Clean Technologies and Environmental Policy (2019) 21:1937–1948
https://doi.org/10.1007/s10098-018-1647-7

ORIGINAL PAPER

Utilization of paper waste as growing media for potted ornamental plants

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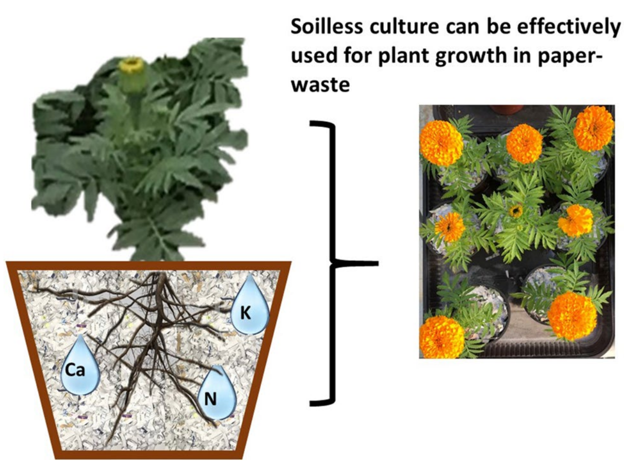
Received: 24 July 2018 / Accepted: 15 November 2018 / Published online: 27 November 2018

Abstract

The paper industry generates significant quantities of waste. The recycling of paper waste (PW) for peat replacement in growing media for ornamental plants cultivation was studied. Five ratios of PW–peat (0%, 10%, 30%, 50% or 100% v/v) were evaluated for marigold (*Calendula officinalis* L.), petunia (*Petunia × hybrita* L.) and matthiola (*Matthiola incana* L.) plants. Addition of PW increased the substrate pH and mineral content but decreased the air-filled porosity. In marigold, the use of 100% PW reduced plant height, plant diameter, fresh weight for both leaves and flowers and the total number of flowers produced compared to the control (100% peat). In matthiola, 100% PW reduced plant height, whereas the addition of PW even at 10% decreased plant diameter and fresh weight (biomass) but increased dry matter content. Petunia plants grown in 100% PW exhibited lower growth (plant height and diameter), whereas adding ≥ 50% of PW decreased plant fresh weight. The total number of flower buds and open flowers increased (more than twofold) on plants grown in 30% PW compared to the control substrate, indicating flower earliness. Plant leaf chlorophyll content (Chl *a*, Chl *b*, total Chl) decreased as the PW ratio increased. Total phenolics and antioxidant capacity as well as plant damage index and enzymes scavenging activities varied among species. Mineral content fluctuated among species with decreases of N and P in plants grown in PW mixtures while matthiola showed phytotoxicity symptoms. The present study suggests that peat can be substituted by up to 30% of PW for marigold and petunia for potting culture, but not for matthiola, as the physicochemical properties of the substrate need further improvement.

Graphical abstract



Keywords Paper waste · Ornamental · Peat · Recycling · Seedlings · Enzyme activity

Extended author information available on the last page of the article

Introduction

Global revenues of the pulp and paper sector exceed 500 billion dollars annually, with over 300 million tons of products (Jaria et al. 2017). The current paper mill waste is estimated around 3 million tons yearly, and with an annual growth prediction at 2.5%, the industry will need to handle an additional 2.5 million tons of biosolid waste by 2050 (Rashid et al. 2006). Yilmaz and Gumuskaya (2015) reported that the production of 1 ton of recycled paper is saving 2.5 tons of petroleum and 26 tons of water. The pulp/paper industry needs to adapt to the increasing energy costs for waste management (Jaria et al. 2017), eco-efficient assessment and tighter environmental legislation (Thant and Charmondusit 2010). Although very common, disposition of the sludge to landfills is very expensive (Bravo et al. 2015), and alternative management practices need to be explored. Paper waste (PW) sludge added into the ceramic products industry was able to reduce up to 60% the disposal to landfills (Vieira et al. 2016). De Azevedo et al. (2018) reported that up to 15% of PW sludge could be used for lime in cementitious mortars. Recently, a small proportion of the sludge is being composted, either with traditional composting processes or with various species of worms composting (vermicompost) (Kumar et al. 2009). The composted paper mill sludge was typically circulated as straightforward soil conditioners without recognizing that the material could also be fit as growing media for crop production. Tucker et al. (2004) alluded that under 1.4% of paper industry sludge (less than 5000 tons out of 343,000 tons of sludge generated) was composted in the UK. Paper waste is a part of paper industry sludge and large amounts can be recycled and/or used in different areas, including agriculture.

Despite the benefits derived by composting paper mill sludge, including material stability and decreased odors, landfill or land spread disposition has generally been the typical transfer course (Tucker and Douglas 2006). Land spreading is an ideal path for soil application, as it returns minerals and organic material back to the land, whereas differently they would have been lost. Agronomic improvements from sludge lie more in enhancing soil structure, as sludge generally contains low amounts of minerals essential for plants. Repeated use of sludge as a soil amendment increases nitrogen sequestration, unless amended with synthetic fertilizers or natural sources. Additionally, issues of storing, handling and transporting the paper mill sludges need to be considered due to the added cost on waste management.

