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Physico-chemical properties and phyto-toxicity assessment of co-composted winery solid wastes with and without effective microorganism inoculation

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ABSTRACT

This study assessed both the physico-chemical properties of winery solid waste (WSW) composts with or without microbial inoculation and the phyto-toxicity of their extract. Four different composts with initial pile height of 1 or 1.5 m were prepared through aerobic thermophilic process by mixing the filter materials (FM) and waste plant materials at 40 : 60 ratio on dry volume basis. Cured composts were evaluated for selected physico-chemical properties and germination attributes at varied extract concentrations (0, 10, 25, 50 and 100%) using cowpea, maize and tomato seeds. Microbial inoculation exerted significant effects on compost Bray-P2 content, while interaction between inoculation and compost pile size similarly had significant effect on ammonium-N content. The contents of bulk density, volatile solids, water holding capacity, pH, electrical conductivity, nitrate-N and exchangeable K among the various composts did not differ significantly. The composts possessed high electrical conductivity (range : 9.03-10.23 dS/m) suggesting high soluble salts concentrations. Compost type and extract concentration interaction exerted significant effect on the germination index (GI) of all three crops; with phyto-toxic effects on maize and tomato at 50% extract concentration and beyond. The compost extracts showed varying degree of phyto-toxicities to maize and tomato, while cowpea experienced no phyto-toxicity effect. Besides, the composts also showed phyto-nutrient and phyto-stimulant capabilities with greater than 100% root length and GI values. Nonetheless, the phyto-toxicity recorded in maize and tomato can be eliminated using lower application rates.

Key words : Germination index, microbial inoculation, phyto-toxicity, winery solid waste compost

INTRODUCTION

The effective microorganisms (EMs) technology is one of the new technologies that have been proposed in an attempt to improve the management of solid and liquid wastes. Effective microorganisms' inoculum has been described as a combination of about 80 co-existing beneficial microorganisms that were selected from more than 2000 species isolated from various environments (Mayer *et al.,* 2010). Lactic acid bacteria, photosynthetic bacteria, yeasts, actinomycetes and fermenting fungi are the main microorganisms in EM (Mayer *et al.,* 2010; Zakaria *et al.,* 2010). Producers of EM claimed that it could accelerate the decomposition of organic wastes (Cóndor-Golec *et al.,* 2007). Numerous studies have also suggested that its uses and applications are diverse including agriculture, livestock, gardening and landscaping, composting, bioremediation, cleaning septic tanks, algal control and household uses (Namsivayam *et al.,* 2011).

Composting is currently a widely used solid organic waste treatment method. It is a biological waste treatment technology that transforms organic wastes into organic fertilizer and soil conditioners (Malakahmad *et al.,* 2017). However, it is important to understand the characteristics of the composted products in order to avoid potential negative effects (Soares

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et al., 2013) that may accompany their use. The possible negative effects of compost utilization include the introduction of toxic heavy metals (Tittarelli *et al.,* 2007), phenolic compounds, ethylene and ammonia, and excess accumulation of salts and organic acids into the soil (Soares *et al.,* 2013). The negative effects may lead to retardation of seed germination and plant growth (Selim *et al.,* 2012). Toxic heavy metals can also enter the food chain in significant amounts through their uptake by plants from the soil (Tittarelli *et al.,* 2007) and result in health risks for humans and animals. Phyto-toxicity assessment is, therefore, one of the most important criteria for evaluating the suitability of composts for application on agricultural soils (Obuotor *et al.,* 2017) for crop production. Among other physical, chemical and biological parameters used to assess compost maturity include C/N ratio, changes in nitrogen species, pH, EC, cation exchange capacity, organic chemical constituents, reactive carbon, humification parameters, optical density, temperature, colour, odour, structure, specific gravity, plant assays, respiration, microbial population changes, enzyme activity, germination tests (Kumar *et al.,* 2016; Obuotor *et al.,* 2017), as well as calorimetric and spectroscopic tests (Quatmane *et al.,* 2013). The objective of this study was to assess the physico-chemical properties of winery solid waste (WSW) composts with or without microbial inoculation and their toxicity effect on seed germination attributes.

