Are raw materials or composting conditions and time that most influence the maturity and/or quality of composts? Comparison of obtained composts on soil properties

Are raw materials or composting conditions and time that most influence the maturity and/or quality of composts? Comparison of obtained composts on soil properties

Adele Muscolo[1]*, Teresa Papalia[1], Giovanna Settineri[1], Carmelo Mallamaci[1], Agnieska Jeske-Kaczanowska[2],

1 Dipartimento di Agraria, Università Mediterranea Feo di Vito 89122-Reggio Calabria, ITALY

2 Department of Soil Environment Sciences. University of Life Sciences, Nowoursynowska 166, 02-787 Warsaw, POLAND

Correspondence to: Adele Muscolo, Department of Agriculture, "Mediterranea" University, Feo di Vito 89122- Reggio Calabria Italy. Telephone: 003909651694364 Fax: 003909651694550

Mobile:00393397760414, amuscolo@unirc.it

Abstract

Waste composting is a process which is spreading worldwide to reduce waste disposal in landfill. The composting technical currents give little attention to the type and chemical composition of biomass that are mixed not considering that these can affect quality and maturity of the compost produced. In addition, during the composting process the amount of oxygen and temperature are generally only monitored but not set up. Our hypothesis is that composts, prepared from different organic wastes, can be chemically different with consequent different fertilizer properties. Stability and quality of composts are dependent on multivariate parameters such as raw material source, proportions used, composting procedure, and maturation time. Starting from this consideration a composting experiment was carried out to evaluate if were the raw materials (chemical composition, mixture and ratio), or the composting conditions and time, to influence the maturity or the quality of composts. We prepared four composts starting from different combinations and ratios of vegetable residues and/or olive pomace. After 120 days, the four composts were physically, chemically and biologically characterized to evaluate maturity degree, stability and quality of the products obtained under the same composting conditions and time. Their ability, as soil improver, was evaluated assessing soil chemical and biochemical properties 90 days after the compost addition. Here we show that the chemical composition of raw materials and the set up parameters of composting processes can have a different weight in influencing compost stability and quality. Our results evidenced that during the composting process all the composts had a similar percentage of C/N ratio reduction and all of them achieved an acceptable maturity degree. The composts produced by olive pomace showed the highest degree of maturity as demonstrated by T value and organic matter loss, both indices of compost stability. Conversely the composts coming from green vegetable residues were richest in nutrients and phenols and had the highest CSC all indices of better quality. . In this

work we identified two composts able to increase carbon stock, and water holding capacity parameters that positively influencesoil structure, , and two compost able to increase the amount of soil microbial biomass, their activity and soil biodiversity, improving soil biological fertility. These results highlighted that compost maturity doesn't mean compost quality, suggesting that compost maturity is mainly linked to composting setup parameters, while compost quality is mainly linked to chemical composition. FDA and DHA activities have been identified as markers for assessing the quality of amended soils.

Keywords: compost; olive pomace; phytotoxicity; soil properties; vegetable residues

1. Introduction

Research is increasingly oriented to use agronomic techniques for improving productivity in terms of quantity and quality of products (Edgerton, 2009) promoting, at the same time, the conservation of natural resources (Zhao et al., 2018), the protection of soil system and the reduction of environmental impact (O'Connor et al., 2018). For these reasons there is an urgent need, especially in Mediterranean countries where soil fertility is under exploitation (Lacirignola et al., 2014), to use organic fertilizers to maintain or increase soil productivity. Research comparing soils organically and chemically fertilized, have recognized a higher content of soil organic matter, total nitrogen (N) and productivity to the organic than chemically fertilized soils (Drinkwater et al., 1995; Yang et al., 2016). As demonstrated by Curtis and Claassen (2009) and Carrizo et al. (2015) the addition of organic amendments (compost from wastes or manure) is able to stabilize soil structure and decrease soil bulk density, providing a healthy soil environment. In Mediterranean countries the most common wastes come from olive sector that produces, yearly, a huge quantity of organic by-products in a short time (November–February) (Montemurro et al., 2011; Tortosa et al., 2012) and from agriculture and agro-food-processing sectors that produce a lot of citrus and fresh

74 vegetable residues. The residues of olive processing cycles for the production of oil are
75 recognized as pollutant and phytotoxic wastes (Diaz et al., 2002; Siles et al., 2011; Pinho et
76 al., 2017) for their high content of phenols and wax that affect soil and groundwater quality,
77 while the vegetable residues coming from fourth range production system, if conferred in
78 landfill, can emit greenhouse gas with consequences for the carbon balance (Fritsch et al.,
79 2017).(). Their removal represents an ecological problem brought to light for the increase in
80 environmental knowledge. Amid the waste management strategies, composting is getting
81 interest for disposal organic waste with economic and environmental profits (Varma et al.,
82 2014). With the use of biological processes, we can transform agricultural wastes into organic
83 fertilizers (Panuccio et al., 2016; Muscolo et al., 2017a) for developing a sustainable
84 agriculture. The rate and extent of these transformations generally depend on the nature of the
85 starting materials and on the composting conditions. Numerous researches have been carried
86 out, over the last 15 years, to define the chemical, physical and microbiological characteristics
87 of the composting process (Alburquerque et al., 2006; Baeta-Hall et al., 2005; Canet et al.,
88 2008), and of compost as fertilizer, but studies aimed to distinguish the weight of composting
89 process parameters from the chemical nature of the feedstock in influencing the compost
90 maturity and the agronomic effects in terms of productivity are not exhaustive yet (Garcia-
91 Ruiz et al., 2012; Altieri and Esposito, 2010). In view of the above considerations, this study
92 was conducted to evaluate if were the raw materials (chemical composition, mixture and
93 ratio), or the composting conditions and time, to mostly influence the maturity and/or the
94 quality of composts. The composts were analysed to verify if their characteristics fall within
95 the marketability limits permitted by the current Italian regulation. Their ability as soil
96 improver was subsequently assessed evaluating changes in soil chemical and biochemical
97 properties, 90 days after the compost addition.

98 **2. Materials and Methods**

99 2.1. Feeding materials

100 Raw organic materials used for composting consisted of broadleaf vegetable residues (rocket
101 salad, lettuce, cabbage, carrot and valerian) coming from fourth range production system
102 (November 2016), olive pomace obtained from traditional three phases olive oil extraction
103 process and from two-phase centrifugation olive mill Decanter Multi Filter process (DMF)
104 (collected in November 2016), straw, as structuring material, and manure, as starter of
105 composting process (Table 1).