Peat is a component for growing media in nurseries and used extensively in the most recent decades, and its availability is questionable in the coming years because of environmental/ecological constraints (Bugbee 2002). The extraction of peat results decreases carbon sinks and leads to higher greenhouse gases emission (Kern et al. 2017). Gruda (2012) reviewed that one ton of CO_2 is emitted from the extraction of four or five tons of peat after a short period of use with significant economic cost. The interest for soilless substrates in horticulture for vegetables, flowers and potting plants expands due to the well-known benefits of soilless culture, with increasing yields and quality, controlling fertigation and water utilization being some advantages among others (Marinou et al. 2013). At the same time, environmental problems from peat extraction or other non-renewable media use [destruction of fragile ecosystems (Holmes 2009), potential C emission sources (Bullock et al. 2012)] drive the need for the identification and development of substrates with a greener profile (Abad et al. 2001).

Industrial processes including agriculture produce solid organic wastes that can potentially be used as growing media, either alone or in mixtures (Fascella 2015). For instance, olive waste compost (Chandra and Sathiavelu 2009) as well as biochar and compost derived from various materials can be used as potting media or for other agricultural purposes providing an eco-friendly solution for waste disposal problems (Fascella 2015), while decreasing reliance on peat moss (Bugbee 2002). Paper waste can also be potentially used as a component in growing media. However, rather than trying to formulate paper mill compost as a complete growing media, it may be more feasible to use the paper waste as a peat substitute to (partially or fully) replace the peat segment for potting mixtures. To determine potential mineral deficiencies, plants can be fertigated with a nutrient solution that provides sufficient nutrients like techniques in complete control fertigation frameworks, i.e., hydroponic systems.

Production of ornamental plants takes place in greenhouse and net house and is considered a high-intensity system because of the increased amounts of agrochemical inputs (Lazzerini et al. 2016). Production of potted ornamental plants is affected by the components of the growing media which commonly contain various types of peat and perlite at different ratios (Popescu and Popescu 2015) before transplantation outdoors. Different soilless media have been used independently or in mixtures with other components to grow potted ornamentals (flowering and foliage plants). Soilless media, such as sphagnum, peat and river waste, have been used effectively to produce bedding plants (e.g., *Viola wittrokiana*, *Petunia* × *hybrid* and *Impatiens wallerana*) (Benedetto et al. 2006) for gardens and landscaping projects.

Paper wastes use in peat-free growing media offers many advantages including the low load of toxic elements and pathogens, and the long life span (WRAP 2002). Another characteristic facilitating paper wastes use is their generally consistent composition over time. Several other types of wastes vary considerably in their composition, which could jeopardize the production of a market product of consistent quality (Tucker and Douglas 2006). Previously, we examined the mix of paper waste with olive mill waste in ornamentals, and the results were not promising (Chrysargyris et al. 2018), indicating the need to examine/optimize the use of paper waste individually as a potting medium. Here, we evaluated the potential of PW to replace peat as a substrate in fertigation systems for marigold (*Calendula officinalis* L.), petunia (*Petunia* × *hybrita* L.) and matthiola (*Matthiola incana* L.), which are commonly grown and widely used ornamental crops.

Materials and methods

Plant species and paper waste

Seedlings of marigold, petunia and matthiola were purchased from a local nursery. Substrate media were based on peat and perlite (see Chrysargyris et al. 2018). Paper waste (PW) consisted of A4 paper sheets shredded into 0.5 × 3–4 cm pieces. PW physicochemical properties are presented in Table 1. Heavy metals content was low (Table 1).

Experimental design and growing conditions

The current study was carried out in an unheated plastic fully automated greenhouse in Limassol, Cyprus. Peat (P) and PW were used either alone or in mixtures (v/v) as follows: (1) peat only (100:0), (2) P:PW (90:10), (3) P:PW (70:30), (4) P:PW (50:50) and (5) P:PW (0:100). The percentage of each substrate in the final medium was chosen based on the results of preliminary work. Perlite 10% by volume was added to each substrate to ensure adequate aeration and drainage. Fertigation with a complete nutrient solution was applied manually, every other day or depending on plant water needs (according to Christoulaki et al. 2014). The electrical conductivity (EC) of the fertigation solution was 1.9 mS/cm and the pH 6.0.

Young seedlings at the stage of two true leaves were transplanted in single pots (250 cm^3 volume) and placed on plastic trays to achieve proper drainage (see Chrysargyris et al. 2018). The experiment was replicated eight times for each ornamental species/substrate combination (3 ornamental species × 5 substrates × 8 replicates = 120 pots). Individual replicates were placed randomly in the allocated greenhouse area, and the experiment lasted for 45 days.

