4^{2-}), %	0.0035 ± 0.0006	0.0042 ± 0.0007
Nitrate (NO_3^-), mg kg^{-1}	57.55 ± 10.37	127.32 ± 27.29
Ammonium nitrogen (NH_4^+), mg kg^{-1}	526.01 ± 41.78	728.29 ± 22.31

The values obtained represent the average of three repetitions.

Microbiological characterization

The bacteriological characterization of the different samples was carried out at the beginning and at the end of the composting process. For faecal pollution indicators (CT, CF and E. Coli), were counted by the 3 tube NPP method (Rodier et al., 2009).

While, the count of the total aerobic mesophilic flora (FMAT) and the thermophilic flora (FT) is made by counting colonies on PCA (Plate Count Agar) and incubated respectively) at 30 °C and 44 °C for 72 hours (Rodier et al., 2009).

The counting of fungi is done on Sabouraud agar with chloramphenicol at 5 µg mL^{-1} (yeasts and molds) and incubated at 25 °C in the dark for 72 hours (NM 08.0.123., 2004). The enumeration of lactic acid bacteria is carried out by counting on MRS and incubated at 30 °C. for 72 hours (Guiraud, 1998). Salmonella were observed by inoculation on S-S Agar to determine their presence at 37 °C for 24 to 48 hours (Rodier et al., 2009).

RESULTS AND DISCUSSION

Composts monitoring

Temperature

In this study, the temperature evolution shows different phases during the composting process. It shows in the beginning of the process that the initial temperature is almost the same for all the mixtures (Fig. 3). From the 28^{th} day, the temperature starts increasing for all the treatments to achieve a maximum values at the 84^{th} day, with a high temperature (61.22 °C) for the Gr compost. This temperature increase in the thermophilic phase due to the microbiological activity especially the intense thermophilic microorganism's activity (Mustin, 1987). However, these temperature values remain below 70 °C, which is necessary for a living organism's destruction (Bernal et al., 2009). In addition, heat production by microorganisms is proportional to the mass of the pile (Golden, 1986). However, after the thermophilic phase a temperature decrease was observed. We are talking about the maturation phase, which shows a decrease in temperature to stabilize close to the ambient temperature at the end of the composting process.

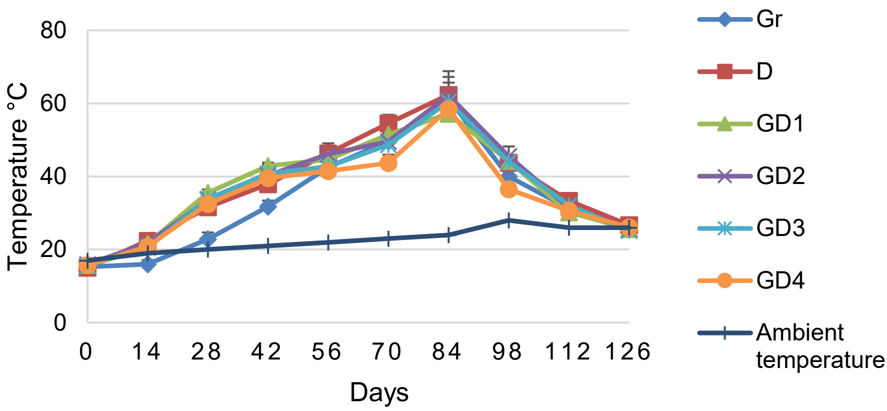


Figure 3. Evolution of the temperature during composting.

pH

The pH is an essential factor, which enters into the majority of the reactions, which allows the bioavailability of the nutrients and the solubility of the mineral elements for the microorganisms.

The pH of the two wastes used and the mixtures are acidic in the initial state with a pH ranging from 5.05 in olive pomace to 6.18 in organic household waste.

During the composting process, all mixtures have nearly the same movement, which they starts by an acidogenic phase then they move to an alkaline phase to stabilize at the end of the composting process near to a neutral pH.

At the beginning of the composting process, a minimum value was observed after 14 days for the GD1 (4.55 ± 0.35). Then, the pH of all mixtures has started increasing to reach a maximum value at the 84th day (8.77 ± 0.10 for the D compost). At the end of the composting process, the pH had a downtrend as to the neutrality for all the treatments with a minimum of (7.31 ± 0.17) in GD4 and a maximum of (7.9 ± 0.29) in olive pomace, this is the maturation phase (Fig. 4).

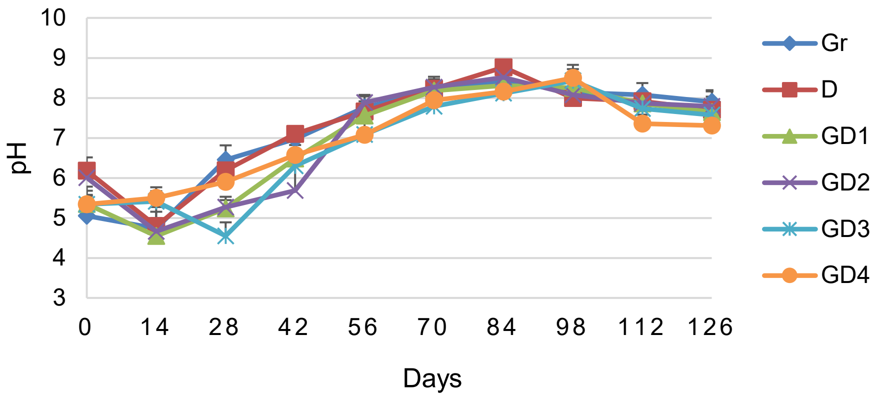


Figure 4. Temporal evolution of pH during composting.

A close pH values were observed at the end of the composting process in a study made by Ameziane et al. (2020) with an olive pomace from Fès-Meknès region mixed with poultry droppings (7.63 ± 0.12) and mixed with cow manure (8.16 ± 0.03).

However, organic household waste pH at T_0 (6.18 ± 0.33) remains lower than other household waste whose pH was neutral (pH = 7.5) (Chennaoui et al., 2016). The types of organic household waste related to seasonal vegetables and fruits can explain this difference in pH.

The pH of pomace at T_0 (5.05 ± 0.53) remains close to the pH of other olive pomace which have a pH of around 5.9 to 6.04 in Fez-Meknes region (Ameziane et al., 2018).