106 2.2. Composting process set up

107 300 L of each mixture were composted in compost bins, and the composting process were
108 repeated three times. The composting parameters were setup as follow: a mesophilic
109 temperature phase for 8 days at 29°C, a thermophilic temperature phase for 20 days at 50°C
110 and a mesophilic temperature phase for 92 days at 27°C. The increase in temperature is due to
111 the intense activity of microorganisms and to the suitable ventilation in the mixture which
112 provides sufficient oxygen for the stimulation of biological activity and for maintaining the
113 aerobic conditions (Liang et al., 2003). After this, the temperature of 27 °C, until to the end
114 of the composting period, was due to the decreased microbial activity and to the reduced
115 amount of organic substrate to decompose. The moisture was maintained at 50% and the
116 oxygen percentage was >15%. Temperature, moisture and oxygen levels were measured
117 daily, by a probe fixed in the middle of the composting mass to be maintained inside the
118 parameters shown above. Water was added, when necessary, to maintain the moisture at 50%.
119 Mixtures were turned over every day to maintain the oxygen percentage greater than 15% for
120 assuring the aerobic decomposition of the organic matter to stable humus. Whole
121 decomposition and stabilization of the materials was accomplished within 4 months. All the
122 compost were air dried and crushed to pass through a 2 mm sieve and thoroughly
123 homogenizedThe chemical characteristics of the raw material used to produce compost (Table

1) indicated that the bulk density values ranged from 461 to 699 kg m^{-3}. The highest value of bulk density (699 kg m^{-3}) was found in the raw materials obtained by DMF oil production system and the lowest ones (461 kg m^{-3}) was found in broadleaf residues. C/N ratio was highest in olive wastes from DMF oil production system and lowest in broadleaf residues.

2.3 Assessment of chemical characteristics and phytotoxicity of composts

Chemical characterization of the initial wastes and composts was carried out according to the methodologies recommended by the ANPA manual (2001). The organic matter mineralization rate was assessed evaluating the loss of organic matter over time. Organic matter loss was valued as reported in the equation 1:

Organic matter loss = [(initial mass carbon-final mass carbon)/initial mass carbon] x 100 (1)

Fluorescein 3,6-diacetate hydrolase was determined according to Adam and Duncan's protocol (2001). Briefly, to 2 g of compost (fresh weight, sieved 2 mm) 15 mL of 60 mM potassium phosphate pH 7.6 and 0.2 mL 1000 mg FDA mL−1 were added. The flask was then placed in an orbital incubator at 30 °C for 20 min. After incubation, 15 mL of chloroform/methanol (2:1 v/v) was added to terminate the reaction. The content of the flask was centrifuged at 2000 rpm for 3 min. The supernatant was filtered and absorbance measured at 490 nm on a spectrophotometer (Shimadzu UV–Vis 1800, Japan) and expressed as μg fluorescein released per g of dry soil (Perucci, 1992). The activity of dehydrogenase (DHA) was determined as described by von Mersi and Schinner (1991). Briefly, to a sample of fresh soil, equivalent to 1 g of oven dried (105 °C) soil, was added 1.5mL of 1MTris–HCl buffer of pH 7.5 followed by 2 mL of 0.5% INT solution (Sigma product No I 8377), and the suspension was kept at 40°C for 1 h. Then 10 mL of extractant (methanol) was added and the samples were mixed using a vortex mixer, and then left in the dark for 10 min. Finally, the solids were filtered out (Whatman's no 40 paper) and the absorbance of the filtrate was

149 determined at 490 nm. Water soluble phenols (WP), were detected by extracting soil in
150 water, and determined by using the Folin–Ciocalteau reagent, following the Box method
151 (1983). Tannic acid was used as standard. Compost samples were extracted with bidistilled
152 water (ratio compost/water 1:10) (Wang et al., 2013) per 24 h at 25 °C to detect ion
153 concentration by using a chromatography systems (Dionex ICS-1100). The capacity to adsorb
154 NaCl was detected for all composts by using five concentrations of NaCl (0, 25, 50, 100 and
155 150 mM). Na^+ and Cl^- concentrations in the extracts, were determined by ion
156 chromatography. The Na^+ and Cl^- adsorption capacity of composts were calculated by the
157 equation used by Lo et al. (2012). Cationic exchange capacity (CEC) was determined by
158 using an aqueous solution of $BaCl_2$ buffered to pH 7.0 to saturate the exchange complex of
159 soils (Mehlich1953) (Compost maturity was estimated following the method of Gariglio et al.
160 (2002), by using *Cucumis sativu*s L seed. The GI (germination index) which combines
161 measures of relative seed germination (%) and relative root elongation (%), has been used to
162 evaluate the toxicity of compost because germination and root elongation has proven to be the
163 most sensitive parameters, capable of detecting low levels of toxicity which affect the root
164 growth, as well as high toxicity levels which affect the germination (Tiquia and Tam 1998),
165 indicating non-phytotoxicity of the compost when the values are higher than 60% (Zucconi et
166 al, 1981).

167 2.4. Soil characteristics and treatments

168 Soil was taken from Motta San Giovanni, Loc. Liso, Italy (x: 561023,1; y: 4204908,9; WGS
169 84 UTM Zone 33 N), the soil is a sandy-loam (11.85% clay, 23.21% silt, and 64.94% sand)
170 textural class according to FAO soil classification system (FAO, 1999). The soils are slightly
171 alkaline with a low content of organic matter and nitrogen (Table 5). Soil amendment was
172 performed in triplicates using pots, each containing 3800 g of soil. 100 g of each compost was

added in each pot corresponding to 1.5q/ha. Non-fertilized soil was used as control. The experiments were performed in greenhouse at 25°C day/19°Cnight and 70% relative humidity. During the experiment, pots were watered regularly to ensure that water content was maintained at 70% of field capacity. Control and amended soils were analyzed 90 days after treatments.

