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Use of livestock waste composts as nursery growing media: Effect of a washing pre-treatment

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A R T I C L E I N F O

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A B S T R A C T

The search for alternative materials for peat substitution in soilless systems has led to an increasing use of compost as ingredient of growing media. These materials may have similar characteristics to peat for their potential use as substitutes of this non-renewable material. However, the high salinity is one of the most usual limiting factors in compost for its use in growing media. This work evaluates the effect of the use of a washing pre-treatment to improve the quality of livestock waste-derived composts as peat substitutes in substrates for pepper (*Capsicum annuum* L.) seedling production. For this, different growing media were prepared using as ingredients five composts from livestock manures and anaerobic digestates (M1, M2, M3, D1 and D2), with or without a washing pre-treatment. Each respective material was mixed with peat in the proportions 25 %, 50 % and 75 % (volume:volume), using as control treatment pure (100 %) peat. The main physico-chemical, chemical and physical characteristics of the composts before and after washing and those of the growing media were studied, as well as germination and biomass production of the seedlings. The use of a washing pre-treatment was effective in the reduction of compost salinity, without implying a negative effect on the physical properties and nutrient content of the growing media, which were adequate for being used in seedling production, as reflected in the beneficial effects on the germination and growth of pepper seedlings.

1. Introduction

In the last years, the environmental concern associated with the extraction and growing demand of peat, as the main component used in growing media for conventional and organic seedling production in the EU, has increased (Ceglie et al., 2015). As a consequence of this, in many countries several restrictions have been established for the use of this material (Moral et al., 2013). This fact has led to the search for alternative eco-friendly materials, with low cost and high quality as substrate components. A great variety of organic materials has been studied as total or partial ingredients of growing media, such as residual biomasses (Noguera et al., 2003; Medina et al., 2009; Cocozza et al., 2011; Andreu-Rodriguez et al., 2013), as well as other organic wastes after proper composting, such as municipal organic wastes, manures, green wastes and/or agri-food wastes (De Lucia et al., 2013; Ceglie et al., 2015; Restrepo et al., 2013; Bustamante et al., 2008; Lazcano et al., 2009; Sáez et al., 2016; Morales et al., 2017; Jara-Samaniego et al., 2017). Specifically, the composting process improves the characteristics of the waste material, reducing the potential hazardous presence of parasites, pathogens and weed seeds (Bernal et al., 2009). Thus, composts not only can partially substitute mineral fertilisers, but may also improve the properties of the growing media. However, composts may also show several limitations, such as the temporal variability in their properties, poor physical properties, presence of organic phytotoxins and/or heavy metals, high pH and/or high salinity (Rinaldi et al., 2011; Ceglie and Abdelrahman, 2014; Sáez et al., 2016). In fact, the high concentrations of salts or nutrients are usually the reasons that prevent composts for their direct use as substrates for soilless crop cultivation (Abad et al., 2001; Bustamante et al., 2008). The high salinity is a common limiting factor in compost that strongly depends on their origin (Chong, 2005), this aspect being especially relevant in compost from livestock manures (Bustamante et al., 2010). Thus, high salt levels in the substrate is a

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factor especially critical in seedling production, due to the lower tolerance of the plant to salinity at the first growth stages (Fornes et al., 2007, 2010).

Several studies have reported different methods to reduce salinity in the composts, such as the use of zeolite (Koushafar et al., 2011) or the application of electrochemical methods, especially to remove sodium ions (Baek et al., 2000). However, the most common methods to reduce salinity in compost are based on its dilution by mixing with other materials (Bustamante et al., 2008; Tittarelli et al., 2009; Restrepo et al., 2013) and the application of leaching techniques prior to or during their use as ingredient of growing media (Fornes et al., 2010; Illera-Vives et al., 2014). The leaching techniques are mainly based on the irrigation with water (Fornes et al., 2010), with an acid or a nutrient solution (Chong, 2005; Mazuela et al., 2005). However, the main drawback of leaching techniques is water consumption and thus, this method requires to be perfectly designed to be a cost-effective and environmentally procedure that minimizes the amount of water used.

Another alternative option to reduce salinity in composts prior to be used as growing media and/or growing media components is their pre-treatment by elution or washing with water, in which the material is not into a container and it is not irrigated as in the leaching techniques. In this technique, the material is mixed with distilled water in a determined ratio, shaken during a determined time and dewatered (using free drainage and/or mechanical methods such as the centrifugation). However, the use of this technique to reduce compost salinity and its effect on the characteristics of the final materials, especially on the physical properties, have been scarcely studied. Only Liu et al. (2014) used this methodology to reduce salinity in sewage sludge compost prior to its utilization as nursery growing medium, reporting promising results.