Similarly, a similar pH was observed in an Italian study on the use of solid waste from olive oil as a soil amendment (pH = 6.6) (Nasini et al., 2013). However, pH alkalinity towards the end of the process is characterized by ammonia production due to the degradation of protein amines in addition to the release of bases bound to organic matter (Kochtizky et al., 1969; Gray et al., 1971; Peters et al., 2000). A slightly alkaline pH of products or compost, at the end of the composting process, as a soil amendment is favorable for the assimilation of nitrogen, phosphorus and potassium, which is necessary for plant development (Nefzaoui, 1985). In addition, a pH close from 6 to 8 ensures the development of bacteria and fungi responsible for the organic matter degradation (Mennane et al., 2010).

In the acidogenic phase, the pH decrease can be explained by the organic acids production following the carbohydrates degradation, fats and other substances. During the aerobic degradation, the CO_2 produced contributes to the environment acidification, by dissolving it in water and producing the carbonic acid (Mustin, 1987). This pH decrease promotes the fungi growth and the lignin and cellulose degradation (Paredes et al., 1999).

Electrical conductivity

Electrical conductivity shows the compost salinity degree, and indicates its effectiveness in phytotoxicity tests and when used as a fertilizer for plant growth (Lin, 2008).

During the composting process, the electrical conductivity of the different piles fluctuates due to the organic matter degradation.

The conductivity underwent a decrease for the majority of the mixtures. However, organic household waste and the GD4 mixture showed a small increase (Fig. 5).

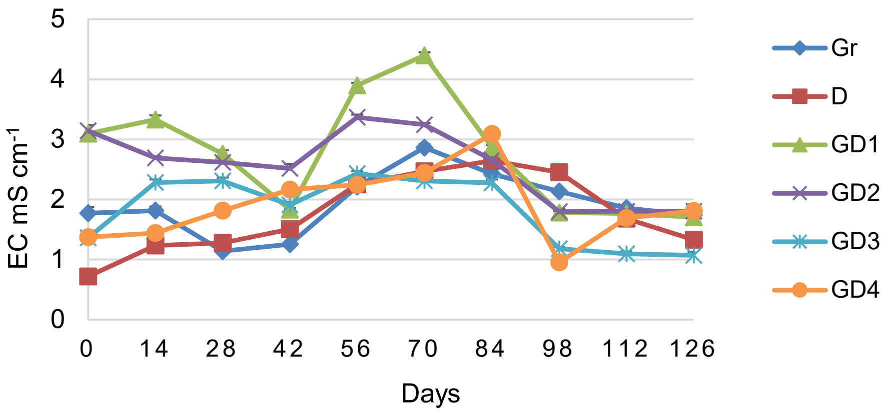


Figure 5. Electrical conductivity evolution during the composting process.

The lowest conductivity was recorded in organic household waste at T_0 from 0.72 mS cm^{-1} to 1.33 mS cm^{-1} in T_f. This value remains quite low compared to that found in other household waste (4.9 mS cm^{-1}) (Chennaoui et al., 2016) and in other waste such as olive pomace in T_0 (1.77 mS cm^{-1}). The latter remains close to that found in olive pomace (1.883 ± 0.56 mS cm^{-1}) from Fez-Meknes (Ameziane et al., 2020).

The electrical conductivities obtained in this study at the end of the composting process, were lower than those found by Ameziane et al. (2020) in a compost by olive pomace and poultry droppings (2.1 ± 0.45 mS cm^{-1}) and a compost by olice pomace and cow manure (2.06 ± 0.22 mS cm^{-1}).

The final product conductivity of all composts does not exceed the limit value of 3 mS cm^{-1} (Soumaré et al., 2002), so their use cannot harm plant growth. Generally, composts with low electrical conductivity can be used directly on the ground, while composts with high conductivity must be well mixed with other agents such as soil or other materials that have low electrical conductivity (Chen, 1999).

Moisture evolution

Humidity is a very important parameter for greater microbial activity, which accelerates the composting process (Chennaoui et al., 2016).

With the exception of olive pomace, which has a humidity equal to 26.5%, humidity shows a decrease from 92.1% at T_0 to 26.41% at T_f in organic household waste. These moisture contents underwent a significant decrease towards the end of the process with a minimum content of 12.36% in the GD1 mixture.

From the 42^{sd} day, the thermophilic phase have already begun, which is manifested by a decrease in the humidity level of the composts (Jemali et al., 1996). During composting, moisture records the greatest rate of decrease (83.25%) in the GD1 mix. (Fig. 6).

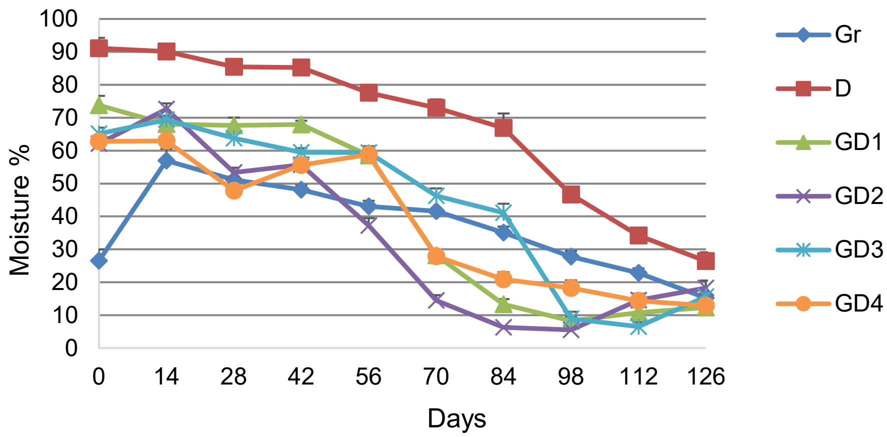


Figure 6. Moisture evoluuion during the composting process.

This decrease in humidity amounts to the decrease in water in all composts, either by leaching or by evaporation under the effect of the increase in temperature due to microbial activity during composting (Jemali et al., 1996).

These results have been much lower than those found in a compost by olive pomace and poultry droppings (30 ± 0.3%) and a compost by olive pomace and cow manure (30.4 ± 0.14%) (Ameziane et al., 2020).