Table 1 Physicochemical properties of substrate media used consisting of a mixture of paper waste (PW) and commercial peat (P) at five different ratios

	P:PW (100:0)	P:PW (90:10)	P:PW (70:30)	P:PW (50:50)	P:PW (0:100)
Organic matter (%)	99.42	82.99	79.72	77.59	75.52
Organic C (%)	57.67	48.14	46.24	45.01	43.81
pH	4.57	5.16	5.77	5.62	6.3
EC (mS/cm)	0.163	0.213	0.310	0.511	1.175
C:N	105.9	97.1	116.8	120.3	153.9
Total N (%)	0.54 (0.87)	0.49 (0.67)	0.39 (0.58)	0.37 (0.65)	0.28 (0.19)
P (g/L)	0.36 (0.48)	0.22 (0.56)	0.30 (0.51)	0.18 (0.77)	0.09 (0.12)
K (g/L)	0.33 (1.51)	0.48 (1.72)	0.42 (1.83)	0.67 (2.34)	0.64 (1.32)
Ca (g/L)	3.25 (10.97)	35.80 (20.01)	29.57 (27.81)	32.48 (41.47)	62.28 (116.21)
Mg (g/L)	0.99 (2.70)	0.94 (3.18)	0.95 (4.70)	1.89 (7.51)	0.70 (1.33)
Na (g/L)	0.33 (2.44)	0.63 (2.83)	0.87 (2.45)	0.97 (3.74)	2.03 (2.95)
Fe (mg/L)	611.19 (701.83)	1130.76 (1060.25)	1822.28 (1618.38)	1180.21 (640.72)	156.92 (150.99)
Cu (mg/L)	141.87 (141.46)	107.61 (52.81)	164.89 (1173.19)	490.62 (948.70)	134.82 (189.56)
Mn (mg/L)	16.13 (20.16)	21.08 (37.46)	26.47 (39.96)	21.23 (36.91)	9.36 (15.21)
Zn (mg/L)	16.63 (18.22)	25.57 (19.64)	29.03 (136.08)	32.06 (63.05)	29.81 (31.91)
B (mg/L)	n.d.^{Z} (112.96)	n.d.^{Z} (115.47)	n.d.^{Z} (60.47)	n.d.^{Z} (109.94)	n.d.^{Z} (121.70)
TPS (%)^Z	89.57	79.04	67.45	65.66	86.19
AFP (%)^Z	28.57	20.95	13.33	12.38	29.52
AWHC (%)^Z	61.00	58.09	54.11	53.28	56.67
BD(g/cm^3)^Z	0.201	0.219	0.195	0.191	0.107

Mineral values in parenthesis refer to the mineral content at the end of experiment (45 d)

^{Z}Total pore space (TPS), air-filled porosity (AFP), available water holding capacity (AWHC), bulk density (BD) by volume. n.d. not detectable

Measurements

Growing media properties

Total pores space (TPS), air-filled porosity (AFP), available water holding capacity (AWHC) and bulk density (BD) by volume of the growing media were measured following the European Standards, EN 13041 (European Committee for Standardization 1999). The Walkley–Black chromic acid wet oxidation method was applied for organic content and organic C determination. Electrical conductivity and pH were determined with the 1:5 dilution method. Following hydrochloric digestion of the sample ash, mineral analysis for macro- and micronutrients was carried out with inductively coupled plasma atomic emission spectrometry (ICP-AES: PSFO 2.0 Leeman Labs INC., USA). The Kjeldahl method was used for total N determination.

Plant growth and tissue elemental analysis

Two weeks after transplanting, we started counting every 7 days the: (a) number of flowers (total and open) per plant and (b) plant height and diameter. At harvesting stage, we determined the: (c) total plant and flower biomass (fresh weight and dry matter content in percentage) and (d) chlorophyll *a* (Chl *a*), chlorophyll *b* (Chl *b*) and total chlorophyll (t-Chl) content using a spectrophotometer (Chrysargyris et al. 2017).

Plant marketability was assessed on a 1–4 scale [(1) not marketable quality (i.e., decolorization, toxicity, necrosis); (2) medium quality (i.e., small size, decolorization); (3) good quality; and (4) extraordinary quality].

Leaf tissue was analyzed for minerals on four replicates/substrate (replicate = pool of all leaves from two plants). Mineral determination of K and Na was carried out by flame photometry (Lasany Model 1832, Lasany International, India), P by spectrophotometry (Multiskan GO, Thermo Fischer Scientific, USA) and N by the Kjeldahl method (BUCHI, Digest automat K-439 and Distillation Kjelflex K-360, Switzerland) following Chrysargyris et al. (2018).

Total phenolics and antioxidant activity

Total phenolics were extracted with methanol with four replicates per treatment (pool of two plants per replicate). The supernatant was stored at − 20 °C until use in analyses. The total content of phenols and the scavenging activity of antioxidants were measured using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) and ferric reducing antioxidant power (FRAP) methods, respectively.