In both types of techniques (leaching and washing), the leachates generated must be properly managed and their volume minimised. In this sense, there are several potential options to manage and recycle this effluent, such as the use as liquid fertiliser (Gils et al., 2005; Tejada et al., 2008), in hydroponic cultures (Jarecki et al., 2005) and even as biostimulator (Stirk et al., 2004) and/or disease inhibitor (Scheuerell and Mahaffee, 2002), depending on its characteristics.

Therefore, this work studies the effects of different livestock manure-derived composts, previously pre-treated or not with a washing pre-treatment, in a peat substitution experiment for the seedling production of pepper (*Capsicum annuum* L.). For this, the effects of compost origin, proportion in the substrate and of the application of a previous washing pre-treatment have been studied on parameters associated to the growing media and to the pepper seedlings.

2. Materials and methods

2.1. Growing medium ingredients and washing pre-treatment

Five composts (M1, M2, M3, D1 and D2) derived from livestock wastes were used as organic growing medium components. M1, M2 and M3 were prepared mainly using livestock manures: M1 using pig slurry (PS) obtained from a fattening pig farm in Orihuela (Alicante, Spain), M2 using a mixture at 50:50 of sheep manure and goat manure (SGM) and M3 using PS collected in a sows and piglets farm located in Guazamara (Almería, Spain). D1 and D2 were prepared from the solid fraction of anaerobic digestates from cattle manure (CD) and pig slurry (PD), respectively. In M2, the mixture of sheep manure and goat manure came from the experimental farm of the Escuela Politécnica Superior de Orihuela (EPSO-Miguel Hernández University). In D1, CD was produced after the continuous, anaerobic co-digestion of cattle slurry in an industrial biogas plant located in Valencia (Spain); while in D2, PD was obtained after the continuous, anaerobic thermophilic digestion of pig slurry in an industrial biogas plant placed in Lleida (Spain), after mechanical separation by centrifugation without any additive addition. These livestock wastes were mixed with several bulking agents for their composting: cotton gin waste (CW); grass clippings (GC); wheat straw (WS); vine shoot pruning (VP); maize straw (MS). The proportions (on a fresh matter basis) of the initial wastes used in the mixtures and the principal characteristics of the composting processes are shown in Table 1. The composting piles M2, M3 and D2 were prepared at an industrial scale using the turning windrow system, while M1 and D1 were composted by the Rutgers static pile composting system in a pilot plant (2000 kg), with forced aeration on temperature demand, which maintains a temperature ceiling (65 °C) in the pile, involving on-demand ventilation through temperature feedback control. A good development of the bio-oxidative phase was observed in all the mixtures, with a different duration (Table 1), carrying out different turnings depending on the composting system used, to homogenize the mixture and improve the process. In all piles, the bio-oxidative phase of composting was considered finished when the temperature of the piles was stable and near to that of the atmosphere. Then, all the piles were allowed to mature for 2 months. More details about the compost elaboration of M1, M3 and D1 and D2 can be found elsewhere (Santos et al., 2016; Sáez et al., 2017; Bustamante et al., 2012). The composts had pH values close to neutrality, high electrical conductivity values, especially M1 and D2, adequate concentrations of organic matter and total N, and a C/N ratio < 20 (Table 2), limit value established for compost maturity (Bernal et al., 2009).

To decrease salt contents and thus, to improve their quality for their use as growing medium ingredients, a pre-treatment washing with distilled water was applied to all the composts. For this, 5 L of each compost was mixed with deionised water in a proportion 1:1 (v:v) and shaken for 30 min at 25 °C. After that, washed compost samples (labelled LM1, LM2, LM3, LD1 and LD2) were spread on a gauze with a diameter of 10 mm and allowed to drain. Then, the original composts (M1, M2, M3, D1 and D2) and the washed composts (LM1, LM2, LM3, LD1 and LD2) were used as ingredients of the growing media.

2.2. Experimental design

All the composts (original and after washing pre-treatment) were respectively mixed with a commercial peat with no previous fertilisation, a weakly-decomposed *Sphagnum* moss limed (pH = 6.42). The main characteristics of this material are included in Tables 3 and 4. These mixtures resulted in thirty growing media, prepared by mixing the ten composts (M1, M2, M3, D1, D2 and LM1, LM2, LM3, LD1, LD2) with

Table 1
Proportions of the raw materials in the composts and main characteristics of the composting process.

	M1	M2	M3	D1	D2
Initial mixture composition					
PS (% fw)	87	–	75	–	–
SGM (% fw)	–	85	–	–	–
CD (% fw)	–	–	–	90	–
PD (% fw)	–	–	–	–	90
CW (% fw)	13	–	25	–	–
GC (% fw)	–	8	–	–	–
WS (% fw)	–	7	–	–	–
VP (% fw)	–	–	–	10	–
MS (% fw)	–	–	–	–	10
Composting development					
Duration bio-oxidative phase (days)	103	88	146	95	132
Composting system used	Static pile (Rutgers)	Turning	Turning	Static pile (Rutgers)	Turning
Number of turnings	2	5	5	2	5

PS: solid fraction of pig slurry; SGM: mixture (50:50) of sheep and goat manure; CD: solid fraction of anaerobic cattle manure digestate; PD: solid fraction of anaerobic pig slurry digestate; CW: cotton gin waste; GC: grass clippings; WS: wheat straw; VP: vine shoot pruning; MS: maize straw.