Organic matter and ash evolution

Initially, the loss on ignition remains above 85% in all the mixtures with a maximum value of 95.80% observed in the GD3 mixture (Fig. 7).

The olive pomace value at T_0 in this study remains higher than that observed in pomace from Fez-Meknes region (77.02% ± 0.08%) at T_0 (Ameziane et al., 2020). However, the rate of organic matter recorded in household waste in T_0 (89.87%) remains very close to that of other household waste (92%) (Chennaoui et al., 2016).

Composting is an organic matter degradation, so a decrease in organic matter concentration is expected as the main result during composting (Ameziane et al., 2020), which is remarkable for all treatments.

During composting, the organic matter rate decreases with a rate that varies between 53.78% (GD1) and 43.02% (G). A close organic matter rates were observed at the end of the composting process in a study with an olive pomace from Fès-Meknès region mixed with poultry droppings (43.15 ± 0.15%) and mixed with cow manure (38.4 ± 0.76%) (Ameziane et al., 2020).

However, the mineral matter rate increases with a maximum rate in the GD3 mixture (91.16%) due to mineralization by microorganisms (Fig. 7).

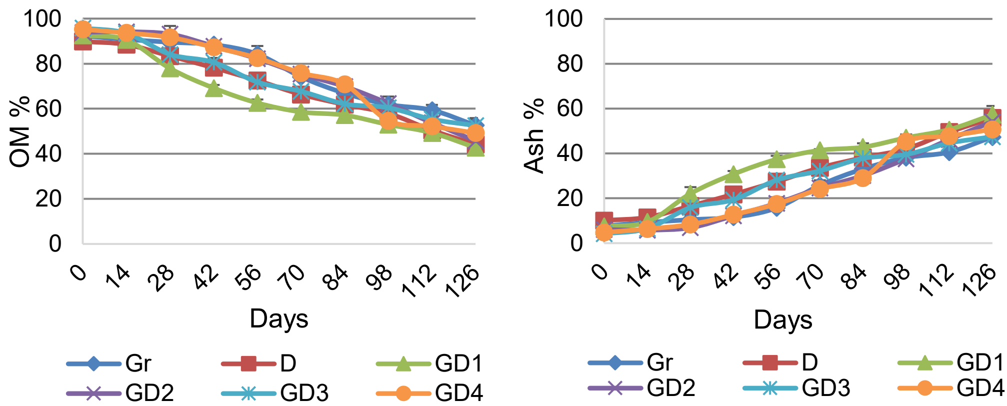


Figure 7. Organic matter and ashes evolution.

This significant organic matter loss can be reflected in a decrease in volatile solids and total organic carbon throughout the process (Ameziane et al., 2020 in Garcia-Gomez et al., 2003), which is due to the presence of relatively stable organic compounds probably represented by lipids, polyphenols, lignins, cellulose, hemicellulose and pectin (Aviani et al., 2010; Michailides et al., 2011; Tortosa et al., 2012).

The organic matter content diminution is ensured by different groups of microorganisms that work according to the temperature evolution and the compost mass (Keener et al., 2000). Furthermore, bacteria leads the composting phase early, while fungi are present throughout the process, but are very active at water levels below 35% and inactive at temperatures above 60 °C (Bernal et al., 2009). As well as fungi, actinomycetes predominate during the maturation phase, which have the ability to degrade very resistant polymers (Bernal et al., 2009; Federici et al., 2011; Agnolucci et al., 2013).

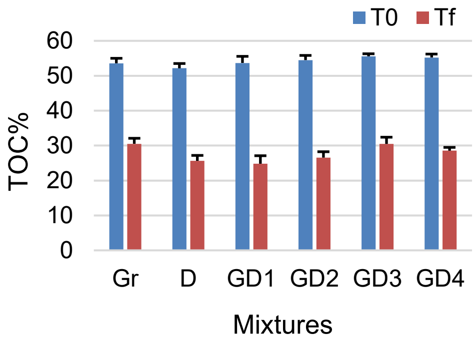
Macro-elements parameters

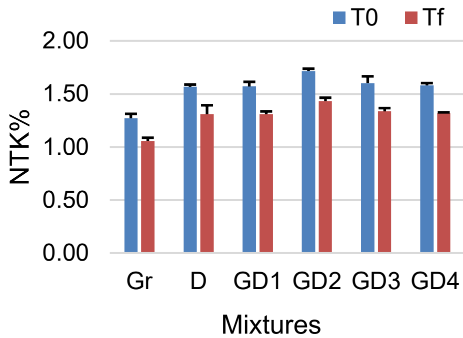
Total organic carbon (TOC), total Kjeldahl nitrogen (TKN) and C/N ratio

In this study, we observe a decrease in the C/N ratio for all the mixtures due to the mineralization of the organic matter with a strong decrease in the GD2 mixture whose C/N ratio went from 31.75 at the state initial to 18.56 in the final state (Fig. 8).

The decrease in the C/N ratio is due to the depletion of carbon compounds that constitute the main component of organic molecules than nitrogen for microorganisms (Chennaoui et al., 2016).

The mixtures (D, GD1 and GD2) have a C/N lower than 20 corresponding to a norm for a mature compost (Hirai et al., 1983) (Fig. 8).





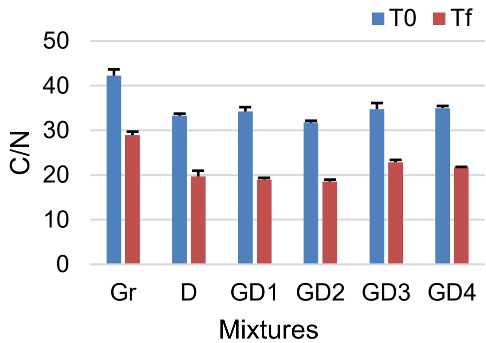


Figure 8. COT, NTK and C/N ratio characteristics.

At the end of the composting process, C/N values a little bit lower than those in this study, were observed in composts by olive pomace from Fes-Meknes region mixed with poultry droppings (16.72) and mixed with cow manure (17.16) (Ameziane et al., 2020).