2.5. Soil analysis

Soils were air-dried and sieved at 2 mm for the chemical analyses, whereas fresh soil sieved at 2 mm were used for microbiological analyses. Soil water content was expressed on a gravimetric basis. Water content was measured by weighing a wet soil sample, drying the sample to remove the water, then weighing the dried soil sample again and expressed as percentage. Water content was detected, at the beginning of the experiment and every 15 days for all the duration of the experiment in each soil treatment. The corresponding equation related to the increase over time of water holding capacity in treated soil has been calculated. Particle size analysis was carried out by using the method of Bouyoucos (1962); dry matter (dm) was determined weighting the samples after 24 h at 105°C; pH and EC were measured as reported in Muscolo et al., (2017b).Organic carbon was determined by oxidimetric method following the Walkley–Black procedure (1934), total nitrogen was detected by the digestion procedure, using sulfuric acid at temperatures of 380 ºC following the Kjeldahl method (1883). The amount of microbial biomass carbon (MBC) was determined by using the chloroform fumigation–extraction procedure (Vance et al., 1987) with field moist samples (equivalent to 20 g dry wt.). The filtered soil extracts of both fumigated and unfumigated samples were analyzed for soluble organic C using the methods of Walkley and Black (1934). Microbial biomass C was estimated on the basis of the differences between the organic C extracted from the fumigated soil and that from the unfumigated soil, and an extraction efficiency coefficient of 0.38 was used to convert soluble C into biomass C (Vance et al.,

198 1987). . Microbial population was extracted following the method of Insam and Goberna
199 (2004). 2 g of soil and 30 glass beads were mixed with 20 mL 0.90% NaCl and shaken at 4 °C
200 for1 h at 12 000 g to separate bacteria from solid particles. The supernatant was used for
201 further dilutions with sterile one-fourth strength Ringer solution so as to standardize the
202 inoculum density. Soil bacterial population was estimated by Waksman`s (1952) method
203 using the nutrient agar medium at 105 dilutions. Fungal population was estimated by dilution
204 plate method (Johnson and Curl 1972) using Martin`s Rose Bengal agar medium at 103
205 dilutions in water. The activities of fluorescein 3,6-diacetate hydrolase (FDA), and
206 dehydrogenase (DHA) as well water soluble phenol amount, ion concentrations and cationic
207 exchange capacity (CEC) were determined as reported in the section 2
208 All the analysis were performed in triplicates.

209 2.6. Statistical analysis

210 Significant differences were analyzed with the Tukey multiple tests to compare all pairs of
211 means. Simple descriptive analysis was applied to determine the average value of the
212 quantitative variables. Statistical analyses were performed using SYSTAT 8.0 software (SPSS
213 Inc.). P values <0.05 were considered significant as the probability levels.

214 **3. Results**

215 The composting procedure that we repeated three times over time for each typology of
216 compost produced compost with the same chemical characteristics, suggesting that the
217 procedure adopted can be standardized as the results are reproducible. After 4 months of
218 composting, the analysis evidenced significant differences among the four composts produced
219 with the same process (Table 2). pH was slightly and strongly acidic for C1 and C2 compost
220 produced with olive residues, while was alkaline in those produced with broadleaves. Total

organic carbon was highest in C2; conversely, total nitrogen was highest in C3. C/N ratio was 14 and 11 in C3 and C4, respectively, and it doubled in C1 and C2. $N\text{-}NH_4^+/N\text{-}NO_3^-$ ratio was 10 in C2, and 1.30 in C1. ON/TN was instead significantly higher in C1 and C2 (91% and 86%) than C3 and C4 (72% and 64%) (Table 2). All the compost obtained were rich in nutrients but at different extent (Table 3), C4 contained the greatest amount of Ca^{++} (0.71 mg/L), SO_4^{--}(9.49 mg/L) and Cl^- (14.74 mg/L) . C2 had the greatest quantity of PO_4^{---}, while C1 contained a minor amount of nutrients in comparison to C3 and C4. The compost C3 and C4 contained an amount of WSP 2 and 3.5 time greater thanC1 and C2 (Table 4) and at the same time had the greatest CSC. The greatest FDA activity was found in C1 (90.42), while the highest DHA activity was detected in C2 (91.01). C3 and C4 had a similar FDA activity (at about 76 µg fluorescein g^{-1} d.w.), while had different values of DHA, 79.20 for C3 and 39.55 (µg TTF g^{-1} h^{-1}d.w) for C4. Regarding the compost adsorption capacity, all the composts were able to adsorb sodium and chloride but at different extent. C1 had the greatest Na adsorption capacity, C2 showed the greatest capacity for Na removal at 50 mM NaCl and then its capacity decreased with increasing sodium concentration (Fig. 1). C3 and C4 had a gradual adsorption ability, and their sodium removal capacity was lower than C1 moreover at the lowest NaCl concentrations (25 and 50 mM). Regarding chloride adsorption capacity (Fig. 1), all the compost had the capacity to remove it. Increasing Cl^- concentration all the compost gradually increased its adsorption, as for sodium the compost C1 showed the greatest adsorption capacity. The phytotoxicity, indicator of compost maturity, expressed as germination index (Fig. 2) evidenced that all the compost tested on seed germination were not phytotoxic. The germination index, detected 6 days after germination, in presence of the compost at 25 and 50% showed values higher than 80%, falling in the class of phytonutrient. These data are in agreement with the global germination index showing values ranging from 67.5 to 95% that confirmed the non phytotoxicity of the four compost. All the compost

246 affected soil chemical properties, lowering the pH and increasing the EC in comparison to
247 control. The EC values in soil were in any case far from the threshold values of salinization (4
248 dS/m), reaching only in the case of C3 1 dS/m (Table 5). Water holding capacity significantly
249 increased in treated soils as demonstrated by the values of water content (y = 0,083x +
250 21,116, R^2 = 0,9909). The greatest value of water content was detected in soil amended with
251 C1. Carbon and nitrogen significantly increased in amended soils, and the greatest increases
252 were detected in S+C1 and S+C2. The C/N ratio was similar to control in S+C4, lower than
253 control in S+C3 and higher than control in S+C1 and S+C2 (Table 5). WSP significantly
254 increased in all the treatments and the greatest increases were observed in S+C2 and S+C1.
255 Soil biological characteristics were affected by compost treatments at different extent. The
256 MBC increased in presence of the composts and the greatest increment was observed in
257 presence of C3 and C4 (Table 6), the composts that increased the number of actinomycetes
258 and bacteria colonies and the activity of DHA in respect to control and to the other treatments.
259 Fungi increased significantly in soil treated with C1 and C2. Cation and anion amounts
260 changed after the addition of the composts. C3 and C4 increased the amount of K^+, Mg^{+2},
261 Ca^{+2}, NO_3^- and SO_4^{-2} as well Cl^-. C1 and C2 enhanced, in respect to control, the amount of K^+,
262 Mg^{+2} and SO_4^{-2} but at minor extent than C3 and C4. CSC was higher than control in C1, C2
263 and C4, while was lower than control in soils treated with C3.