Table 2
Main physico-chemical and chemical properties of the original composts (M1, M2, M3, D1 and D2) and after the washing treatment (LM1, LM2, LM3, LD1 and LD2).

	M1	LM1	M2	LM2	M3	LM3	D1	LD1	D2	LD2
pH	6.49 ± 0.00	6.80 ± 0.00	7.76 ± 0.01	8.05 ± 0.04	7.49 ± 0.00	7.52 ± 0.01	6.88 ± 0.02	6.64 ± 0.01	5.72 ± 0.01	6.03 ± 0.01
EC (dS/m)	10.5 ± 0.8	6.23 ± 0.04	2.74 ± 0.00	2.39 ± 0.02	6.42 ± 0.07	4.69 ± 0.15	8.21 ± 0.05	6.04 ± 0.05	8.93 ± 0.04	6.14 ± 0.14
OM (%)	57.0 ± 1.5	59.1 ± 1.2	62.1 ± 0.9	56.5 ± 0.5	59.7 ± 0.3	55.7 ± 1.5	70.2 ± 0.2	70.2 ± 0.9	51.1 ± 0.05	48.4 ± 0.2
TOC (%)	37.3 ± 0.6	30.2 ± 0.3	34.2 ± 0.1	30.1 ± 0.0	33.0 ± 0.1	28.8 ± 0.8	39.4 ± 0.5	34.6 ± 0.4	29.8 ± 0.4	24.7 ± 0.1
TN (%)	4.20 ± 0.40	3.33 ± 0.12	3.18 ± 0.23	2.70 ± 0.01	3.35 ± 0.31	2.81 ± 0.01	3.72 ± 0.13	2.90 ± 0.03	3.09 ± 0.10	2.60 ± 0.07
C/N ratio	8.9 ± 0.1	9.07 ± 0.06	10.7 ± 0.1	11.1 ± 0.0	9.86 ± 0.05	10.2 ± 0.1	10.6 ± 0.1	11.9 ± 0.1	9.63 ± 0.0	9.50 ± 0.1
TP (g kg^{-1})	15.9 ± 0.2	15.7 ± 0.2	12.1 ± 0.5	10.1 ± 0.1	27.8 ± 2.3	22.5 ± 1.5	6.95 ± 0.14	6.58 ± 0.18	32.2 ± 1.2	31.1 ± 0.2
TK (g kg^{-1})	37.3 ± 0.0	21.5 ± 0.1	8.73 ± 0.02	8.50 ± 0.01	25.4 ± 0.2	15.0 ± 0.0	16.4 ± 0.1	13.7 ± 0.1	10.5 ± 0.0	7.99 ± 0.13
TNa (g kg^{-1})	13.2 ± 1.1	9.12 ± 0.18	9.90 ± 0.18	7.62 ± 0.52	13.6 ± 1.2	10.4 ± 0.2	5.83 ± 0.53	11.2 ± 0.6	12.9 ± 0.2	9.62 ± 0.16

EC: electrical conductivity; OM: organic matter; TOC: total organic C; TN: total nitrogen; TP: total phosphorus; TK: total potassium; TNa: total sodium. Data values reported as mean value ± standard error.
M1: 87 % PS + 13 % CW; M2: 85 % SGM + 8% GC + 7% WS; M3: 75 % PS + 25 % CW; D1: 90 % CD + 10 % VP; D2: 90 % PD + 10 % MS. For the abbreviations of the raw materials, see Table 1.

Table 3
Effect of the different factors considered (compost type (C), proportion in the substrate (P) and pre-treatment (W)) in the main physico-chemical and physical properties of the growing media elaborated.