Values very close to the olive pomace TOC in this study (53.57%) at the beginning of the composting process were found in pomace from Fes-Meknes region at T_0 with contents of 49.31% to 50.79% (Ameziane et al., 2018). Moreover, similar values were observed in Portugal 53.51% (Lopez-Pineiro et al., 2006) and in Italy 52.43% (Proietti et al., 2015).

At the end of the composting process, TOC values a little bit lower were observed in a composts by olive pomace from Fes-Meknes region mixed with poultry droppings (25.09 ± 0.76%) and mixed with cow manure (22.32 ± 0.89%) (Ameziane et al., 2020).

Values very far from the NTK of this study (1.27%) were found in pomace from the Fes-Meknes region at T_0 with a content of 0.001% and 0.004% (Ameziane et al., 2018). However, similar values were observed in Tunisia 1% (M'sadak et al., 2015) and in Italy 1.62% (Proietti et al., 2015).

At the end of the composting process, a close TNK values were observed in a composts by olive pomace from Fes-Meknes region mixed with poultry droppings (1.5 ± 2.43%) and mixed with cow manure (1.3 ± 1.89%) (Ameziane et al., 2020).

Nitrates (NO_3^--N) and ammonium nitrogen (NH_4^+-N)

The NO_3^- concentration increased during the composting process for all mixtures. The maximum NO_3^- content is recorded in the GD4 mixture at the beginning (150.32 mg kg^{-1}) and at the end of the process (295.61 mg kg^{-1}). While the minimum content in the GD2 mixture at the beginning 44.42 mg $kg^{-1}$to be around 251.70 mg kg^{-1} at the end of the process (Fig. 9).

This increase in nitrates can be explained by the process of hardening of the compost by the temperature increase, which inhibited the growth of nitrifying bacteria (Chennaoui et al., 2016).

A similar increase was observed in a study carried out on composts prepared from pig manure and sawdust, which it has started increasing after the thermophilic phase (Huang et al., 2004). The high temperature and excessive amount of ammonia inhibit the activity and nitrifying bacteria growth in the thermophilic phase (Morisaki et al., 1989).

A decrease in NH_4^+ content was observed during the composting process between the beginning and the end of the process for all mixtures. A minimum value was observed in the GD2 mixture of 182.1 mg kg^{-1}. However, a maximum NH_4^+ content was observed in the GD1 mixture of 365.2 mg kg^{-1} at the end of the process (Fig. 9).

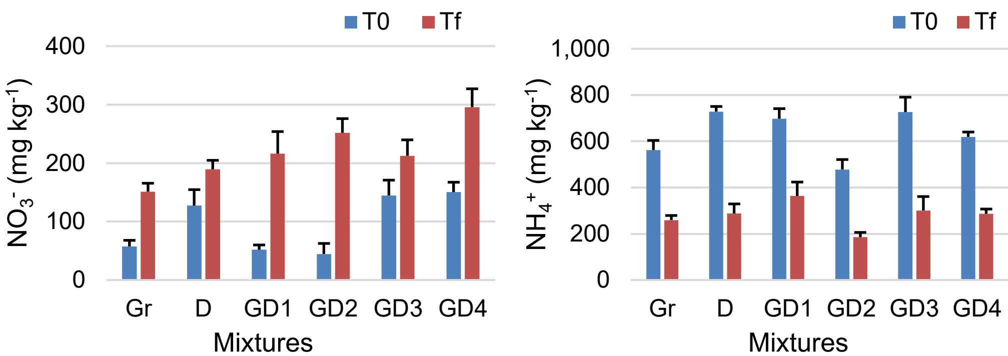


Figure 9. N–NH_4^+ & N–NO_3^- concentrations.

According to Huang et al. (2004), during composting, NH_4-N contents of both piles increased significantly and reached peak values due to ammonification with an increase in temperature and pH, as well as the mineralization of organic-N compound (Fang et al., 1999; Mahimairaja et al., 1994). After an initial increase, NH_4-N contents decreased by volatilization loss and immobilization by microorganisms (Huang et al., 2004). Final NH_4-N contents in two mixtures from pig manure and sawdust with different percentages (pile A 3/2 and pile B 4/1), pile A was close in term of NH_4–N (316 mg kg^{-1}) to the concentrations obtained in this study especially to the GD4 mixture. However, pile B (912 mg kg^{-1}) was so far.

This decrease can be explained by the organic matter decomposition containing nitrogen by microorganisms by converting it into ammonia (Chennaoui et al., 2016). Similarly, the decrease in NH_4^+ is an indicator of a good maturation process (Chennaoui et al., 2016). The absence of or decrease in NH_4–N is an indicator of a good composting and maturation process (Hirai et al., 1983; Riffaldi et al., 1986). Zucconi & de Bertoldi (1987) recommended a maximum NH_4^+ content of 400 mg kg^{-1} in mature compost.

Available phosphorus (P_2O_5) and Orthophosphate (PO_4^{3-})

Phosphorus is an essential element resulting from the decomposition of organic matter. The assimilable phosphorus content in this study increased in all mixtures with a maximum content in organic household waste (0.0654%) and a minimum content observed in pomace (0.0194%) at the end of the process (Fig. 10).

The P_2O_5 content of olive pomace at T_0 (0.014%) in this study remains close to those found for pomace from Fez-Meknes region at T_0 with 0.0001% to 0.0425%. (Ameziane et al., 2018).

At the end of the composting process, P_2O_5 values too far were observed in a composts by olive pomace from Fes-Meknes region mixed with poultry droppings (0.3 ± 0.87%) and mixed with cow manure (0.42 ± 0.86%) (Ameziane et al., 2020).

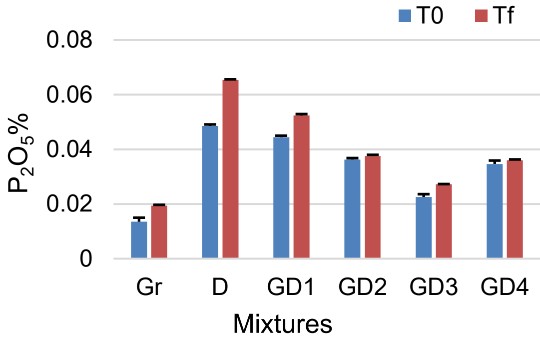


Figure 10. Available phosphorus P_2O_5 characteristics.