264 **4. Discussion**

265 Composting is a complex aerobic process carried on by different microorganisms that use
266 nitrogen (N) and carbon (C) for their metabolic purpose (Diaz et al., 2007). Bacteria, fungi,
267 and actinomycetes are actively implied in composting process with variable intensity (Hassen
268 et al., 2001; Asharaf et al., 2007), depending on composting set up parameters such as
269 temperature (Mustin, 1987), moisture content and oxygen percentage (Sunar et al., 2009), and

chemical characteristics of raw materials in particular C/N ratio (;;). The proportions 30:1 of C and N in the starting raw materials is considered an optimal value for stimulating the activity of microorganisms to obtain mature compost. Zou (2017) verified that the time of composting is also important and showed that it increased when the initial C/N ratio was high. Our results showed high variability between the raw materials in respect to their organic matter and nitrogen contents which depended on the chemical compounds that made up the material. Although the raw materials used to produce compost, had a C/N ratio of 40 for C1, 60 for C2, 33 for C3 and 20 for C4 respectively, during the composting process a similar percentage of reduction in the C/N value for all composts was observed, with the consequent achievement of a good degree of maturity. Because of the heterogeneity of materials used in the composting processes, and to confirm the above results, we considered also the starting and ending values of the C/N ratio, the T value (T value = the final C/N ratio/the initial C/N ratio) that is used to evaluate organic matter stabilization in composting (Jara-Samaniego et al., 2017). A T values < 0.70 is in fact indicative of compost maturity (Zhang et al., 2013), the higher the value, the less mature the compost. In our experiment, all the composts had values minor than 0.70 and C1 and C2 with the less values showed the highest degree of maturity. The organic matter loss, measured at the end of composting process (Raj and Antil, 2012), is also considered an index of compost maturity if the values are greater than 40-42% as already reported by Raj and Antil (2012). A great loss of organic matter was observed in all the four composts. The loss of carbon ranged from 40 for C1 to 55% for C4, indicating that all the obtained composts were matures. Additionally, the composts passed the standard germination index, highlighting also their stability. The germination index showed values greater than 80%, indicating absence of phytotoxins as reported by Zucconi et al. (1981) and Barral and Paradelo (2011), and also compost stability and maturity as reported by Tiquia et al. (1996) and Sellami et al. (2008). All the composts showed sodium and chloride adsorption capacity,

but the greatest one was observed for C1, the compost that showed the greatest maturity index. Our study evidenced that even if the starting raw materials were chemically different, the composting processes in terms of set up used, prevailed on the chemical composition, driving the production of stable and mature compost with parameters which felt in the threshold requested by national and international legislations and/or guidelines. Regarding the compost quality, that remains an elusive concept (Lasaridi et al., 2006) we observed that the differences among the compost effects were mostly related to the chemical composition of the raw materials rather than to the composting setup parameters. These data perfectly agree with findings of Mangan et al. (2013) demonstrating that the compost quality reflected the chemical makeup of a given compost. A compost can be mature (i.e., fully composted) but can be of poor quality due its low nutrient levels. The levels of nutrients in our composts were different and the C3 and C4 were the richest ones, conversely C1 and C2 contained the greatest amount of organic matter and organic nitrogen showing differences that were well reflected in their fertilizing capacity. All the composts improved the soil physical and chemical characteristics as well enhanced enzyme activities and altered microbial community in respect to the not amended soil. The improving impacts that the different composts had on the diverse parameters of soil fertility were a consequence of their chemical composition and not of the composting process as can be deducted by the parameters indicating compost maturity. The stability and maturity ranking of the composts were in the order C1>C2>C3>C4 while the ranking for compost quality was C4>C3>C1>C2. Compost C1 and C2 decreased soil pH, increased soil organic carbon, C/N ratio, and CEC parameters linked to a better humification of soil organic matter and consequently to a better soil stability. In agreement with previous finding of Bhattacharyya et al. (2009) indicating that soil carbon sequestration in agricultural soil has been suggested as a strategy to improve soil stability. This assertion was supported also by the increased amount of fungi that are involved in the

320 humification process. In general, a higher fungi/bacteria ratio has been linked to a higher
321 capacity of soils to sequester carbon. Six et al. (2006) showed that changes in microbial
322 community with fungal dominance reflected organic carbon accumulation due to enhanced
323 fungal mediated soil aggregation. For instance, Strickland and Rousk (2010) and Waring et al.
324 (2013) demonstrated that a greater amount of fungi in soil resulted in increased carbon use
325 efficiency. Our results showed an increase in microbial biomass, bacteria, actinomycetes,
326 DHA and FDA in soil amended with C3 and C4 suggesting an intense biological activity
327 driving a mineralization processes with a greater release of nutrients, increase in EC and pH.
328 The increase in bacteria and actinomycets and the contemporary decrease in fungi can be
329 explained by the elevate EC. As reported by Chen and co-authors (2013) fungi are more
330 sensitive than bacteria to high salt concentrations. In this work we identified two composts
331 that were able to better improve the soil stability, increasing alsowater holding capacity, and
332 two composts able to improve soil fertility and biodiversity, discriminating the weight that the
333 chemical composition of raw materials and the setup parameters of composting processes
334 have relatively to the degree of stability and quality of composts. The production of compost
335 from recalcitrant wastes of agro-food-processing sectors can be considered a beneficial
336 process from an environmental and economic point of view, leading to significant reductions
337 in the emission of greenhouse gases into the atmosphere (Bong et al., 2017) and economic
338 benefits (Zaman, 2016; Pergola et al., 2018). A tonne of compost is on average sold for 30
339 euros in the EU countries, to which must be added about 38 euros saved by the reduction of
340 CO_2 and CH_4 emissions, the decrease in the manufacturing and use of chemical fertilizers and
341 pesticides and the reduction of costs for disposal in landfills that allow to include composting
342 process among cleaner production processes as also reported by Aye and Widjaya (2006).
343 These authors evaluated five different way of waste disposals: open dumping (OD),
344 composting in centralized plant (CPC), composting in small intensive plants (CPL), biogas

345 production in an anaerobic digester combined with compost production from the solid
346 digester effluent (BGP), and landfilling combined with methane capture and electricity
347 generation (LFE). Aye and Widjaya (2006) found CPL and CPC had the lowest process cost,
348 compared with remaining alternative options confirming the economic benefit of composting
349 process. Subsequently other studies (Kim, Set al. 2011; Elagroudy et al. 2011) found that
350 composting provided reduced environmental impacts, confirming also the economic
351 advantage of composting over other alternatives.