	pH	EC (dS m^{-1})	BD (g cm^{-3})	TPS (% vol)	AC (% vol)	TWHC (mL L^{-1})	Shrinkage (% vol)
Compost origin							
IS[a]	5.2–6.3	< 0.5	≤ 0.4	> 85	20–30	550–800	< 30
Peat	6.5b	0.15a	0.209b	85.1b	36.3b	494a	19.9ab
M1	6.8d	2.60e	0.195ab	87.7c	36.2b	522b	27.8c
M2	7.7e	1.15b	0.309d	81.3a	30.6a	512b	21.3ab
M3	7.6e	2.25d	0.297d	81.7a	31.1a	512b	21.8b
D1	6.7c	2.09c	0.188a	87.6c	35.3b	529b	27.5c
D2	6.3a	3.32f	0.260c	84.3b	31.9a	530b	19.4a
ANOVA	***	***	***	***	***	***	***
Compost proportion							
0% compost	6.5a	0.15a	0.209a	85.1a	36.3c	494a	19.9a
25 % compost	6.8b	1.40b	0.240b	84.4a	32.9a	521bc	23.5b
50 % compost	7.0c	2.45c	0.251bc	84.7a	34.3b	509ab	22.8b
75 % compost	7.2d	3.01d	0.258d	84.5a	31.8a	533c	24.4b
ANOVA	***	***	***	*n.s.*	***	***	***
Pre-treatment							
Without washing	6.9a	2.6a	0.266b	83.6a	35.4b	488a	22.9a
With washing	7.1b	1.8b	0.230a	85.6b	30.7a	554b	23.9b
ANOVA	***	***	***	***	***	***	*
Interactions among the factors							
C x P	***	***	***	***	***	***	***
C x W	***	***	***	***	***	***	***
P x W	**	***	***	***	*n.s.*	***	**
C x P x W	**	***	***	***	***	***	*

M1: 87 % PS + 13 % CW; M2: 85 % SGM + 8% GC + 7% WS; M3: 75 % PS + 25 % CW; D1: 90 % CD + 10 % VP; D2: 90 % PD + 10 % MS. EC: electrical conductivity; BD: bulk density; TPS: total pore space; AC: air capacity; TWHC: total water holding capacity. For the abbreviations of the raw materials, see Table 1.
n.s.: not significant $P > 0.05$; *, **, ***: significant at $P < 0.05$, 0.01 and 0.001, respectively. For each parameter and factor, values in columns followed by the same letter are not statistically significant according to the Tukey-b test.
[a] IS: ideal substrate (Abad et al., 2001; Noguera et al., 2003).

peat in the proportions 25 %, 50 % and 75 % by volume of compost. Pure peat was used as control treatment (Peat). The growing media used were not fertilised before planting. The experiment was developed in a commercial nursery (Semilleros El Raal-Cox S.L., Alicante).

A horticultural crop (pepper, *Capsicum annuum* L. cv. Largo de Reus Pairal) was selected and raised (a seed per cell) in foamed polystyrene plug trays (70 × 46 cm) with 294 inverted pyramid cells. The treatments (substrates) were conducted in a full randomised plot design, using a tray per treatment (four replicates per treatment). The germination was developed at established conditions (27 ± 1 °C and 95 % relative humidity) in an air-conditioned chamber.

The percentage of germination was calculated by counting the number of germinated seeds after 48 h from seeding (Bustamante et al., 2008). Then, the trays were placed on rails with natural daylight conditions in an unheated polyethylene-covered greenhouse. During the experimental period, the average temperature was 16 °C, with a maximum temperature value of 19 °C and a minimum value of 7 °C, with an average solar radiation of 140 w/m^2. The plants were irrigated daily with a mobile, sprinkler system and fertirrigated twice a week using an irrigation solution composed of 136 mM N (NO_3^- + NH_4^+), 49.4 mM P_2O_5, 23.4 mM K_2O, 22.8 mM CaO, 6.25 mM Fe, 0.24 mM Cu, 3.18 mM Mn, 0.54 mM Zn and, 0.16 mM Mo (Bustamante et al., 2008).

Once most of the plantlets reached the commercial transplanting size (on day 84 after germination), from each plug tray, 16 seedlings were randomly harvested, avoiding the seedlings from the edges. Aerial fresh weight (AFW), shoot height (H) and root fresh weight of the plantlets were determined before washing and drying transplants to determine aerial and root dry weight (ADW and RDW, respectively) (at 55 °C in an air-forced oven for 72 h). After this, the shoot samples were ground to a 0.5 mm powder for the analytical determinations.

2.3. Analytical methods

The physical parameters of the substrates were determined following the methodology used by Bustamante et al. (2008). Electrical conductivity (EC) and pH were determined according to EN 13038 (1999) and

Table 4
Effect of the different factors considered (compost type (C), proportion in the substrate (P) and pre-treatment (W)) in the main chemical characteristics of the growing media elaborated.