Orthophosphate concentrations increased during composting in all mixtures with maximum content in household organic waste (0.0876%) and minimum content in pomace (0.0260%) at the end of the process (Fig. 11).

The increase in electrical conductivity is explained by the release of mineral salts such as phosphorus (P) by the decomposition of organic substances (Gómez-Brandon et al., 2008). Moreover, the change of total P follows the same trend as total N with a gradual increase throughout the composting period, which is due to the net loss of dry mass (Huang et al., 2004). A low P value was observed at the end of the composting process in a compost of olive industry waste mixed with poultry manure (0.0258%) (Bargougui et al., 2019).

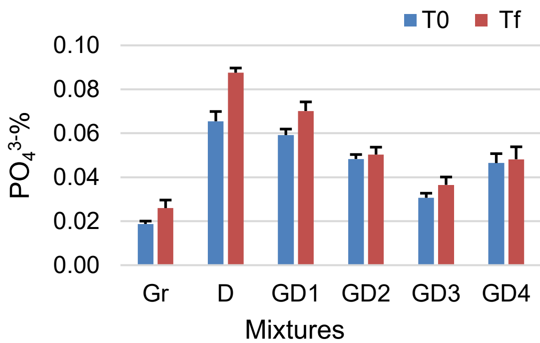


Figure 11. Orthophosphate PO_4^{3-} characteristics.

Sodium (Na_2O) and Potassium (K_2O)

Sodium Na^+ knew a significant increase in all mixtures with a maximum concentration in the GD2 mixture (0.70%) with an increase rate of 65.57% and a minimum content observed in olive pomace (0.19%) (Fig. 12).

The sodium content of olive pomace at T_0 (0.05%) remains quite far and much lower than those found for olive pomace in Fez-Meknes region at T_0 with 0.9% to 1% (Ameziane et al., 2018).

At the end of composting process, these values were too far and very high from those found by Bargougui et al. (2019) in a compost of olive industry waste mixed with poultry manure (0.029%).

Unlike Na^+ ions, the composts potassium characteristics during composting show that all mixtures undergo a reduction over time.

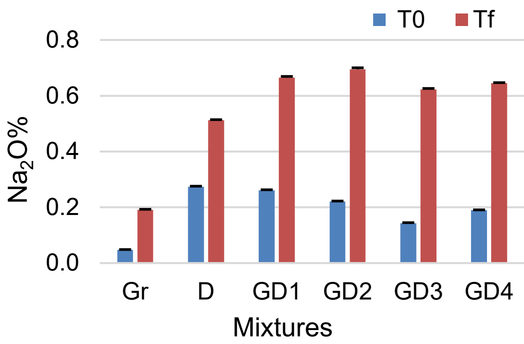


Figure 12. Sodium Na_2O characteristics.

In terms of mixtures, organic household waste has a maximum K_2O content of 0.95% (this is due to the remarkable presence of this element in fruits and vegetables) and a minimum content in pomace of 0.40% at the end of the process (Fig. 13).

These values remain quite far and much lower than those found by (Ameziane et al., 2018) for olive pomace from Fez-Meknes region at T_0 with 4.6% to 9.4%.

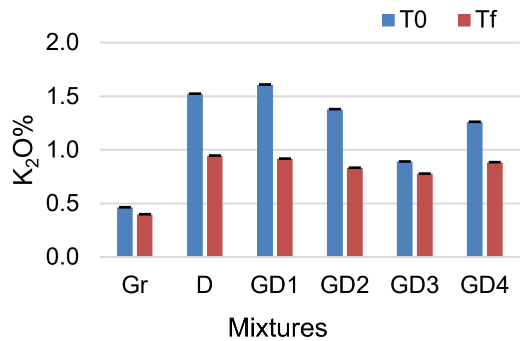


Figure 13. Assimilable potassium K_2O characteristics.

At the end of the composting process, a higher K_2O values were observed in a composts by olive pomace from Fes-Meknes region mixed with poultry droppings (2.9 ± 1.22%) and mixed with cow manure (2.8 ± 0.36%). (Ameziane et al., 2020). Moreover, a low K value was observed in a compost of olive industry waste mixed with poultry manure (0.38%) (Bargougui et al., 2019).

Calcium (CaO) and Magnesium (MgO)

The composting process has seen an increase in calcium concentrations in all mixtures with a high concentration in raw olive pomace (0.38%) and a minimum content (0.22%) in organic household waste (Fig. 14).

This value of olive pomace at T_0 (0.22%) is very close to that found for pomace in Fez-Meknes region at T_0 with 0.16% to 0.32% (Ameziane et al., 2018).

An excess of calcium can impair the absorption of some elements such as B, Cu, Mn and Fe (Ben Kheder, 1998). This increase from the second turning of the composts could be explained by the fact that all the mixtures enter the cooling phase (Znaidi, 2002). The presence of Ca^{2+} ions which increase during composting following humification and which play a role of buffer in the environment is the cause of the stability of the pH in the phase of maturation (Juste, 1980; Morel et al., 1986).

The magnesium concentrations evolution shows that there is a decrease in the different mixtures. With a high concentration in the GD4 mixture which is characterized by the highest concentration with a value of 0.07% and a minimum value 0.04% in the GD1 and GD3 mixtures towards the end of the composting process (Fig. 15).

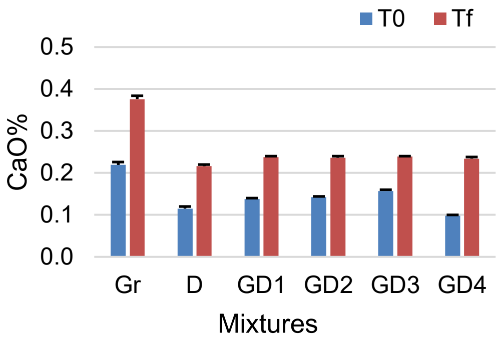


Figure 14. Calcium CaO characteristics.

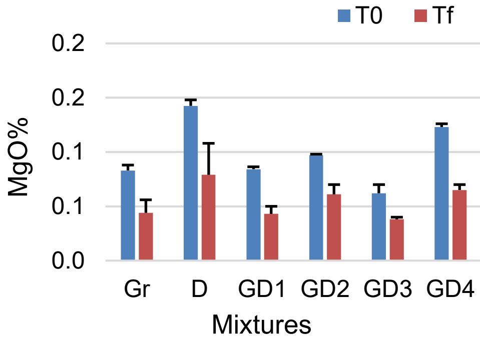


Figure 15. Magnesium MgO characteristics.