MATERIALS AND METHODS

Description of Study Sites and Compost Preparation Processes

The WSW composts were produced in heaps through aerobic-thermophilic composting on an open field at the research farm of the Agricultural Research Council/ Nietvoobij (-33.9168°S, 18.85988°E), Western Cape, South Africa. The WSW materials used for the co-composting included (i) filter materials (FM) that comprised diatomaceous earth (DE) and perlite, and (ii) chopped grapevine pruning canes (GPC), grape stalks (GS), and grape seeds and skins mixture (MSS), which were collectively described as waste plant materials (WPM). Prior to the WSW compost preparation, samples of the waste plant materials used were subjected to laboratory analyses for chemical characterization following standard laboratory procedures. The EM used during the compost preparation comprised microbial inoculum (EM-1) that was activated using dechlorinated water and molasses (voermolas). The EM-1 inoculum, a product of Microzone Polokwane CC, had a pH value of 3.34, contained 6.8×10^7 CFU/ml of lactic acid bacteria (*Lactobacillus casei*) and 2.4×10^2 CFU/ml of yeast (*Saccharomycess cerevisiae*). The activation of the EM-1 was performed following the procedure described by EMROSA (2008). The activated EM (EM-A) was considered ready for use when its pH value was below 4.0 (Sreenivasan, 2013).

Four WSW compost types were produced over 19 weeks period and comprised inoculated compost with an initial heap height (herein referred to as pile size) of 1 m (INC1), inoculated compost with pile size of 1.5 m (INC1.5), uninoculated compost with pile size of 1 m (UNC1), and uninoculated compost with pile size of 1.5 m (UNC1.5). The compost pile size of 1.5 m was considered an optimum pile size under natural aeration (Biddlestone *et al.,* 1981). Each WSW compost pile size (1.0 and 1.5 m) type was produced in triplicates on a hardened soil surface lined with a high-density polyethylene liner. All compost piles were prepared by mixing FM and WPM at a ratio of 40 : 60 on per cent volume basis. The 40% FM comprised 90% perlite and 10% DE, while the 60% WPM consisted of 80% GPC, 10% GS and 10% MSS on dry volume basis. Diluted EM-A (1 : 50, v/v) was sprayed per heap at 3 l/m^3 on appropriate piles once fortnightly (EMNZ, 2016). Additional water was added as required until the moisture content of each compost heap reachesd 60% on weight basis (AAFRD, 2005). Compost piles were turned at 2-weekly intervals with the moisture content monitored throughout the composting period and maintained at 70% (w/w) to allow optimal microbial activities and proper curing.

Temperature Monitoring

Temperature monitoring on each compost pile including the ambient commenced a day after the first turning with daily reading taken using a digital TCL 305 thermometer at depths of 50 and 75 cm for the 1 and 1.5 m piles, respectively. Both compost pile temperature and ambient temperature were measured at 8 a. m.; and monitoring continued until compost temperature approached ambient temperature (Antil *et al.,* 2013). Random compost sub-samples were collected at three locations in each compost pile at maturity and bulked into a composite sample per pile, air-dried, ground, sieved (0.85 mm), and used for physico-chemical characterization and phyto-toxicity test.

Physico-chemical Characteristics of the Waste Materials and Cured Composts

Moisture content in the composts was determined gravimetrically through loss on ignition (Mupondi *et al.,* 2010), while bulk density and water holding capacity (WHC) were determined according to the methods described by Ahn *et al.* (2008). Total volatile solid (VS) was determined through incineration and the final content estimated as described by Chummun *et al.* (2011). The pH in 1 M KCl and electrical conductivity (EC) in water (1:10; m/v) of the composts and waste materials measured were determined using PHS-3BW microprocessor pH meter and DDS-11AW conductivity meter, respectively (Masowa *et al.,* 2016). Total C and N contents were determined on Leco TruMac CNS analyzer, while total mineral N (TMN) was computed as the sum of nitrate (NO_3) and ammonium (NH_4) N concentrations determined colorimetrically following extraction with 0.1 N K_2SO_4 solution (Okalebo *et al.,* 2002). Available P content in composts was determined colorimetrically following Bray-2 procedure (Bray and Kurtz, 1945), while exchangeable K was extracted with 1 N NH_4AOc solution and its concentration determined on atomic absorption spectrophotometer (Okalebo *et al.,* 2002).