	OM (%)	TOC (%)	TN (%)	WS Na (g L^{-1})	WS K (g L^{-1})	WS P (g L^{-1})	Chloride (g L^{-1})	Sulfate (g L^{-1})	Nitrate (g L^{-1})
Compost origin									
Peat	92.1e	49.1e	1.1a	0.02a	0.08a	0.02a	0.01a	0.10a	0.05a
M1	65.2c	41.9c	3.1d	0.52d	2.55e	0.44e	0.71e	1.30e	5.42d
M2	63.0b	41.0c	2.8c	0.38b	0.94b	0.09c	0.47c	0.56b	1.19b
M3	65.7c	39.4b	2.7c	0.60e	2.15d	0.41d	0.70e	0.76c	1.27b
D1	73.7d	45.5d	2.7c	0.46c	1.21c	0.06b	0.35b	1.32e	2.28c
D2	60.0a	33.6a	2.4b	0.65f	1.12c	0.49f	0.59d	1.09d	5.66d
ANOVA	***	***	***	***	***	***	***	***	***
Compost proportion									
0% compost	92.1d	49.1d	1.1a	0.02a	0.08a	0.02a	0.01a	0.10a	0.05a
25 % compost	73.7c	44.2c	2.3b	0.32b	0.96b	0.22b	0.31b	0.48b	1.69b
50 % compost	63.7b	39.8b	2.8c	0.50c	1.62c	0.31c	0.60c	1.15c	3.13c
75 % compost	59.1a	36.8a	3.1d	0.75d	2.20d	0.37d	0.78d	1.38d	4.68d
ANOVA	***	***	***	***	***	***	***	***	***
Pre-treatment									
Without washing	66.7a	40.1a	2.6a	0.60b	1.83b	0.30b	0.69b	1.00b	3.51b
With washing	66.0b	41.1b	2.7a	0.41a	1.25a	0.28a	0.39a	0.95a	2.60a
ANOVA	**	***	*n.s.*	***	***	***	***	***	***
Interactions among the factors									
C x P	***	***	***	***	***	***	***	***	***
C x W	***	**	***	***	***	***	***	***	***
P x W	*n.s.*	***	*n.s.*	***	***	***	***	*n.s.*	***
C x P x W	***	**	***	***	***	***	***	***	***

OM: total organic matter; TOC: total organic carbon; TN: total nitrogen; WS: water-soluble. *n.s.*: not significant $P > 0.05$; *, **, ***: significant at $P < 0.05$, 0.01 and 0.001, respectively. For each parameter and factor, values in columns followed by the same letter are not statistically significant according to the Tukey-b test.M1: 87 % PS + 13 % CW; M2: 85 % SGM + 8% GC + 7% WS; M3: 75 % PS + 25 % CW; D1: 90 % CD + 10 % VP; D2: 90 % PD + 10 % MS. For the abbreviations of the compost raw materials, see Table 1.

EN 13037 (1999), respectively. Dry matter was determined by drying at 105 °C for 12 h, and organic matter (OM) by loss on ignition at 430 °C for 24 h (Bustamante et al., 2008). Total nitrogen (TN) and total organic carbon (TOC) were determined by dry combustion at 950 °C with a Leco TruSpec C–N Elemental Analyzer (Leco Corp., St. Joseph, MI, USA). P fractions were determined colorimetrically as molybdovanadate phosphoric acid; total P, in the extract obtained after HNO_3-HClO_4 digestion and water-soluble P, in the water-soluble extract (1:5, v:v). Flame photometry (Jenway PFP7 Flame Photometer, Jenway Ltd., Felsted, UK) was used to determine Na and K, water-soluble fraction in the water-soluble extract (1:5, v:v) and total fraction, after HNO_3-HClO_4 digestion. Sulfates, chlorides and nitrates were determined in the 1:5 (v:v) water-soluble extract using ion chromatography. All the analytical determination were conducted in triplicate.

2.4. Statistical analysis

The univariate linear general model (LGM) was used to study the effects of the factors studied: type of substrate, compost proportion in the mixture and treatment of the compost prior to the elaboration of the mixture (washed and not-washed). The post-hoc contrast was carried out by the Tukey-b test. Principal component analysis (PCA) was carried out to reduce dimensionality and assess the extent of treatment differentiation in relation to the different factors considered. The statistical analyses were determined using STATISTICA v. 8.0 software (StatSoft, TIBCO Software Inc., Palo Alto, CA, USA).

3. Results and discussion

3.1. Effect of the washing pre-treatment on the composts

In general, the washing pre-treatment applied to the composts produced a significant effect on several of the final properties of the materials (Table 2). The pH values slightly increased in all the composts except for M3, whose value remained constant, and compost D1, whose value decreased with the pre-treatment. However, the electrical conductivity (EC) clearly decreased in all the composts after the pre-treatment, with percentages of diminution of 40.7 % for M1, 12.8 % for M2, 26.9 % for M3, 26.4 % for D1 and 31.2 % for D2. Thus, this effect was especially remarkable in the composts with the initial highest salinity (M1, D1 and D2), indicating ion removal (Illera-Vives et al., 2014). Also, the contribution of the ions to the EC depends on their total amount leached, their initial concentration in the compost and therefore the leaching efficiency.