These values remain quite far and much higher than those found for olive pomace from Fez-Meknes region at T_0 with 0.192% to 1.776% (Ameziane et al., 2018) which are a bit far to that of olive pomace in this study at T_0 (0.080%).

Sulfate (SO_4^{2-}) and Chloride (Cl^-)

Sulfate content showed a small decrease during the composting process for all mixtures.

The compost of organic household waste which has a maximum concentration with a value of around 0.0037% and a minimum final content in the GD3 mixture with a content of 0.0029% towards the end of the process (Fig. 16).

For the chloride concentration during the composting process, it is revealed that the different mixtures have increased, with a maximum concentration observed in organic household waste with a value of 0.0301% and a minimum content of 0.0235% in the GD3 mixture towards the end of the process (Fig. 17).

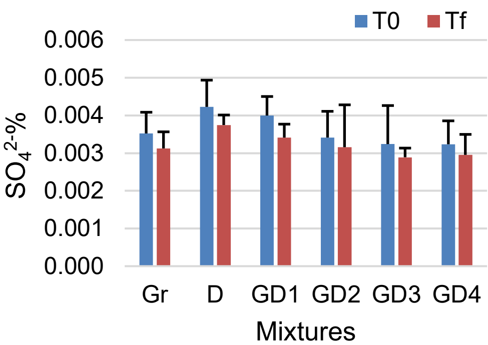


Figure 16. Sulfate SO_4^{2-} characteristics.

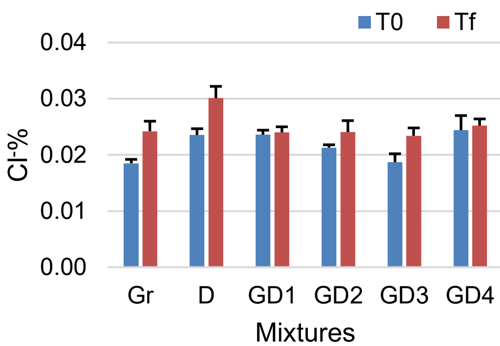


Figure 17. Chloride characteristics Cl^-.

This increase in chloride ions may be due to the increase in electrical conductivity during the composting process.

The table below summarizes the results obtained (Table 3):

Table 3. Physico-chemical properties of mature composts

Composts (T_f)	Gr	D	GD1	GD2	GD3	GD4
pH	7.90 ± 0.29	7.70 ± 0.33	7.65 ± 0.19	7.79 ± 0.37	7.57 ± 0.25	7.31 ± 0.17
EC mS cm^{-1}	1.74 ± 0.08	1.33 ± 0.13	1.70 ± 0.06	1.80 ± 0.07	1.07 ± 0.06	1.81 ± 0.11
Moisture %	15.22 ± 1.47	26.41 ± 2.70	12.36 ± 2.00	18.22 ± 2.31	15.65 ± 1.43	12.88 ± 1.85
OM %	52.62 ± 2.71	44.18 ± 2.70	42.77 ± 3.95	45.79 ± 2.91	52.55 ± 3.31	49.21 ± 1.63
Ash %	47.38 ± 2.71	55.82 ± 2.70	57.23 ± 3.95	54.21 ± 2.91	47.45 ± 3.31	50.79 ± 1.63
TOC %	30.52 ± 1.57	25.62 ± 1.57	24.81 ± 2.29	26.56 ± 1.69	30.48 ± 1.92	28.54 ± 0.95
NTK %	1.06 ± 0.03	1.31 ± 0.09	1.31 ± 0.03	1.46 ± 0.03	1.34 ± 0.03	1.32 ± 0.01
C/N ratio	28.90 ± 0.81	19.68 ± 1.28	18.97 ± 0.39	18.56 ± 0.41	22.84 ± 0.53	21.66 ± 0.14
PO_4^{3-} %	0.0260	0.0875	0.0701	0.0503	0.0365	0.0482
P_2O_5 %	0.0088	0.0194	0.0656	0.0524	0.0376	0.0360
CaO %	0.38	0.22	0.24	0.24	0.24	0.23
MgO %	0.04	0.08	0.04	0.06	0.04	0.07
K_2O %	0.40	0.95	0.92	0.83	0.78	0.88
Na_2O %	0.19	0.51	0.67	0.70	0.62	0.65
Cl^- %	0.0242	0.0301	0.0240	0.0241	0.0234	0.0252
SO_4^{2-} %	0.0036	0.0035	0.0038	0.0043	0.0026	0.0035
NH_4^+ mg kg^{-1}	151.11 ± 14.44	189.29 ± 15.46	216.07 ± 37.85	251.78 ± 24.30	212.46 ± 27.29	295.70 ± 31.36
	259.25 ± 19.84	287.93 ± 41.32	363.43 ± 60.36	185.44 ± 20.36	300.74 ± 60.36	286.43 ± 20.59

The values obtained represent the average of three repetitions.

Microbiological parameters characteristics

In the composting process, microorganisms have a very important role. The presence of certain species reflects the qualities of mature compost (Ryckeboer et al., 2003).

Total aerobic mesophilic flora (TAMF) and thermophilic flora (TF)

The TAMF concentrations comparison at the initial state (T_0) and the final state (T_f) showed a decrease for all the mixtures.

Thus, the initial state of the mesophilic phase is dominated by a high bacterial concentration of TAMF varies between a maximum (1.26 10^{10} UFC g^{-1} of DM) observed in olive pomace and a minimum (2.23 10^9 UFC g^{-1} of DM) in organic household waste. (Fig. 18).