The total content of P, K and Na using an Inductively Coupled Plasma Mass Spectrometer (ICP-MS; Model : NexIONTM 300Q, Perkin Elmer) was measured in samples following wet acid digestion procedure. Briefly, 0.25 g of each waste materials and compost sample was digested with 6 ml HCl (32%) and 5 ml of HNO_3 (55%) at 66°C for 45 min in a microwave reaction system (Microwave 3000, Anton Paar). Sample digests were transferred into separately labelled 100 ml Erlenmeyer flask and 2 ml $HClO_4$ (70%) added. Each digest including a blank was diluted to 100 ml with deionized water and thereafter filtered using Munktell filter paper (110 mm). The concentration of P, K and Na in the filtrate was subsequently read on the ICP-MS. Total phenolic content (TPC) in compost (1:10 m/v, compost per pure methanol) was determined following the Folin-Ciocalteu method using a UV spectrophotometer at 760 nm (Slinkard and Singleton, 1977). The contents of acid detergent lignin (ADL), acid detergent fiber (ADF) and neutral detergent fiber (NDF) including the residual ash were determined following the filter bag technique.

Germination Index Test

The germination index (GI) test involved the procedure described by Tiquia *et al.* (1996) with slight modification. Briefly described, compost extracts were made by separately mixing each compost sub-sample with deionized water (1:10; w/v). Each compost extract was subsequently diluted to varying concentrations (10, 25, 50 and 100%) using deionized water; and cowpea (*Vigna unguiculata*), maize (*Zea mays* L.) and tomato (*Lycopersicon esculentum*) seed germination was evaluated. The 100% extract concentration represented pure extract, while 10, 25 and 50% concentration represented 90, 75 and 50 ml distilled water addition, respectively. Ten seeds of each of crop were placed in 90-mm diameter petri dishes lined with a filter paper and moistened with 5 ml extract of each of the various compost concentrations with deionized water used as a control. Hence, the various compost types and the extract concentrations per petri dish constituted treatment factors. Maize seeds were soaked in 250 ml deionized water overnight prior to sowing to minimize the lag-phase in seedling germination (Nadeem *et al.,* 2017), while the seeds of cowpea and tomato were directly sown without prior soaking. Triplicate petri dishes containing treatment factors were placed in Electro-Thermostatic incubator (Model : CNW ETI-9052) whose temperature was maintained at 25°C. Seeds that germinated after five days were counted and recorded, while the length of the primary root was measured using a measuring ruler. The value of GI was calculated according to Priac *et al.* (2017) using equation 1 below :

$$GI=(RLS \times GSS)/(RLC \times GSC) \quad \ldots(1)$$

Where, RLS–Mean root length in compost extract; RLC–Mean root length in control; GSS–Number of germinated seeds in extract; and GSC–Number of germinated seeds in control.

Data Analysis

Data on WSW composts physico-chemical properties, GI, TPC and the content of fibre fractions were subjected to analysis of variance (ANOVA) using Statistical 10.0 computer software program. The differences among treatment means were separated by Fisher's protected least significant difference (LSD) test at p≤0.05. Simple Pearson correlation analysis was performed among per cent seed germination, per cent root length, GI, pH and EC to establish their relationship.

RESULTS AND DISCUSSION

Chemical Characteristics of the Winery Waste Materials

Results of the WSW materials showed that perlite was very strongly alkaline with a pH value of 9.42, while the other waste materials were acidic in nature; with the DE being ultra-acidic with pH value of 2.11 (Table 1). The EC of waste materials ranged from 0.10 dS/m in GS to 4.52 dS/m in perlite. The DE had much lower C content (6.8%) than the remaining waste materials that had generally high C content (>30%). Total N content ranged from 0.26% in DE to 4.19% in perlite, while total P content ranged from 0.23 g/kg in DE to 3.45 g/kg in perlite. The perlite contained relatively very high K content (140 g/kg), while the Na content ranged from 1.62 g/kg in GPC to 3.38 g/kg in perlite.

Table 1. Physico-chemical properties of raw winery solid waste materials used in composting

Parameters	Raw materials				
	Perlite	DE	GS	MSS	GPC
pH (KCl)	9.42	2.11	6.43	5.84	5.98
EC (dS/m)	4.52	2.68	0.10	1.04	0.69
Bulk density (g/cm)	0.47	0.46	0.27	0.34	0.16
VS (%)	67	20	98	89	90
Total C (%)	31.3	6.8	32.5	42.8	33.6
Total N (%)	4.19	0.26	0.36	2.8	0.76
Total P (g/kg)	3.45	0.23	0.84	2.22	1.35
Total K (g/kg)	140	2.75	3.08	21	2.09
Total Na (g/kg)	3.38	1.74	1.82	1.84	1.62
TPC (mg GAE/g DW)	1.77	0.94	1.64	1.44	1.60
NDF (%)	nd	nd	66	72	77
ADF (%)	nd	nd	60	64	62
ADL (%)	nd	nd	39	55	36

DE–Diatomaceous earth; GS–Grape stalks; MSS–Mixture of grape seeds and skins; GPC–Grapevine pruning canes; EC– Electrical conductivity; VS–Volatile solids; TPC–Total phenolic content; GAE–Gallic acid equivalents; NDF–Neutral detergent fiber; ADF–Acid detergent fiber; ADL–Acid detergent lignin and nd–Not determined.