Moreover, Carrión et al. (2005), in an experiment of leaching of agricultural waste-derived composts, also reported that the composts showed a different behaviour to salt leaching. This behaviour depended on the initial waste materials, composting process and therefore, compost physical and chemical characteristics, such as particle size, bulk density, total water holding capacity and especially organic matter contents. Concerning the chemical parameters, the washing pre-treatment seemed to produce a reduction of the organic fraction, probably due to the leaching of the water-soluble organic fraction (Table 2). The total concentration of the main macronutrients (N, P and K) and of Na, one of the main phytotoxic ions together with chloride, also decreased after the washing pre-treatment, especially for K and Na, due to their highly soluble nature in the compost. Fornes et al. (2010) and Illera-Vives et al. (2014) also reported in leaching experiments with different types of compost the highest leaching efficiency for these ions compared to P, possibly due to the chemical binding or adsorption processes of this ion in composts (Guo and Chorover, 2004; Fornes et al., 2010). In addition, Liu et al. (2014) also found that using an elution proportion of 1:1 (compost:water), reduced the Na concentrations to values within the range for plant tolerance in sewage sludge compost.

3.2. Effect on the physical and chemical properties of the growing media

Table 3 shows the incidence of the factors studied (compost type, compost proportion in the growing media and the washing pre-treatment) on the main physico-chemical and physical characteristics of the substrates prepared. The incorporation of the composts to the substrates had a variable effect on the physico-chemical properties depending on the compost type.

The use of manure derived-composts (M1, M2 and M3) induced higher pH (mean values) than those from anaerobic digestates, while the lowest EC values were observed in the growing media prepared with composts M2 and D1. In addition, the increasing compost percentage in the mixtures increases the pH and EC values. This effect was also found in previous studies of peat substitution by compost in substrates (Bustamante et al., 2008; Ceglie et al., 2015; Sáez et al., 2016). In addition, the washing pre-treatment induced an increase of the pH and a reduction of the EC (Table 3), effect that was also observed by other authors (Fornes et al., 2010; Gonani et al., 2011).

Concerning the physical characteristics, in general, the average values were similar to those of pure peat (control treatment) and within or close to the optimum values of an ideal growing medium according to Abad et al. (2001) and Noguera et al. (2003). The washing pre-treatment was the variable that showed the greatest influence, with significant effects on all the physical properties. This could be due to changes in the particle size and pore distribution in the washed composts as shown by the reduction of the air capacity and in the increase in the total pore space, total water holding capacity and shrinkage (Table 3). Previous published papers have studied the effect of different treatments to reduce salinity in organic materials, such as leaching and washing/elution (Carrión et al., 2005; Mazuela et al., 2005; Fornes et al., 2010; Illera-Vives et al., 2014; Liu et al., 2014). However, only Fornes et al. (2010) reported a relationship between the efficiency of salt displacement when leaching and the type of compost. This fact is due to leaching efficiency, which depends on certain physical properties in porous materials, such as particle size and porosity and the diffusion of solutes within the aggregates (Fornes et al., 2007).

All the factors studied (type of compost, proportion in the substrate and pre-treatment) showed a significant influence on the substrate chemical characteristics (Table 4).

This fact was especially relevant for the concentrations of the water-soluble elements, which augmented with the raising proportion of compost and were higher in the growing media in comparison with peat. However, the opposite behaviour was observed for the washing pre-treatment, showing a decrease in the concentrations of these elements with respect to the original compost. Liu et al. (2014) also reported that this treatment removes most soluble salts from sewage sludge compost, including Na^+, K^+, Ca^{2+}, Cl^-, and Mg^{2+}. Fornes et al. (2010) also observed that the decrease in the soluble mineral elements of composts from lignocellulosic wastes, mainly K^+, Ca^{2+}, Cl^-, SO_4^{2-} and Na^+, coincided with the drop in the electrical conductivity previously commented.

3.3. Seed germination and seedling growth

The factors considered showed a significant influence, especially the compost origin and the washing pre-treatment in the pepper seed germination (Table 5). The incorporation of the composts M1, M3 and D2 in the substrates induced the lowest values of seed germination, coinciding this fact with the highest increase of the salinity produced by these composts when were incorporated in the substrates (Table 3). The compost proportion in the substrates only produced a decrease in the germination at the highest percentage of peat substitution (75 %). The reduction of the germination at high proportion of compost in the growing media has been also found in previous studies (Bustamante et al., 2008; Ceglie et al., 2015). However, the washing pre-treatment of the composts had a positive effect on the pepper seed germination, probably due to the effect of salinity reduction. Fornes et al. (2010) also observed a higher growth of the plant species studied (*Calendula officinalis* and *Calceolaria hybrida*) in the growing media obtained with leached composts with respect to the growing media prepared with the original compost. Moreover, Liu et al. (2014) reported that the treatment of water elution was effective for alleviating saline stress on seedling growth.

In addition, the percentage of compost in the substrate and the washing pre-treatment had a significant influence, especially in the aerial and root fresh weight, which showed the highest average values for the percentage of 25 % of compost and for the use of the pre-treatment (Table 5). These results show that the washing pre-treatment had a positive effect on the germination, the shoot height and on the seedling biomass production of pepper. Other authors have also reported increases in the seedling biomass production when composts are used as growing medium ingredients (Pérez-Murcia et al., 2006; Bustamante et al., 2008; Sáez et al., 2016), due to the nutrient incorporation, such as N and P, with composts. In this experiment, the increases in seedling biomass production despite the washing pre-treatment indicate that salinity has been reduced, but without implying a negative effect on the germination and growth of the seedlings associated to the decrease of the water-soluble mineral elements.