Polyphenol content was determined using the Folin–Ciocalteu reagent (Merck, Germany), (see Marinou et al. 2013), and results were expressed as mg of gallic acid equivalents per gram of fresh weight (mg GAE/g FW). Antioxidant capacity was evaluated with the DPPH and FRAP assays (Chrysargyris et al. 2017).

Determination of H_2O_2 content and lipid peroxidation

H_2O_2 content was measured following Chrysargyris et al. (2017) and lipid peroxidation following Azevedo Neto et al. (2006). Lipid peroxidation was determined using the malondialdehyde (MDA) content.

Activities of antioxidant enzymes

The activity of antioxidant enzymes (catalase: CAT, and superoxide dismutase: SOD) was assessed based on Chrysargyris et al. (2017). Data were expressed as CAT units per mg of protein (1 unit = 1 mM of H_2O_2 reduction/min). For SOD, activity was assessed by the quantity of enzyme that inhibited 50% of nitro blue tetrazolium (NBT) photoreduction rate.

Statistical analysis

Analysis of variance (ANOVA) was used to compare treatments at $P = 0.05$ in IBM SPSS v.22 (IBM Corp., Armonk, NY, USA). The post hoc Duncan's multiple-range test (DMRT)was applied to compare treatment means. Pairwise metabolites effects correlations were calculated by Pearson's correlation coefficient in R software.

Results and discussion

The main disposal for PW is through landfill or land spread, and only very few quantities are composted and used as growing media or soil improvements (Das et al. 2016). Paper mill sludges do not compost well alone (Tucker and Douglas 2006). In most cases, additional amounts of nitrogen are needed in relatively large quantities, as well as structural amendments. Indeed, the required composting quality is not always achieved, resulting in increased cost and environmental constraints for the final marketable composted growing media product (Feldkinchner et al. 2003). Therefore, intensive fertigation management through a hydroponic nutrient solution could overpass the above problems and equalize any mineral deficiencies.

The use of PW as growing media for partial peat replacement was studied for ornamental potting crops, and

Table 2 Impact of five mixtures of paper waste (PW) and commercial peat (P) on marigold, petunia and matthiola seedling height (cm/plant), diameter size (cm), leaf and flower fresh weight (fwt, g/plant), dry matter content (dm, %), total biomass as well as flower number produced and opened on ornamental plants grown in a greenhouse

	Mixtures	Height	Diameter	Leaf fwt	Flower fwt	Leaf dm	Flower dm	Total biomass	No flowers	Open flowers
Marigold	P:PW (100:0)	14.31[a,Y]	13.93[a]	6.93[a]	10.17[a]	12.22[a]	13.46[a]	17.18[a]	3.37[a]	1.25[a]
	P:PW (90:10)	14.62[a]	14.18[a]	5.93[ab]	8.91[a]	12.22[a]	12.96[a]	14.88[a]	2.87[ab]	1.00[a]
	P:PW (70:30)	14.81[a]	13.93[a]	5.16[ab]	7.40[a]	13.05[a]	13.22[a]	13.56[a]	2.62[ab]	1.12[a]
	P:PW (50:50)	13.87[a]	13.26[b]	4.65[b]	8.99[a]	17.29[a]	13.53[a]	14.84[a]	2.50[b]	1.00[a]
	P:PW (0:100)	12.43[b]	12.81[b]	3.95[b]	3.50[b]	13.99[a]	13.82[a]	7.47[b]	2.12[b]	1.00[a]
Petunia	P:PW (100:0)	10.06[ab,Y]	15.81[a]	23.09[a]	1.35[a]	7.33[b]	10.78[a]	24.44[a]	2.12[b]	1.50[b]
	P:PW (90:10)	10.68[ab]	15.12[a]	18.02[ab]	1.69[a]	9.02[ab]	11.22[a]	19.72[ab]	2.62[b]	2.37[b]
	P:PW (70:30)	11.58[a]	15.77[a]	16.47[ab]	2.25[a]	10.90[a]	12.13[a]	18.73[ab]	5.37[a]	4.00[a]
	P:PW (50:50)	9.87[ab]	14.62[a]	12.72[bc]	2.07[a]	11.85[a]	8.27[a]	14.79[bc]	3.12[b]	2.37[b]
	P:PW (0:100)	8.75[b]	11.18[b]	5.98[c]	1.14[a]	11.13[a]	11.69[a]	7.12[c]	2.50[b]	2.00[b]
Matthiola	P:PW (100:0)	13.31[a,Y]	11.81[a]	12.08[a]	–	13.62[c]	–	12.08[a]	–	–
	P:PW (90:10)	11.87[a]	8.87[bc]	7.33[b]	–	15.89[b]	–	7.33[b]	–	–
	P:PW (70:30)	11.50[a]	7.50[bc]	4.11[bc]	–	18.82[a]	–	4.11[bc]	–	–
	P:PW (50:50)	13.25[a]	9.31[b]	4.26[bc]	–	18.79[a]	–	4.26[bc]	–	–
	P:PW (0:100)	7.12[b]	6.93[c]	2.62[c]	–	19.23[a]	–	2.62[c]	–	–