352 **5. Conclusions**

353 The results of this study provided more information concerning the best strategy for
354 composting wastes from agro-food-processing sector. Previous works were mainly focused on
355 the indiscriminate mixing of wastes from agro-food industries without considering in detail
356 their chemical composition and the consequence that could have on the final properties of the
357 composts obtained. This study, in respect to previous knowledge, highlights the importance of
358 chemical composition of biomass wastes and setup composting parameters for the final
359 properties and the potential added value of the end-products obtained. Our results evidenced
360 many differences between compost properties highlighting that stability/maturity doesn't
361 means quality. In some case these properties may overlap, but in the majority of the situation
362 can be different and need to be discriminated. Maturity and stability are mainly linked to
363 composting parameters and can be assessed by measuring C/N, TN values and carbon loss. .
364 While the quality of composts is mainly linked to chemical composition of raw material, and
365 can be assessed evaluating the compost effects on soil ecosystem functioning by monitoring
366 fungi/bacteria ratio, FDA, DHA and nutrient amount.

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561 **Table 1** Percentage and sources of raw materials used to produce composts. Carbon/Nitrogen
562 ratio (C/N), bulk density (BD, Kg/m^3) and water content (WC, %) of raw material differently
563 mixed at the beginning of composting processes. *p ≤0.05

Compost ID	Compostable materials	Sources	C/N	BD	WC
C1	90% wastes from olive oil (pulp and kernel of olives) + 10% straw	Wastes from traditional olive oil production system (purchased from Barone Macrì farm Locri-Reggio Calabria, Italy in November 2016)	50^{b*}±1.9	602^{b}±5.8	73^{c}±2.1
C2	90% wastes from olive oil + 10% straw	Wastes from DMF olive oil production system (purchased from Statti Farm-Lamezia Terme, Italy in November 2016)	60^{a}±1.9	699^{a}±7.4	67^{d}±1.3
C3	10% Straw + 80% broadleaf vegetables + 10% manure	Purchased in November 2016 from fourth range industry (COF) located in Lamezia Terme, Italy	23^{c}±1.5	533^{c}±8.2	80^{b}±2.4
C4	10% Straw + 90% broadleaf vegetables	Purchased in November 2016 from fourth range industry (COF) located in Lamezia Terme, Italy	20^{c}±1.4	461^{d}±6.9	87^{a}±2.1

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575 **Table 2** Physico-chemical properties of composts 120 days after the composting process. pH (H_2O and KCl); electric conductivity (EC, ms cm^{-1}); water
576 content (WC, %); total organic carbon (TOC, %); Total Nitrogen (TN, %); carbon/nitrogen ratio (C/N); ammonium-nitrogen/nitrate-nitrogen ratio (NH_4^+-
577 N/NO_3^--N); organic nitrogen/total nitrogen ratio (ON/TN, %). *p≤0.05

ID	pH (H_2O)	pH (KCl)	EC	WC	TOC	TN	C/N	NH_4^+-N/NO_3^--N	ON/TN
C1	6.32^{b*}±0.11	5.72^{b}±0.28	1.80^{d}±0.35	45.6^{b}±0.34	49.06^{b}±0.28	1.89^{c}±0.001	25.99^{b}±0.40	1.30^{d}±0.06	91.00^{a}±1.68
C2	5.04^{c}±0.35	4.72^{c}±0.19	12.03^{a}±0.80	56.7^{a}±0.55	57.62^{a}±0.49	2.04^{b}±0.003	28.22^{a}±0.51	10.00^{a}±0.41	86.00^{a}±1.36
C3	8.54^{a}±0.45	8.00^{a}±0.45	7.89^{b}±0.61	46.15^{b}±0.85	37.69^{c}±0.95	2.69^{a}±0.009	14.01^{c}±0.33	6.50^{b}±0.09	72.00^{b}±1.15
C4	8.30^{a}±0.44	8.10^{a}±0.59	5.06^{c}±0.26	45.85^{b}±0.36	24.01^{d}±0.86	2.03^{b}±0.004	11.97^{d}±0.41	2.80^{c}±0.07	64.00^{c}±1.95

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585 **Table 3** Ion concentration (mg/l) detected in the different composts (C1, C2, C3 and C4) at the end of the composting process (120 days).

586 *p ≤0.05

ID	Na^+	NH_4^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	NO_2^-	NO_3^-	PO_4^{3-}	SO_4^{2-}
C1	1.39^{b*}±0.05	0.16^{c}±0.01	17.64^{c}±0.02	1.30^{b}±0.02	0.24^{d}±0.04	0.75^{d}±0.11	0.01^{a}±0.004	0.04^{b}±0.010	0.41^{d}±0.04	0.24^{d}±0.03
C2	0.85^{c}±0.04	0.26^{b}±0.03	19.22^{b}±0.01	1.20^{b}±0.04	0.53^{c}±0.01	3.83^{c}±0.47	0.01^{a}±0.003	0.01^{c}±0.002	2.00^{a}±0.21	1.17^{c}±0.15
C3	3.93^{a}±0.40	0.76^{a}±0.23	23.25^{a}±0.03	1.49^{a}±0.01	0.62^{b}±0.01	5.32^{b}±0.28	nd	0.04^{b}±0.011	0.59^{c}±0.03	3.81^{b}±0.72
C4	3.73^{a}±0.37	0.70^{a}±0.19	23.99^{a}±0.04	1.58^{a}±0.01	0.71^{a}±0.01	14.74^{a}±0.18	nd	0.08^{a}±0.010	1.19^{b}±0.16	9.49^{a}±0.66

587 **Table 4** Water soluble phenols (WSP, mg TAE g^{-1} d.w.), fluorescein dyacetate hydrolase
588 (FDA, µg fluorescein g^{-1} d.w.), dehydrogenase (DHA, µg TTF g^{-1} h^{-1}d.w.), cation
589 exchange capacity (CSC, $cmol^{(+)}$ Kg^{-1}) detected in different compost 120 days after the
590 composting process. *p≤0.05