Table 5
Effect of the different factors considered (compost type (C), proportion in the substrate (P) and pre-treatment (W)) in the germination and morphological parameters of the pepper seedlings.

	G (%)	H (cm)	AFW (g)	ADW (g)	RFW (g)	RDW (g)
Compost origin						
Peat	89.4c	8.6d	1.98b	0.22ab	0.54a	0.06a
M1	84.9bc	7.8bc	1.95b	0.22b	0.79b	0.07b
M2	89.8c	8.4cd	2.04b	0.22b	0.80bc	0.07b
M3	69.8a	7.7b	1.98b	0.22ab	0.89c	0.08b
D1	87.1c	8.6d	1.99b	0.23b	0.87bc	0.08b
D2	80.6b	6.9a	1.78a	0.20a	0.86bc	0.08b
ANOVA	***	***	***	***	***	*
Compost proportion						
0% compost	89.4b	8.6bc	1.99bc	0.22a	0.54a	0.06a
25 % compost	86.3b	8.8c	2.15c	0.24b	0.91c	0.08b
50 % compost	85.1b	8.0b	1.92ab	0.22a	0.82bc	0.07b
75 % compost	75.9a	6.8a	1.78a	0.21a	0.81b	0.07b
ANOVA	***	***	***	***	***	**
Pre-treatment						
Without washing	80.5a	7.8a	1.81a	0.20a	0.77a	0.07a
With washing	84.5b	8.0b	2.10b	0.23b	0.90b	0.08b
ANOVA	***	***	***	***	***	**
Interactions among the factors						
C x P	***	***	***	***	***	**
C x W	***	***	***	***	**	**
P x W	*n.s.*	**	*n.s.*	*n.s.*	*n.s.*	*n.s.*
C x P x W	***	***	***	***	*	**

G: germination; H: shoot height; AFW: aerial fresh weight; ADW: aerial dry weight; RFW: root fresh weight; RDW: root dry weight. M1: 87 % PS + 13 % CW; M2: 85 % SGM + 8% GC + 7% WS; M3: 75 % PS + 25 % CW; D1: 90 % CD + 10 % VP; D2: 90 % PD + 10 % MS. For the abbreviations of the compost raw materials, see Table 1.
*, **, ***: significant at $P < 0.05$, 0.01, 0.001, respectively. For each parameter and factor, values in columns followed by the same letter are not statistically significant according to the Tukey-b test.

3.4. Principal component analysis (PCA)

The Principal Component Analysis conducted for all the results indicated that the first two components or factors explained together more than 69 % of the total variability (54.03 % and 15.14 %, respectively) (Table 6). A plot of the first and second factors for the growing media is displayed in Fig. 1. In addition, Fig. 2 shows the contributions of the parameters considered in the analysis: a) parameters associated to the growing media (electrical conductivity (EC), total organic matter (OM), total N (TN), total organic carbon (TOC), C/N ratio (CN), total P (TP), water-soluble P (WSP), nitrates, sulfates, chlorides, water-soluble K (WSK), water-soluble Na (WSNa), total sodium (TNa) and total potassium (TK)); b) parameters related to the seedling quality (shoot height (H), aerial fresh weight (AFW), aerial dry weight (ADW), root fresh weight (RFW) and root dry weight (RDW)). Fig. 1 shows the separation of groups of treatments mainly depending on the compost

Table 6
Contribution (%) of the different parameters to each eigenvalue considered in the PCA analysis.

Parameters	F1	F2
WSNa	8.379	0.310
EC	7.953	0.572
Chloride	7.526	0.002
TNa	6.994	0.111
OM	6.176	4.853
WSK	5.840	0.002
TOC	5.835	3.207
AFW	5.829	8.163
H	5.790	1.754
ADW	5.180	8.826
Nitrate	5.119	0.453
CN	5.010	7.837
WSP	4.758	3.852
Sulfate	4.409	0.002
TN	4.371	1.354
TP	4.045	6.251
TK	3.697	2.127
RFW	1.635	23.962
RDW	1.451	26.363

For abbreviations, see Tables 2,4 and 5.