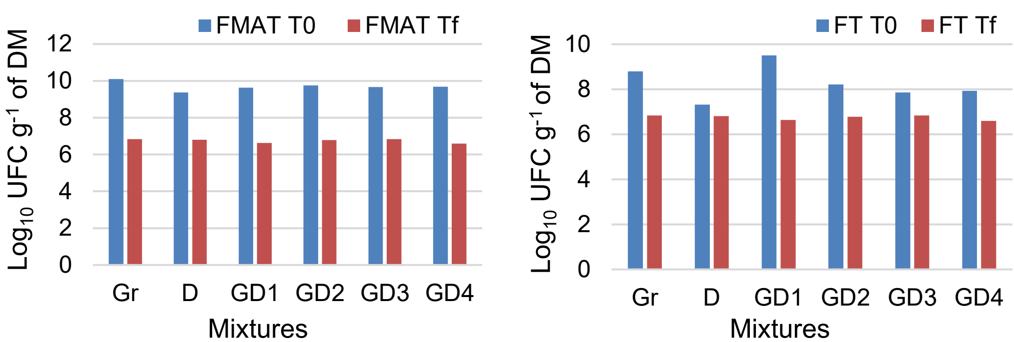


Figure 18. Mixtures characteristics in total aerobic mesophilic flora (TAMF) and thermophilic flora (FT).

These bacterial concentrations decreased at the end of the treatment (Tf), in order to stabilize respectively around 6.78 10^6 UFC g^{-1} of DM in olive pomace and 6.40 10^6 UFC g^{-1} of DM in organic household waste.

The total aerobic mesophilic flora of the mixtures reached high values in all the mixtures that is probably favored by the storage and the putting of this waste in contact with the air and the ground, which allows direct exposure to microbial contaminants.

TAMF olive pomace concentration at T_0 in this study (1.26 10^{10} UFC g^{-1} of DM) remains far superior to that of olive pomace from Jijel, Bejaia & Tizi-Ouzou in Algeria whose concentration varies between 0.45 10^6 UFC g^{-1} of DM and 1.36 10^8 UFC g^{-1} of DM (Boutiche et al., 2020).

By comparing the two states, a decrease in the thermophilic flora is observed for all the mixtures. Thus we observe a decrease in the GD1 mixture (15 % G & 85 % D) whose concentration increased from 3.21 10^9 UFC g^{-1} of DM (T_0) to 4.34 10^6 UFC g^{-1} of DM (T_f) and from 6.32 10^8 UFC g^{-1} of DM to 6.78 10^6 UFC g^{-1} of DM in olive pomace.

Fungal microflora

At the beginning of composting (T0) the different mixtures were characterized by a high concentration of fungal microflora. A high concentration at T0 was observed in the GD1 mixture with 4.59 1,010 UFC g^{-1} of DM in order to be around of 1.67 105 UFC g^{-1} of DM at the end of the process (Fig. 19).

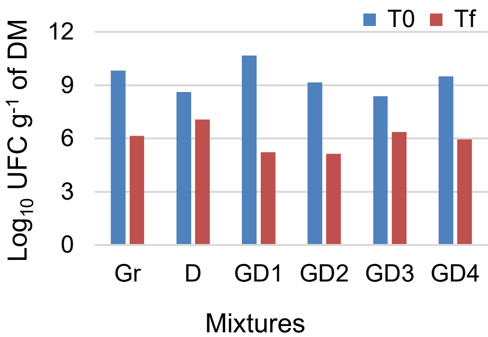


Figure 19. Mixtures characteristics of fungal microflora.

The concentration of fungi for olive pomace at T_0 in this study (6.61 10^9 UFC g^{-1} of DM) was much higher than those found during the olive pomace characterization with concentrations of 2.00 10^6 UFC g^{-1} of DM to 4.76 10^7 UFC g^{-1} of DM in Algeria (Boutiche et al., 2020).

At the end of the composting process (T_f) the fungal microflora has decreased. This decrease can be explained by the increase in temperature in the thermophilic phase, by creating unfavorable conditions for their growth, and by the decrease in humidity. (Greenberg et al., 1986; Guene, 2002).

Lactic acid bacteria

During composting, the lactic acid bacteria concentrations for all mixtures underwenta small increase with a maximum rate in organic household waste from 8.69 10^4 UFC g^{-1} of DM at T_0 and 2.23 10^7 UFC g^{-1} of DM at T_f. (Fig. 20).

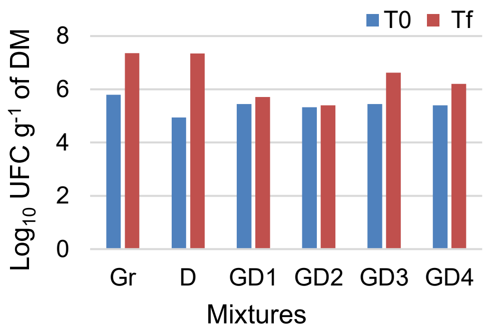


Figure 20. Mixtures characteristics of lacticacid bacteria.

The lactic acid bacteria concentration for olive pomace at T_0 in this study (6.17 10^5 UFC g^{-1} of DM) was slightly higher than those found in olive pomace in Algeria (0.13 10^4 UFC g^{-1} of DM to 3.0 10^5 UFC g^{-1} of DM) (Boutiche et al., 2020).

This increase is due to their growth during the acidogenic phase of the composting process.

Coliforms and E. Coli

The pathogenic micro-organisms presence in composted waste can represent a potential risk of contamination of harvested plants where compost has been spread. The use of composts in the agricultural sector requires the validation of their agronomic efficiency but above all the assurance of their environmental and health safety (Houot et al., 2009).

The mixtures studied characteristics show a high concentration of faecal coliforms at the beginning of the composting process and which suffered a reduction at the end of the treatment with a strong reduction in the GD3 mixture from 4.19 10^7 CF g^{-1} of DM à 63.3 CF g^{-1} of DM with a decrease rate (76.34%) is observed at the level of the GD3 mixture (Fig. 21).

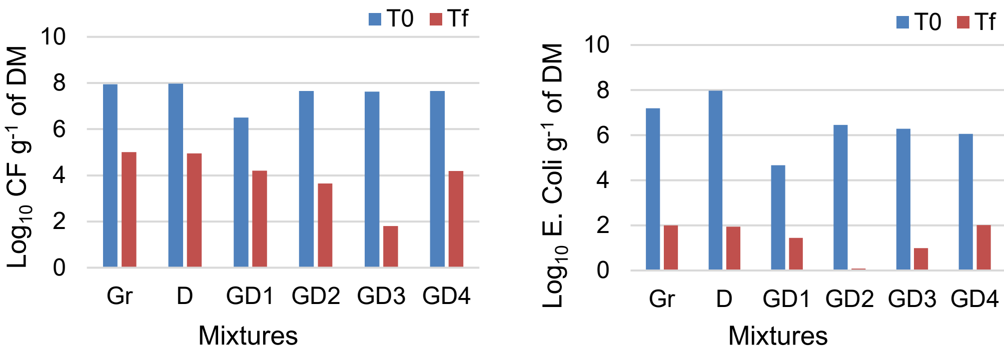


Figure 21. Mixtures characteristics of fecal coliforms and E. Coli.