Dynamics of Composts Temperature during the Composting Process

Fig. 1 shows the compost pile and ambient temperatures measured during the 19 weeks of (co-) composting period. The figure reveals that the 1.0 m compost heaps

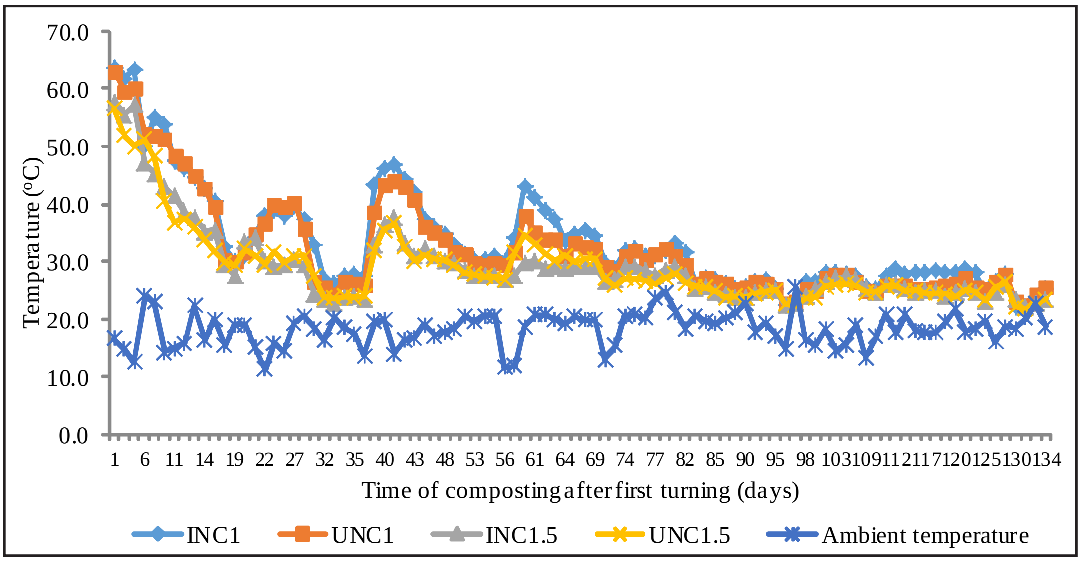

Fig. 1. Compost piles and ambient temperatures during 19 weeks of composting.

experienced extended thermophilic phase (above 45°C) up to 13 days after the first turning, while the 1.5 m compost heaps only stayed in this phase for the first seven days after the initial turning. The highest temperature measured was greater than 60°C in the 1.0 m compost piles but less than 60°C in 1.5 m piles after the first turning, while the ambient temperature ranged from 11.2°C to 25.6°C throughout the (co-)composting period.

Treatments and their Interaction Effects on WSW Composts Physico-chemical Properties

Table 2 shows the results of physico-chemical properties and fiber fractions of the composts. There was no significant difference in the bulk density, VS content and WHC among the various compost types. The composts bulk density ranged from 0.34 g/cm^3 (INC1) to 0.39 g/cm^3 (UNC1). The WHC ranged from 3.24 g water/g compost in both INC1 and NIC1.5 to 3.76 g water/g compost in INC1.5. The VS content ranged from 49% (NIC1) and 54% (NIC1.5). The pH (KCl) values 9.68 to 9.76 for the composts revealed alkalinity, while the EC values of 9.03 to 10.23 dS/m suggested moderate variation albeit high salt contents among the composts.