[Y]Values ($n=8$) in columns followed by the same lower case letter are not significantly different, $P \leq 0.05$

any mineral deficiencies were eliminated with the fertigation of a complete nutrient solution. Use of PW in different ratios with peat increased the pH for all the growing media (Table 1). Mohammadi Torkashvand et al. (2010) found that paper mill sludge increased soil pH in a dose-dependent manner. He et al. (2009) showed that paper mill lime mud could be used to correct the pH of soils with acidity problems. The increase in pH from 4.57 to 6.30 in the current study (Table 1) may have improved plant growth by increasing mineral availability to the plants. At high (alkaline) pH, the availability of all minerals except for molybdenum is very low, while at low (acidic) pH, the availability of nitrogen, phosphorus, potassium and magnesium is low, while micronutrients can reach toxic levels (Havlin et al. 2005). Benefits in plant growth because of an improvement in substrate pH were reported before (Atiyeh et al. 2001). In the current study, addition of PW increased availability of calcium, iron, zinc and copper (Table 1). At the experiment completion, no deficiencies or accumulation/toxicities of minerals have been identified macroscopically on the plants, owing to the well-balanced fertigation that corrected possible nutrient imbalances—either excessively low or high levels of a nutrient.

The movement of air through the substrate and its ability to hold water are crucial for plant growth and influence thermal properties, biological activity and mineral availability (Klock 1997). Adding PW (up to 50%) into the growing media reduced total pore space, and as a consequence reduced air-filled porosity. The size and perhaps the shape of paper waste used could affect the AFP,

Table 3 Impact of five mixtures of paper waste (PW) and commercial peat (P) on marigold, petunia and matthiola chlorophyll (Chl *a*, Chl *b* and total Chl) content and marketability (scale 1–4 from lower to higher quality) grown in a greenhouse

	Mixtures	Chl *a*	Chl *b*	Total Chl	Marketability
Marigold	P:PW (100:0)	1.02[a,Y]	0.29[a]	1.32[a]	3.98[a]
	P:PW (90:10)	0.75[a]	0.19[bc]	0.94[abc]	4.00[a]
	P:PW (70:30)	0.84[a]	0.22[ab]	1.06[ab]	3.85[a]
	P:PW (50:50)	0.70[ab]	0.19[bc]	0.89[bc]	3.13[b]
	P:PW (0:100)	0.48[b]	0.11[c]	0.60[c]	2.12[c]
Petunia	P:PW (100:0)	0.72[a,Y]	0.29[a]	1.01[a]	4.00[a]
	P:PW (90:10)	0.62[ab]	0.25[a]	0.87[ab]	4.00[a]
	P:PW (70:30)	0.57[ab]	0.24[a]	0.81[ab]	3.91[a]
	P:PW (50:50)	0.61[ab]	0.26[a]	0.87[ab]	3.15[b]
	P:PW (0:100)	0.52[b]	0.23[a]	0.75[b]	1.95[c]
Matthiola	P:PW (100:0)	0.54[a,Y]	0.16[a]	0.70[a]	3.75[a]
	P:PW (90:10)	0.33[b]	0.09[b]	0.42[b]	3.40[ab]
	P:PW (70:30)	0.25[c]	0.08[bc]	0.34[bc]	2.05[b]
	P:PW (50:50)	0.23[c]	0.08[bc]	0.31[c]	1.15[c]
	P:PW (0:100)	0.20[c]	0.06[c]	0.25[c]	1.00[c]

[Y]Values ($n=4$) in columns followed by the same lower case letter are not significantly different, $P \leq 0.05$

while folded PW could possibly have an impact on AFP. Similarly, Jayasinghe (2012) reported reduced porosity with the increase of sugarcane bagasses sewage sludge compost into the growing media for lettuce. Pore space is occupied by either air or water and is within the suggested limits as the total volume of empty pores should

Fig. 1 Impact of five mixtures of paper waste (PW) and commercial peat (P) on marigold, petunia and matthiola during plant growth in a greenhouse

be in the range of 60–90% (Klock 1997). As expected, PW medium is a light material, as it has a low BD with high TPS percentage. Paper waste normally has a moderate to high carbon:nitrogen (C:N) ratio (Chrysargyris et al. 2018), necessitating the addition of N to speed up decomposition (Evanylo and Lee Daniels 1999). In the current work, the nutrient solution has been enriched with N to support both media organic matter decomposition and plant needs. The substrate met a couple of the parameters of the profile for an “ideal substrate” (Abad et al. 2001). For example, addition of PW in the substrate resulted in pH values within limits, but increased calcium and sodium content, at the both start and completion of the experiment. This resulted in increased EC values that might cause crop phytotoxicity, underlying the importance of gaining a deep knowledge of the physicochemical characteristics of new types of substrates to achieve optimum growing conditions.