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ID	WSP	FDA	DHA	CSC
C1	2.31^{c*}±0.10	90.42^{a}±2.16	32.42^{d}±1.16	23.80^{d}±0.86
C2	1.84^{d}±0.11	15.83^{c}±5.21	91.01^{a}±3.57	26.78^{c}±1.03
C3	4.02^{b}±0.50	75.50^{b}±4.91	77.65^{b}±1.83	43.65^{a}±1.26
C4	7.03^{a}±0.81	79.20^{b}±3.72	39.55^{c}±2.12	33.02^{b}±1.12

Table 5. Soil chemical characteristics pH, electric conductivity (EC, µS cm^{-1}), water content (WC, %), total organic carbon (TOC, %), total nitrogen (TN, %), carbon/nitrogen ratio (C/N), water soluble phenols (WSP, µg TAE g^{-1} d.s.) detected 3 months after the addition of compost to the soils. Soil plus compost 1 (S+C1), soil plus compost 2 (S+C2), soil plus compost 3 (S+C3), soil plus compost 4 (S+C4) and un-amended soil (control, CTR). *p≤0.05

ID	pH	EC	WC	TOC	TN	C/N	WSP
CTR	8.50^{a*}±0.04	350.00^{e}±8.04	21.40^{c}±1.10	3.09^{c}±0.05	0.17^{c}±0.003	18.40^{c}±0.06	14^{e}±1.120
S+C1	8.00^{b}±0.05	460.00^{c}±5.77	28.40^{a}±0.91	4.50^{a}±0.23	0.22^{a}±0.002	20.10^{b}±0.01	45^{b}±1.073
S+C2	8.00^{b}±0.08	410.00^{d}±8.13	24.50^{b}±1.53	4.36^{a}±0.21	0.21^{ab}±0.001	21.30^{a}±0.03	50^{a}±1.601
S+C3	8.20^{b}±0.07	1063.00^{a}±4.23	24.10^{b}±1.80	3.57^{b}±0.09	0.21^{ab}±0.002	16.91^{d}±0.01	20^{c}±1.660
S+C4	8.10^{b}±0.05	740.00^{b}±2.36	25.50^{b}±1.15	3.70^{b}±0.12	0.20^{b}±0.003	18.52^{c}±0.03	17^{d}±1.010

599 **Table 6** Biological soil characteristics: microbial biomass C (MBC, µg C g^{-1} f.s.) fluorescein diacetate (FDA, µg fluorescein g^{-1} d.s.)
600 dehydrogenase (DHA, µg TTF g^{-1} h^{-1}d.s.), bacteria (BACT, UFC g^{-1} d.s.), fungi (FUN, UFC g^{-1} d.s.), actinomycetes (ACTINOM, UFC g^{-1} d.s.)
601 detected 3 months after the addition of compost to the soils. Soil plus compost 1 (S+C1), soil plus compost 2 (S+C2), soil plus compost 3
602 (S+C3), soil plus compost 4 (S+C4) and un-amended soil (control, CTR). *p≤0.05
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ID	MBC	FDA	DHA	BACT	FUN	ACTINOM
CTR	433.30^{e*}±2.72	3.95^{b}±0.05	26.98^{c}±0.11	$1.3*10^{5d}$±0.21	$4.6*10^{4b}$±0.53	$6.7*10^{4d}$±0.47
S+C1	541.78^{c}±4.31	3.48^{c}±0.02	23.96^{d}±0.02	$1.3*10^{5d}$±0.19	$1.0*10^{5a}$±1.28	$1.0*10^{5c}$±0.22
S+C2	469.44^{d}±4.50	3.16^{d}±0.01	21.20^{e}±0.06	$2.0*10^{5c}$±0.13	$1.0*10^{5a}$±0.89	$1.0*10^{5c}$±0.27
S+C3	915.56^{a}±2.99	6.22^{a}±0.13	29.52^{b}±0.09	$4.0*10^{5b}$±0.18	$2.6*10^{4d}$±0.04	$2.3*10^{5a}$±0.15
S+C4	761.40^{b}±5.65	3.81^{b}±0.01	38.09^{a}±0.51	$8.3*10^{5a}$±0.44	$3.0*10^{4c}$±0.02	$1.3*10^{5b}$±0.01

604 **Table 7** Cations (mg g^{-1} d.s.**)**, anions (mg g^{-1} d.s.) and cation exchange capacity (CSC, $cmol^{(+)}$ Kg^{-1}) detected 3 months after the addition of

605 compost to the soils. Soil plus compost 1 (S+C1), soil plus compost 2 (S+C2), soil plus compost 3 (S+C3), soil plus compost 4 (S+C4) and un-