None of the C/N ratio, and total C, N, P, K and Na content was significantly affected by compost pile size or its interaction with EM inoculation (Table 2). However, EM inoculation and variation in compost types exerted significant effects on total K content. The C/N ratio ranged from 7.45 (INC1) to 8.45 (INC1.5), total C ranged from 17% (UNC1) to 19% (INC1 and INC1.5), while total N varied between 2.10% (UNC1) and 2.56% (INC1). The total P content ranged from 4.87 g/kg (UNC1) to 6.04 g/kg (INC1). The total K content in INC1 (251 g/kg) was significantly higher than in UNC1 (165 g/kg). Generally, the inoculated 1.0 m heap compost had quantitatively higher total C, N and P contents than the uninoculated 1.0 m compost pile, while the 1.5 m inoculated pile compost similarly had quantitatively higher total C, P, K and Na contents than the uninoculated compost pile. The contents of NH_4-N and Bray P2 differed significantly across the two compost pile sizes, while EM inoculation only exerted a significant effect on the composts Bray-P2 content. The inoculated 1.0 m compost pile had significantly lower

Table 2. Effect of compost type on physico-chemical properties and the contents of fibre fractions of NDF, ADF and ADL

Parameter	Compost type				LSD $_{(0.05)}$	CV (%)
	INC1	UNC1	INC1.5	UNC1.5		
pH (KCl)	9.69	9.68	9.76	9.75	0.21	1.19
EC (dS/m)	9.36	9.03	10.23	9.79	1.62	9.00
Bulk density (g/cm)	0.34	0.39	0.36	0.36	0.07	10.00
VS content (%)	50.00	49.00	53.00	54.00	7.00	7.00
WHC (g H_2O/g)	3.24	3.46	3.76	3.24	0.78	12.00
Total C (%)	19.00	17.00	19.00	18.00	3.00	9.00
Total N (%)	2.56	2.10	2.29	2.29	0.48	11.00
NO3-N (g/kg)	3.30	2.18	2.32	2.09	1.49	32.00
NH4-N (g/kg)	0.07b	0.09a	0.09a	0.09a	0.01	9.00
TMN (g/kg)	3.37	2.27	2.41	2.18	1.49	31.00
Total P (g/kg)	6.04	4.87	5.72	5.27	1.68	16.00
Bray-P_2 (g/kg)	2.75b	2.90ab	2.83ab	3.12a	0.29	5.00
C/N ratio	7.45	8.29	8.45	8.08	1.08	7.00
Total K (g/kg)	251a	165b	215ab	195ab	73.00	19.00
Exch. K (g/kg)	60.00	59.00	64.00	63.00	9.00	8.00
Total Na (g/kg)	5.03	5.29	6.20	5.29	1.21	12.00
TPC (mg GAE/g DW)	1.62	1.74	1.72	1.61	0.39	13.00
NDF (%)	37.00	38.00	34.00	39.00	5.00	8.00
ADF (%)	50.00	51.00	49.00	47.00	7.00	8.00
ADL (%)	38.00	37.00	36.00	35.00	8.00	11.00

Means with the same letter(s) on the same row are not significantly different at 5% probability level; where no letters are shown indicating no significant differences; INC1 and INC1.5 denote inoculated composts with initial heap heights of 1 and 1.5 m, respectively; UNC1 and UNC1.5 denote uninoculated composts with initial heap heights of 1 and 1.5 m, respectively; EC–Electrical conductivity; VS–Volatile solids; WHC–Water holding capacity; TPC–Total phenolic content; GAE–Gallic acid equivalents; NDF–Neutral detergent fibre; ADF–Acid detergent fibre; ADL–Acid detergent lignin; LSD–Least significant difference and CV (%)–Per cent coefficient of variation.

amount of NH_4-N than the remaining compost types. The contents of TMN, Bray-P2 and exchangeable K in the composts ranged from 2.18 to 3.37 g/kg, 2.75 to 3.12 g/kg and 59 to 64 g/kg, respectively. None of EM inoculation, compost pile size and their interaction showed significant effects on TPC and fiber fractions. The TPC ranged from 1.61 mg GAE/g DW to 1.74 mg GAE/g DW, while fiber fractions in the composts ranged from 34 to 39%, 47 to 51% and 35 to 38%, respectively, for NDF, ADF and ADL. The results in the present study revealed that EM inoculation during composting had inconsequential effect on the TPC content relative to the value in original waste materials. Nevertheless, TPC content was reduced by nearly 7% with EM inoculation in 1.0 m compost pile but increased by 7% in the 1.5 m pile.