Controlling vegetative and floral growth is considered one of the top priorities for commercial production of ornamentals. In marigold, the addition of 100% PW reduced ($P < 0.01$) plant height while ≥ 50% PW into the media reduced plant diameter ($P < 0.05$) (Table 2). Plant biomass decreased in 100% PW, as a consequence of decreased fresh weight ($P < 0.05$) for both leaves and flowers, whereas the leaf and flower dry matter content was similar among treatments. Flower number dropped in plants grown in ≥ 50% PW compared with the peat substrate. However, flower opening was unaffected by the addition of PW into peat. Marigold flower number, pedicel length and plant biomass were reduced when plants were grown in paper mill sludge compost (Evanylo and Lee Daniels 1999). In that study, it was reported that the lower plant available water (PAW) observed in the paper mill sludge compost treatment may have reduced yields, as evidenced in our study for the high (≥ 50%) PW content.

Petunia plants grown in 100% PW exhibited lower growth (plant height and diameter), whereas adding ≥ 50% of PW into the substrate decreased ($P < 0.01$) plant fresh weight compared to the peat substrate (Table 2). Plant fresh weight decreased in the high PW content (≥ 50% PW), mainly due to the decrease of the leaf rather than the flower fresh weight. Therefore, leaf dry matter content was greater in high PW content substrate media. The total number of flowers and the number of open flowers increased (more than twofold) on plants grown in 30% or more PW compared to the control, indicating flower earliness. Similar results were reported by Arancon et al. (2008), who studied effects of different substitution rates for three types of vermicomposts (originating from cattle manure, food waste and paper waste) on the flowering of petunias in a soilless growth medium. In the same study, petunia's shoot dry matter increased with the presence of PW (10–60%) into the substrate, in line with our findings.

In matthiola, the 100% PW reduced (up to 46.5%) plant height, whereas the addition of PW even at a low ratio (i.e., 10%) decreased plant diameter and fresh weight (biomass) but increased (up to 41.2%) dry matter content (Table 2). The reduced plant growth and flowering in the 100% PW were not a result of low nutrient availability because all plants received regular applications of a complete hydroponic nutrient solution. Possible causes for the decreased growth and flowering of plants include PW causing a deterioration of the physical structure of the growth medium that resulted in reduced aeration and drainage (Table 1). A possible explanation is that plant water use efficacy differs among species, suggesting that dose responses to fertigation need further refinement for each crop. Previous researchers found that pepper plants responded differently to the paper mill sludge compost application compared to snap beans, radish and marigold, without any effects of the media on the number of pepper fruits produced (Arancon et al. 2008). The different response of pepper plants was attributed to more efficient use of water than the other crops.

Table 4 Impact of five mixtures of paper waste (PW) and commercial peat (P) on marigold, petunia and matthiola content of total phenols and antioxidant activity (DPPH, FRAP) on ornamental plants grown in a greenhouse

	Mixtures	Phenols		DPPH		FRAP	
		Leaves	Flowers	Leaves	Flowers	Leaves	Flowers
Marigold	P:PW (100:0)	1.19[a,Y]	5.35[b]	1.49[a]	16.98[ab]	6.17[a]	87.98[a]
	P:PW (90:10)	1.64[a]	5.12[b]	2.38[a]	20.83[a]	9.03[a]	92.87[a]
	P:PW (70:30)	1.48[a]	6.18[b]	2.14[a]	19.57[a]	7.84[a]	83.31[a]
	P:PW (50:50)	1.60[a]	8.12[a]	2.21[a]	17.91[ab]	8.45[a]	80.95[ab]
	P:PW (0:100)	1.38[a]	7.91[a]	2.05[a]	15.47[c]	6.94[a]	69.59[b]
Petunia	P:PW (100:0)	1.13[c,Y]	1.48[a]	4.68[b]	6.51[a]	5.77[c]	7.75[a]
	P:PW (90:10)	1.32[bc]	2.77[a]	5.18[b]	11.26[a]	7.64[bc]	18.02[a]
	P:PW (70:30)	1.62[b]	2.81[a]	5.85[b]	8.76[a]	8.75[b]	18.59[a]
	P:PW (50:50)	2.27[a]	1.77[a]	8.57[a]	7.31[a]	13.95[a]	9.80[a]
	P:PW (0:100)	2.10[a]	2.69[a]	8.40[a]	11.44[a]	12.29[a]	16.58[a]
Matthiola	P:PW (100:0)	0.51[c,Y]	–	1.62[c]	–	2.76[c]	–
	P:PW (90:10)	0.58[c]	–	1.88[c]	–	3.34[c]	–
	P:PW (70:30)	0.86[b]	–	2.49[b]	–	5.42[b]	–
	P:PW (50:50)	0.88[b]	–	2.33[b]	–	5.68[b]	–
	P:PW (0:100)	1.11[a]	–	3.06[a]	–	7.46[a]	–

[Y]Values ($n = 4$) in columns followed by the same lower case letter are not significantly different, $P \leq 0.05$

Plant marketability at the end of week 4 was lower (3.13 and 2.12 out of 4.00 for 50% and 100% PW, respectively) for marigold and (3.15 and 1.95 out of 4.00 for 50% and 100% PW, respectively) for petunia (Table 3) (Fig. 1). In matthiola, marketability decreased in substrates with 30% or more PW content and the first symptoms were noticed at the end of week 2 (Fig. 1). Appearance is the main component to evaluate ornamental marketability by the consumers. Therefore, discolorations and marks/symptoms of mineral deficiencies can decrease plant marketability of ornamentals.