The mixtures also all had a significant decrease in terms of E. Coli with a maximum concentration of 9.48 10^7 E. Coli g^{-1} of DM at T_0 in organic household waste towards 88.3 E. Coli g^{-1} of DM at T_f. All the treatments suffered a strong decrease, which means the effectiveness of composting in the elimination of pathogenic germs with a high decreasing rate in the GD2 mixture (98.62%) (Fig. 21).

To have a good compost quality in order to use it in agriculture, it is necessary to be aware of the standards concerning organic amendments (AFNOR, NF U 44-051, 2006) which set threshold values for certain pathogenic germs which are indicators of treatment such as *Escherichia Coli* (Houot et al., 2009).

Salmonella

During our study, we limited ourselves to the qualitative test (presence/absence) of Salmonella. The results obtained show that they were always present in all the mixtures throughout the composting process. This may be due to the lack of a high temperature in the thermophilic phase, which they did not exceed 61.22 °C as a higher temperature degree obtained at the 84th day of composting (Gr compost), to ensure major or total elimination of Salmonella. This temperature limitation can be linked to the working period (winter period). These temperature values remain below 70 °C, which is necessary for a living organism's destruction (Bernal et al., 2009). As microbiological criteria, an organic amendment destined to the vegetable crops must not contain any pathogenic agent (Salmonella) in every 25 g as a limit value (NF V 08-052:1997).

The presence of Shigella and Salmonella is considered as the major and specific problem of the compost hygienic quality (Hussong & Burge, 1985; Brinton & Droffner, 1994; Yanko, 1995; Hay, 1996). This was probably because these bacteria are ubiquitous and have a very fast growth capacity. The United States Environmental Protection Agency (US-EPA) imposes for Salmonella a rate lower than three bacteria in 4 g of dry weight of compost and sludge (Hay, 1996). Salmonella comes from food wastes, especially from meats, poultry, milk and its derrivatives… (Hassen et al., 2001).

Brinton & Droffner (1994) reported that some mutant strains of Salmonella may withstand the high temperatures (42–54 °C), and could recontaminate windrows during compost storage.

Recapitulating what was said, the pH of the aqueous solution of the compost underwent an increase starting from the thermophilic phase. During the thermophilic phase, the alkalinization of the medium is linked to the ammonia (base) produced by the bacterial hydrolysis of protein and organic nitrogen. During maturation, the pH remains basic and then gradually decreases over time to reach neutralization. The pH stability is due to the slow maturation reactions and the buffering capacity of humus (Fauci et al., 1999).

The electrical conductivity is high at the start of composting then decreases as a function of composting time to reach values below the limit value of 3 mS cm^{-1} (Soumaré et al., 2002). During the composting process, the amount of extractable ammoniacal nitrogen gradually decreases with the age of the compost while the amount of nitrate increases. The transition from ammonia nitrogen to nitric nitrogen takes place through the mineralization of complex nitrogen compounds into ammonia and amino acids.

Ammonium can either be used directly in microbial metabolism or be oxidized to nitrates and nitrites by nitrogen-fixing organisms (Lhadi & Aylaj, 2008). The evolution of the C/N ratio is directly related to the biodegradation of organic matter, which results both in the elimination of carbon in the form of CO2 and in the apparent concentration of mineral elements (N, P, K, etc.).

On the other hand, there are losses of nitrogen, in the form of ammonia, during the thermophilic phase. These losses tend to attenuate the drop in the C/N ratio. Other authors (Bousselhaj et al., 1996 and Hafidi, 1996) have reported similar results. The C/N ratio is another indicator of compost maturity (Mathur et al., 1993; Ozores-Hampton et al., 1998; Tazi, 2001; Aylaj, 2002; Lhadi et al., 2004 and 2006).

The pathogenic microorganism's presence in composted waste can represent a potential risk of contamination of harvested plants where compost has been spread. The use of composts in the agricultural sector requires the validation of their agronomic efficiency but above all the assurance of their environmental and health safety (Houot et al., 2009).Composting is essentially a microbiological phenomenon that depends highly on temperature evolution within the windrows. The temperature within a composting mass determines the rate at which many of the biological processes take place and plays a selective role on the evolution and the microbiological communities succession (Mustin, 1987).

CONCLUSION

The composting process in the presence of oxygen (aerobic composting), micro-organisms need oxygen to decompose and degrade organic substances. In this study, the oxygen consumption was adjusted by injecting air while turning the composts. The results obtained show that the mixtures can be successfully composted in a period of 4 months and can give better results than other raw waste composts in terms of the C/N ratio... There are essential parameters (physico-chemical and agrochemical characteristics) such as pH, electrical conductivity, organic matter, P_2O_5, K_2O, CaO… to determine and to assess the quality and the compost maturity. The study of the parameters during the 4 months of composting revealed a strong biological activity during the phase bio-oxidant. This activity has been attributed to the mineralization of materials easily degradable.

The composts produced in this study were satisfactory for their agricultural application with a neutral pH in all the mixtures, an optimal C/N ratio around 20, an electrical conductivity that does not exceed the limit value of acceptance for use as support for the ground (3 mS cm^{-1}). In addition, the mixtures suffered a decrease in terms of pollution indicators. These composts contain nutrients that can allow them to play the role of fertilizer and support for soils poor in minerals...

At the end of the composting process, an optimal C/N was observed in the GD2 mixture (18.56) with a maximum content for Na^+ ions (0.70%) and a minimum content of ammoniacal nitrogen lower than the limit value (400 mg kg^{-1}).

The results we have achieved show the interest of composting this waste. Therefore, these laboratory scale results can be applied in full-scale installations by adjusting the forced ventilation according to the available equipment.

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