Toxicity Test of WSW Compost Extracts on Selected Crops Seed Germination Attributes

The per cent seed germination in cowpea seeds across the different compost types and extract concentrations had no significant difference, while increasing extraction concentrations of the various compost types resulted in significant inhibition of maize and tomato seed germination attributes (Table 3). The mean maize root length (Shrestha *et al.,* 2018) across the various extract concentrations was higher than those of cowpea and tomato. The GI values ranged from 101 to 102% for cowpea, 97 to 105% for maize and 58 to 77% for tomato. Tomato seed GI obtained from inoculated 1.0 m compost pile was highest and differed significantly from the GI value obtained from inoculated 1.5 m compost pile. The GI of all three crops at 50% extract concentrations and beyond were significantly reduced compared to the lower extract concentrations (Table 3; Fig. 2). The GI values of each of the three crop species at 10 and 25% extract concentrations were statistically similar, while the 50 and 100% concentrations gave statistically similar GI for cowpea. Extract concentration of 50% and beyond resulted in significantly reduced GI values in the three crops. The GI of maize and tomato showed a general decreasing trend with increasing compost extract concentration, while cowpea GI at 25% extract concentration was marginally greater than the 10% concentration.

Table 3. Interaction effect of compost type and extract concentration on seed germination, root length and germination index of cowpea, tomato and maize

Compost type	Extract concentration (%)	Seed germination (%)			Root length (%)			Germination index (%)		
		Cowpea	Maize	Tomato	Cowpea	Maize	Tomato	Cowpea	Maize	Tomato
INC1	10	100	87abcd	85ab	109abcd	135ab	149a	109abc	116abc	126a
	25	100	83abcd	81abc	110abc	148a	140ab	110abc	123ab	110ab
	50	100	80abcd	69abcd	92bcde	132ab	77ef	92bcde	106bcd	57cd
	100	100	50f	54def	97abcde	96d	25g	97abcde	48e	14ef
Mean		100	75	72	102	128	98	102	98	77A
UNC1	10	100	93ab	69abcd	106abcd	149a	125abc	106abcd	139ab	85bc
	25	100	93ab	77abcd	114a	152a	117bcd	114ab	143a	90bc
	50	100	90abc	85ab	88de	91d	93def	88cde	81cde	79bcd
	100	100	60ef	42ef	98abcde	97d	29g	98abcde	59e	13ef
Mean		100	84	68	101	122	91	101	105	67AB
INC1.5	10	100	97a	85ab	105abcd	155a	107cde	105abcd	149a	89bc
	25	100	83abcd	65bcde	114ab	134ab	131abc	114ab	114abc	88bc
	50	100	73cde	65bcde	103abcd	106bcd	68f	103abc	79de	46de
	100	97	73cde	38f	90cde	85d	24g	87de	62e	11f
Mean		99	82	63	103	120	83	102	101	58B
UNC1.5	10	100	97a	92a	110abc	130abc	117bcd	110abc	126ab	109ab
	25	100	90abc	73abcd	116a	140a	142ab	116a	126ab	105ab
	50	100	77bcde	73abcd	103abcd	99cd	81ef	103abcd	76de	60cd
	100	97	70de	58cdef	79e	90d	19g	77e	62e	10f
Mean		99	83	74	102	115	90	101	97	71AB

Means with the same letter(s) within same column are not significantly different at 5% probability level; where, no letters are shown indicating no significant differences; INC1 and INC1.5 denote inoculated composts with initial pile size of 1 and 1.5 m, respectively; UNC1 and UNC1.5 denote uninoculated composts with initial pile size of 1 and 1.5 m, respectively; CV (%)=Percentage coefficient of variation.