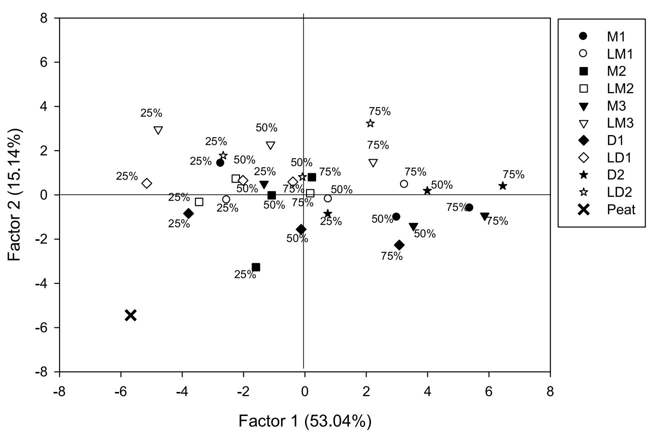

Fig. 1. Plot of the first and second factors extracted from principal component analysis of the parameters studied in the growing media and in the pepper seedlings. M1: 87 % PS + 13 % CW; M2: 85 % SGM + 8% GC + 7% WS; M3: 75 % PS + 25 % CW; D1: 90 % CD + 10 % VP; D2: 90 % PD + 10 % MS. PS: solid fraction of pig slurry; CW: cotton gin waste; SGM: mixture (50:50) of sheep and goat manure; GC: grass clippings; WS: wheat straw; CD: solid fraction of anaerobic cattle manure digestate; PD: solid fraction of anaerobic pig slurry digestate; VP: vine shoot pruning; MS: maize straw.

washing pre-treatment for Factor 2, and the proportion of compost in Factor 1.

In Factor 2 this segregation is defined, showing positive loadings on this axis for the growing media prepared with composts with the washing pre-treatment. Factor 1 classificates the groups depending on the proportion of compost, the mixtures with the highest percentages of compost (50–75 %) being associated with the positive side of this Factor. As it is shown in Fig. 2, positive contributors to Factor 1 included all the parameters related to water-soluble and total fractions of elements, while Factor 2 was mainly influenced by the parameters associated to the seedling characteristics.

4. Conclusions

The use of a washing pre-treatment was an effective method to reduce salinity in livestock waste-derived composts before their use as substrate ingredients. This pre-treatment and the percentage of compost in the substrate showed a significant influence in the germination and

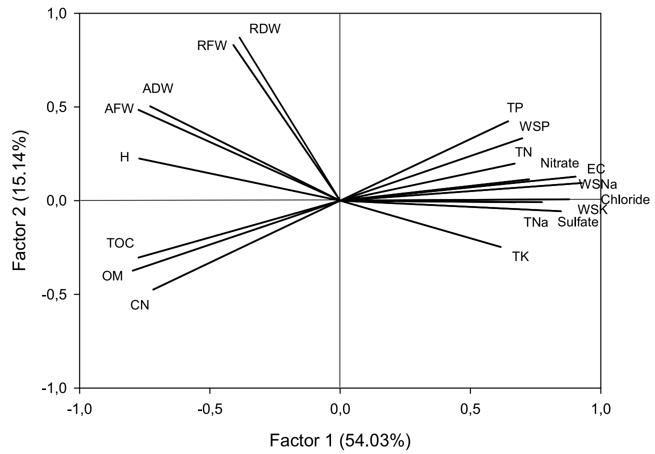

Fig. 2. Contribution to each factor of the parameters considered in the PCA analysis. WSK: water-soluble potassium; WSNa: water-soluble sodium; EC: electrical conductivity; OM: organic matter; TOC: total organic C; CN: carbon to nitrogen ratio; TN: total nitrogen; WSP: water-soluble phosphorus; TP: total phosphorus; TK: total potassium; TNa: total sodium; H: shoot height; AFW: aerial fresh weight; ADW: aerial dry weight; RFW: root fresh weight; RDW: root dry weight.

seedling growth, which showed the highest average values for the percentage of 25 % of compost regardless of its origin, and for the use of the pre-treatment. In addition, the washing pre-treatment did not have a negative influence on the physical properties of the substrates obtained, which were adequate for seedling production. Moreover, the loss of water-soluble elements due to the washing treatment did not have a negative effect, as it was reflected in the positive effect on seed germination and seedling biomass production of pepper of the growing media incorporating the washed composts.

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CRediT authorship contribution statement

M.A. Bustamante: Investigation, Supervision, Methodology, Data curation, Validation, Writing - original draft, Writing - review & editing. **M.P. Gomis:** Investigation, Methodology, Validation. **M.D. Pérez-Murcia:** Supervision, Investigation, Methodology, Validation. **D. Gangi:** Methodology, Investigation, Validation. **F.G. Ceglie:** Investigation, Data curation, Validation, Writing - review & editing. **C. Paredes:** Supervision, Investigation, Methodology, Validation. **A. Pérez-Espinosa:** Supervision, Investigation, Methodology, Validation. **M.P. Bernal:** Investigation, Data curation, Validation, Writing - review & editing, Project administration, Funding acquisition. **R. Moral:** Conceptualization, Supervision, Data curation, Validation, Project administration, Funding acquisition, Resources.

Declaration of Competing Interest

The authors declare no conflict of interest.

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