606 amended soil (control, CTR). *p≤0.05

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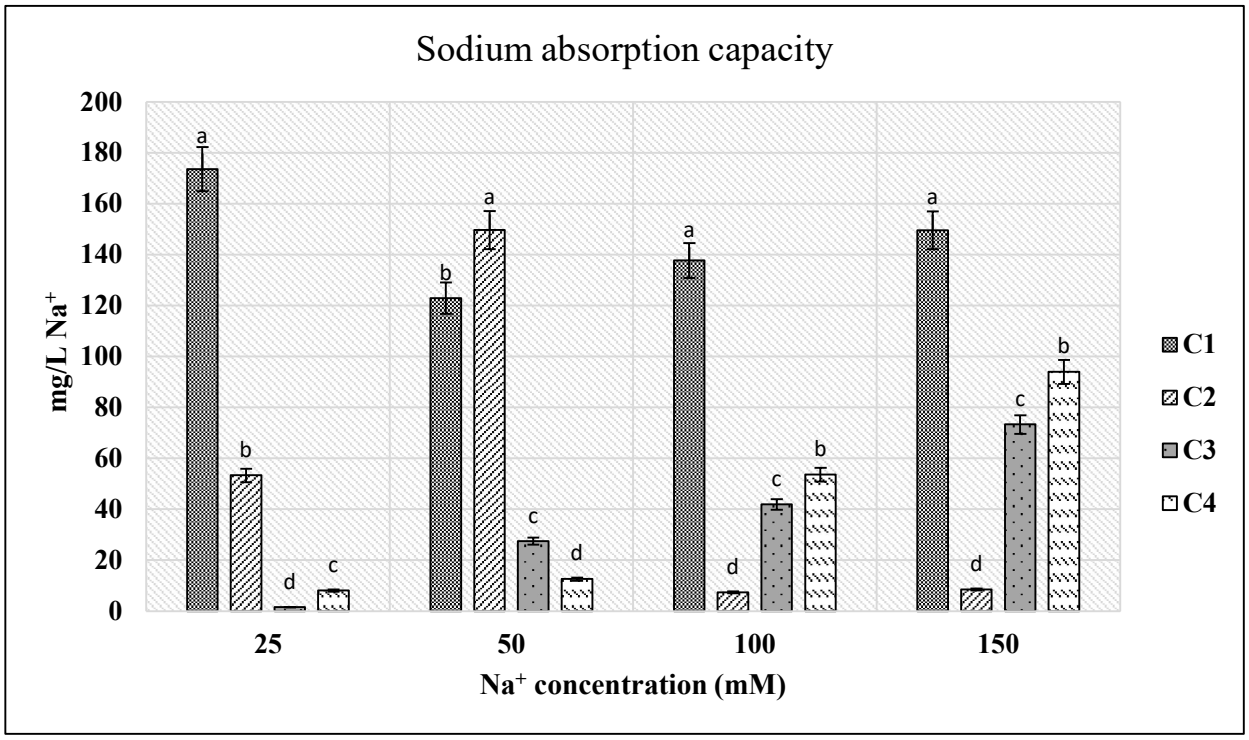
ID	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	NO_2^-	NO_3^-	PO_4^{3-}	SO_4^{2-}	CSC
CTR	0.124^{c*}±0.001	0.110^{e}±0.004	0.023^{d}±0.001	0.858^{c}±0.050	0.206^{d}±0.007	nd	0.022^{c}±0.0004	0.001^{b}±0.002	0.339^{d}±0.050	18.72^{c}±0.101
S+C1	0.160^{b}±0.005	0.143^{d}±0.007	0.029^{c}±0.002	0.468^{e}±0.011	0.261^{c}±0.020	nd	nd	nd	0.682^{c}±0.101	22.30^{a}±0.310
S+C2	0.117^{d}±0.001	0.184^{c}±0.010	0.029^{c}±0.001	0.501^{d}±0.010	0.167^{e}±0.010	nd	nd	nd	0.344^{d}±0.073	21.80^{a}±0.105
S+C3	0.127^{c}±0.001	0.320^{a}±0.031	0.210^{b}±0.004	1.430^{b}±0.013	1.430^{a}±0.101	nd	0.050^{b}±0.0003	nd	11.530^{b}±0.721	13.09^{d}±0.801
S+C4	0.910^{a}±0.080	0.290^{b}±0.023	0.240^{a}±0.001	1.530^{a}±0.030	1.190^{b}±0.040	0.001±0.0008	0.060^{a}±0.0002	0.003^{a}±0.001	13.090^{a}±1.130	20.40^{b}±0.102



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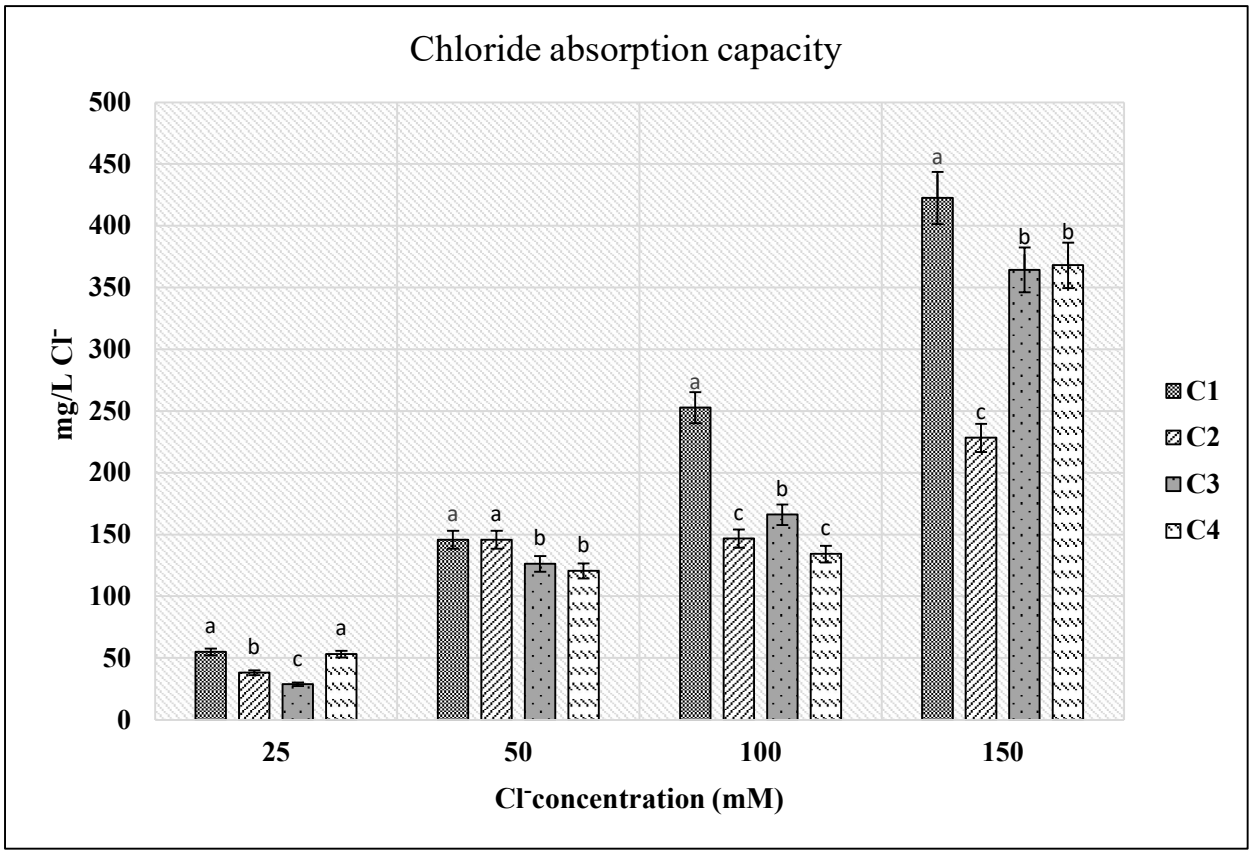