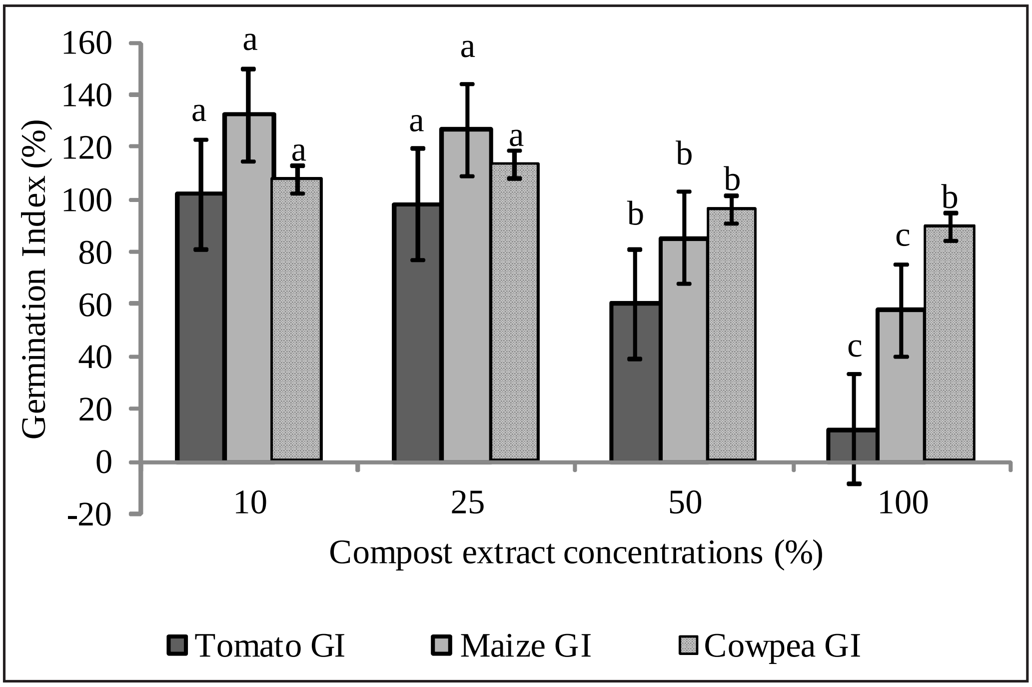

Fig. 2. Effect of extract concentration on the GI of tomato, maize and cowpea across the compost types. Columns labelled with the same letter for each crop type are not significantly different at 5% probability level. Bars indicate standard error (SE) of composts extract concentration.

The results of correlation analysis between seed germination, root length, germination index, pH and EC are presented in Table 4. The pH of the compost extracts correlated negatively and significantly with the per cent root length and per cent GI of maize and tomato, while the EC correlated negatively and significantly ($p<0.001$) with all the measured growth parameters of all crops.

Table 4. Results of correlation analysis between seed germination (SG), root length (RL), germination index (GI), pH (H_2O) and electrical conductivity (EC)

Parameters	pH	EC
pH	1	
EC	0.35*	1
Cowpea-SG	-0.11^{ns}	-0.38**
Maize-SG	-0.24^{ns}	-0.66***
Tomato-SG	-0.26^{ns}	-0.66***
Cowpea-RL	-0.22^{ns}	-0.47***
Maize-RL	-0.41**	-0.68***
Tomato-RL	-0.50***	-0.87***
Cowpea-GI	-0.23^{ns}	-0.50***
Maize-GI	-0.40***	-0.76***
Tomato-GI	-0.49***	-0.84***

*Significant at $p<0.05$; **Significant at $p<0.01$; ***Significant at $p<0.001$, NS=Not significant at $p<0.05$; Cowpea-SG–Cowpea seed germination; Cowpea-RL–Cowpea root length; Cowpea-GI–Cowpea germination index; Maize-SG–Maize seed germination; Maize-RL–Maize root length; Maize-GI–Maize germination index; Tomato-SG–Tomato seed germination; Tomato-RL–Tomato root length and Tomato-GI–Tomato germination index.

The non-significant effect of EM inoculation on the composts' measured physico-chemical parameters suggested that EM inoculation had no direct benefits on these quality indices. Albeit, it exerted indirect beneficial effects on hastening compost maturity and promoted compost sanitization through the extended thermophilic phase. This may be attributed to the rapid proliferation of EMs and microbial loading through molasses addition accompanied with high heat generation, which may have facilitated the decomposition complex substrates including those rich lignin and cellulose (Jusoh *et al.,* 2013). During the thermophilic phase, plant pathogens are destroyed (Hargreaves *et al.,* 2008), while weed seeds and insect larvae are also killed (Chongrak and Koottatep, 2017). The observed non-significant effect of variation in compost pile size on the measured physico-chemical properties of the WSW composts in this study is in agreement with earlier work reported by Sandra (2008). The recorded bulk densities for the composts were nearly 66% below the maximum permissible limit of 1.0 g/

cm^3 prescribed by Indian Fertilizer Control (Singh and Nain, 2014). However, the considerably higher WHC of the composts than their actual weight observed in the current study is in agreement with earlier study (El-Nagerabi *et al.,* 2011) suggesting their potential favourable use in highly drained sandy soils to conserve water for plant growth.

The strongly alkaline nature of the cured composts may be attributed to the high pH and higher amount of the perlite used than the other waste materials. Hence, cautious use of any of these composts and the extracts as soil amendments to avoid excessive soil pH and promote optimal plant nutrients availability for plant root growth (IPNI, 2010). In this regard, the use on acidic soils may serve additional role as liming material for increasing soil pH value. Similarly, utilization based on the experimentally optimum application rates is critical. The EC of compost as a quality parameter reflects its salinity content that largely influences its suitability for crop growth (Gómez-Brandón *et al.,* 2008). The EC range of 1.0 to 10.0 dS/m in the cured composts is considered ideal (Composting Council, 2010), while a threshold value of 1.0 dS/m is desirable for nursery substrate (Chong and Purvis, 2004). Although the measured EC values are generally higher than the prescribed standard limit of 4.0 dS/m (El-Nagerabi *et al.,* 2011; Singh and Nain, 2014), they are lower than the range of 13.6 to 19.1 dS/m regarded as high as cited by Martínez-Nieto *et al.* (2011). Such high EC values will not allow good water and nutrients absorption by salinity sensitive crops such as maize and tomato notwithstanding the variation in sensitivity. Based on the composts measured EC values, cautious use either as nursery substrate or soil amendments is required due to possible inducement of salt and/or organic acid stress in most plant seedlings (Liu *et al.,* 2014), which may hinder plant growth (El-Nagerabi *et al.,* 2011).

Possible N and P release from the WSW composts into soil solution following application is expected due to their lower C/N ratios, which are below 20 : 1 (Gaskell *et al.,* 2011). The less than 20 : 1 C/N ratio of the composts affirms the complete curing (Mangkoedihardjo, 2006), while the greater than 12% total C content suggests that they are rich in C (Singh and Nain, 2014) and may be a good C source for microorganisms (Gougoulias *et al.,* 2014). The considerably high TMN, Bray-P2 and K contents in the composts with NO_3-N content constituting nearly 97% of TMN, further calls for the cautious use so as to prevent any potential environmental pollution hazard particularly, NO_3-N contamination of ground water.

The measured NDF and ADF contents in the WSW composts were generally lower than those from the raw waste materials suggesting the degradation of these fibre fractions during composting. This is in agreement with the findings reported by Fazaeli and Masoodi (2006). The lower lignin (ADL) content in the composts could promote rapid nutrient mineralization when used as nutrient source in the soil (Dimambro *et al.,* 2007). According to Cascant *et al.* (2016), besides reducing the volume of the final product composting also gradually decreases the concentration of phenolic compounds. The observed decrease in TPC in EM inoculated 1.0 m pile but increase in 1.5 m EM inoculated pile may be attributed to the intensive microbial activity as shown by the longer stay of 1.0 m compost in thermophilic phase (>45°C) than the 1.5 m compost (Hachicha *et al.,* 2006). Ghaly *et al.* (2011) attributed the lower degradation of phenolic compounds in the microbial inoculated compost to lower temperature and shorter thermophilic phase in comparison with uninoculated compost.

The significantly reduced GI values of the three crops at extract concentrations greater than 50% suggest the presence of phyto-toxic compounds that impeded seed germination and root growth. The phyto-toxic effect due to high Na content was, however, much lower in cowpea but worst with tomato, which is more salinity-sensitive. The higher than 100% root length and GI values recorded at various extract concentrations for all the three crops also suggest that the composts serve as both phyto-nutrients and phyto-stimulants (Barral and Paradelo, 2011). The greater than 80% mean GI value of cowpea and maize across the extract concentrations suggests the absence of phyto-toxicity (Emino and Warman, 2004) and confirms better tolerance and less salinity sensitivity of these crops than tomato. The observed risks of phyto-toxicity of the composts and their extract (Martinez-Nieto *et al.,* 2011) can be mitigated through various strategies. Soil application at experimentally determined optimum rates could result in dilution effect (Liu *et al.,* 2014) or by restricting the use of these composts to acid soils so as to help increase the soil pH. Carballo *et al.* (2009) in their study recommended the dilution of bovine manure teas with very high EC in order to reduce their phyto-toxicity. The significant but negative correlation observed between EC and growth parameters affirms that lowering the EC through dilution can reduce the salinity problem of the WSW composts.

CONCLUSION

This study revealed that EM inoculation as well as compost pile size exerted inconsequential effects on WSW compost quality parameters. However, the addition of EM inoculant during composting provided indirect benefits of extended thermophilic phase that was much longer in the 1 m compost pile size, which helped to promote compost sanitization. Notwithstanding the potential fertilizer value of the WSW composts produced, the high EC values resulting from high soluble salts concentration specifically Na, constitutes risk for crops and soils. Although maize and tomato demonstrated varying degrees of phyto-toxicities particularly for beyond the 50% extract concentration, cowpea showed complete absence of phyto-toxicity to the different composts extract concentrations. The germination test for the three crop species also revealed the phyto-nutrient and phyto-stimulant nature of the compost extracts with root length and GI values greater than 100%. Experimental studies to determine safe and optimum application rates of the WSW composts are underway.

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