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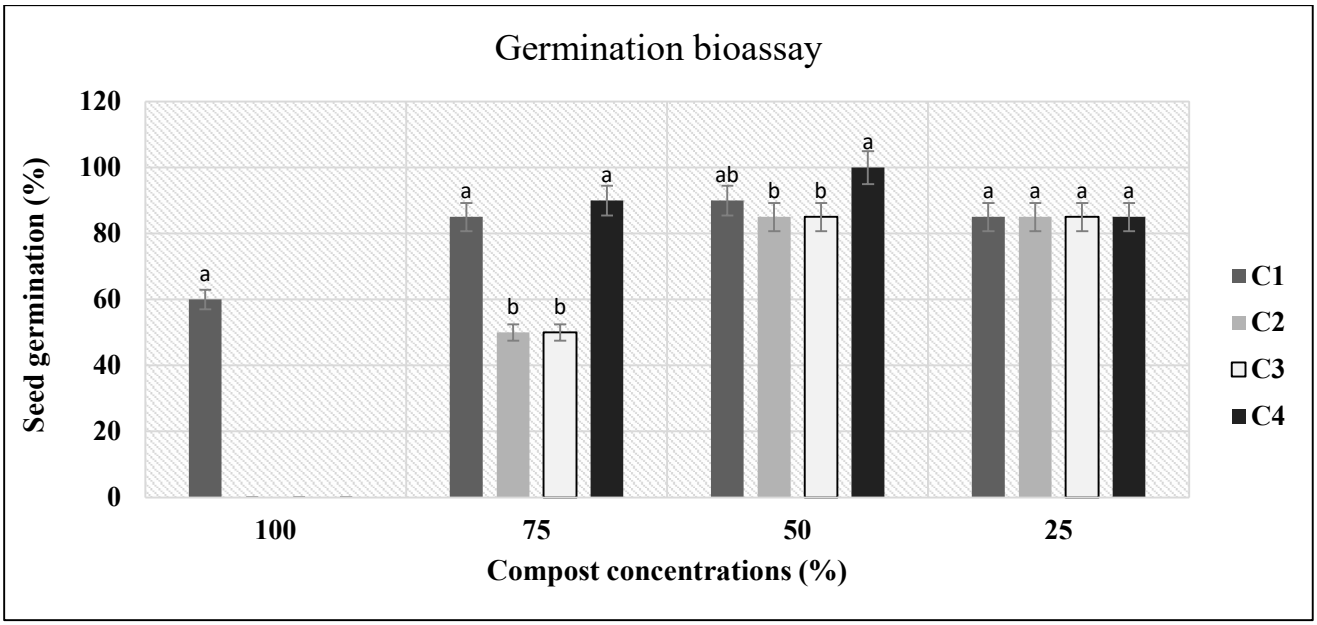
611 **Fig. 1**


Germination bioassay
Seed germination (%)
120
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60
40
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75
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Compost concentrations (%)
C1
C2
C3
C4

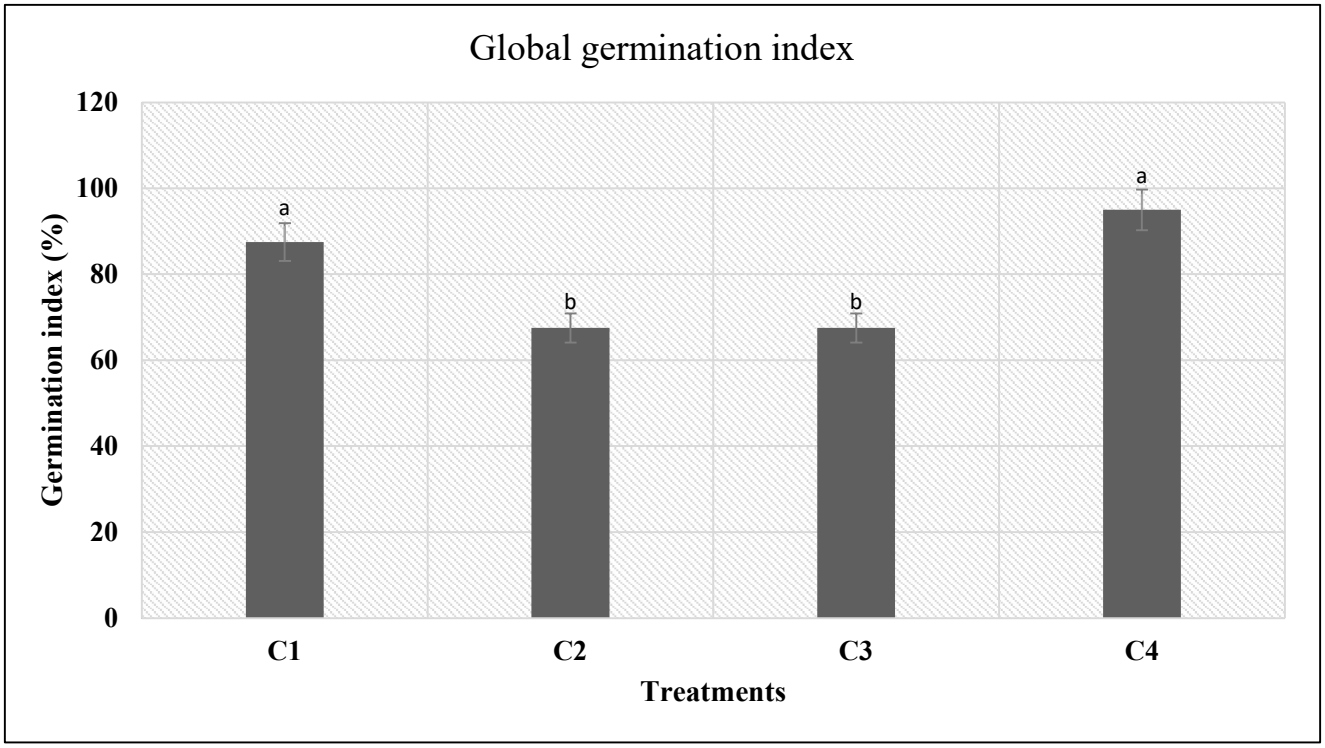
Global germination index
Germination index (%)
120
100
80
60
40
20
0
a
b
b
a
C1
C2
C3
C4
Treatments

Fig. 2