Leaf chlorophyll content (Chl *a*, Chl *b*, total Chl) dropped ($P < 0.01$) as the PW ratio increased for matthiola, whereas for marigold and petunia, mainly Chl a and total Chl were decreased ($P < 0.05$) at high PW content (i.e., 50% or 100%) (Table 3). Since ornamental plants are purchased by consumers according to their appearance, Chl content and color of both leaves and flowers are of importance. The level of chlorophylls is an indicator of plant photosynthetic rate, and therefore any reduction in chlorophyll levels results in a decline in plant growth-related parameters (Kiarostami et al. 2010). Similarly, in the current study, we recorded plant growth decline with the addition of ≥ 50% PW.

Polyphenols and antioxidant scavenging activity of the methanolic extracts changed differently in leaves and

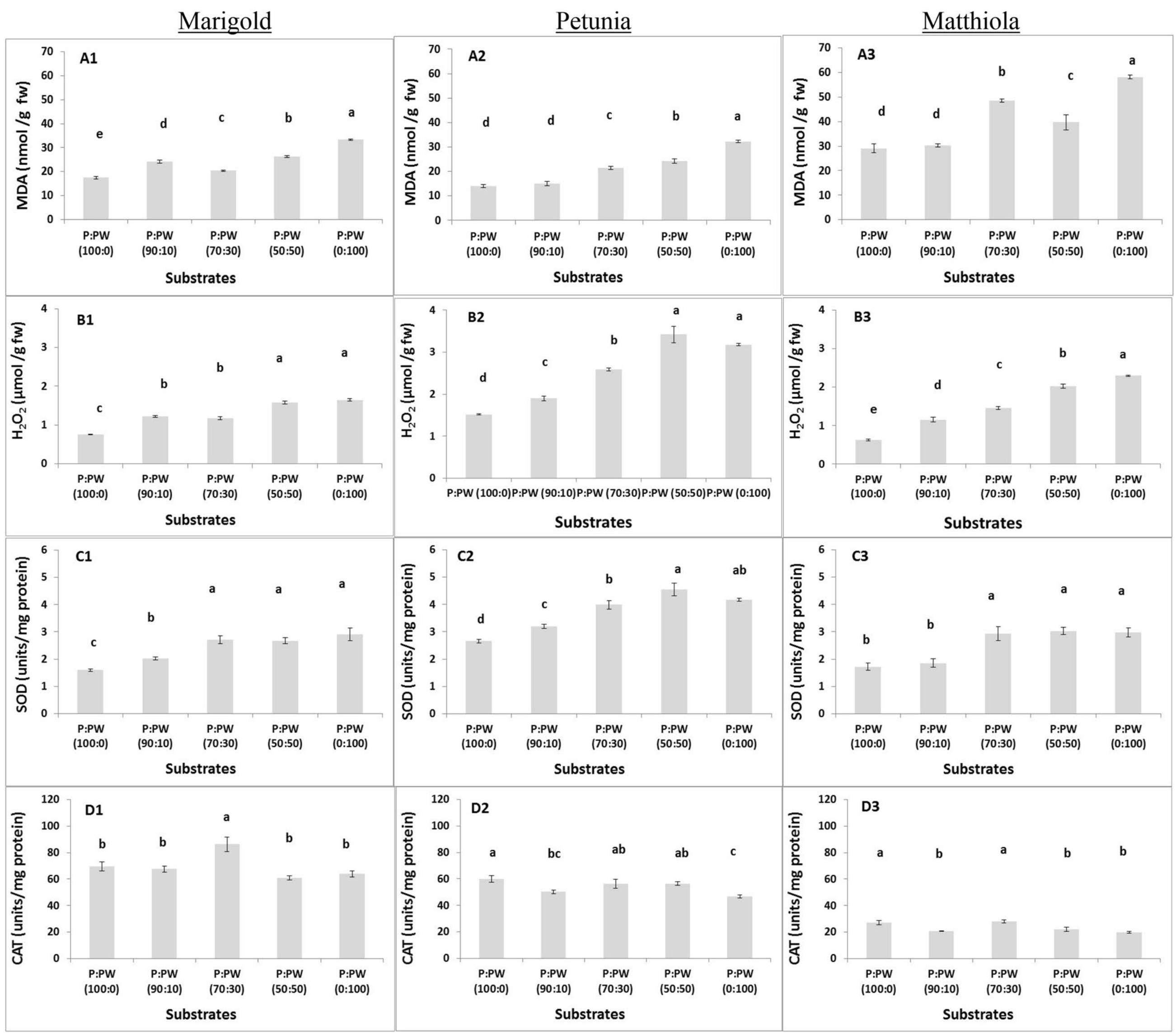


Fig. 2 Impact of five mixtures of paper waste (PW) and commercial peat (P) on the plant damage index measured by lipid peroxidation (MDA), hydrogen peroxide (H_2O_2) production and antioxidant enzymes activities measured by superoxide dismutase (SOD) and catalase (CAT) on marigold (A1, B1, C1, D1), petunia (A2, B2, C2, D2) and matthiola (A3, B3, C3, D3), respectively, at the end of the experiment. Values represent mean (± SE) of measurements recorded on four replications per treatment. Means bearing the same letter are not significantly different at the 5% level

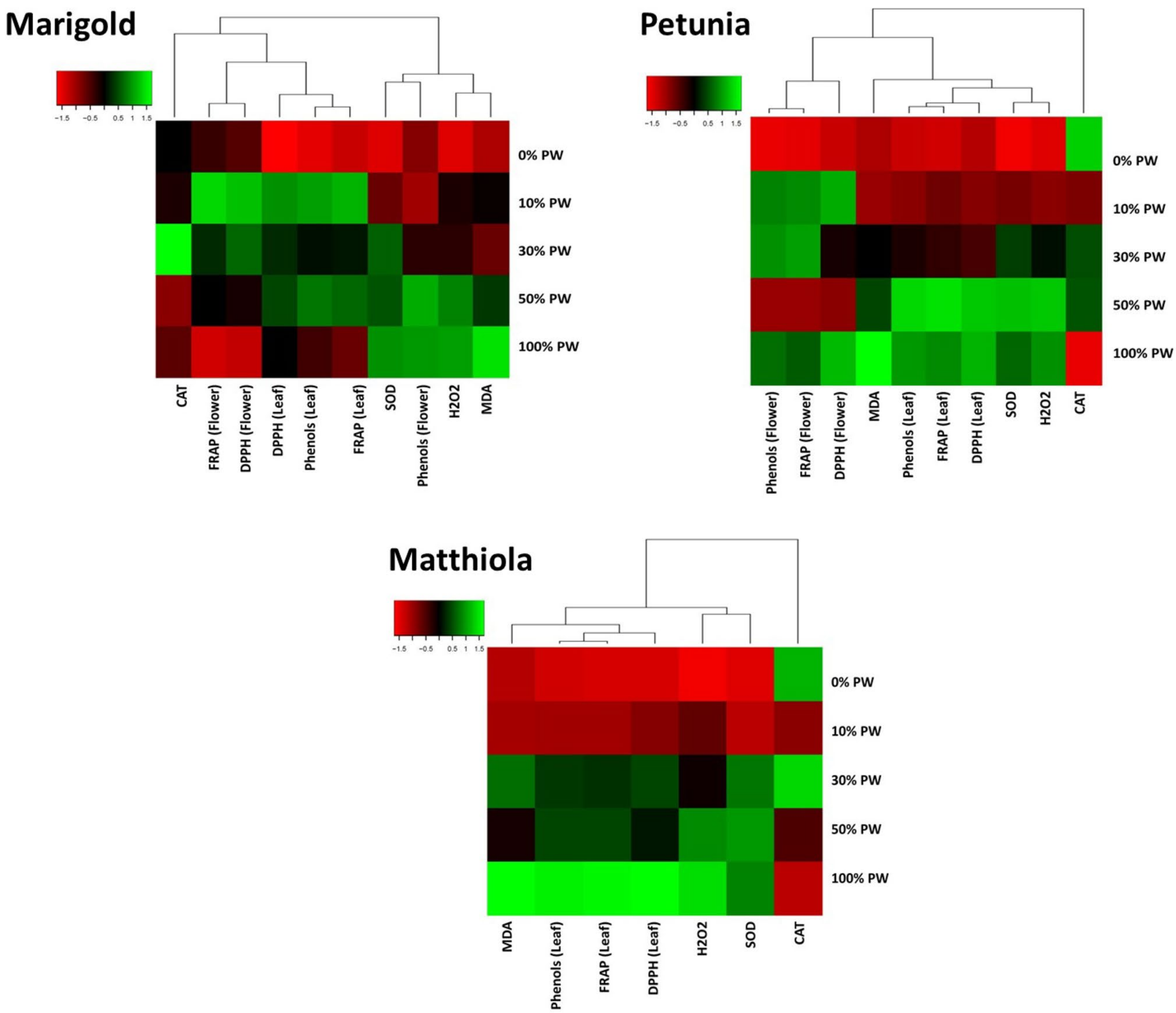


Fig. 3 Metabolite changes in leaves (marigold, petunia, matthiola) and flowers (marigold, petunia). Heat map representing relative expression of phenolics, antioxidants and damage index elicited in leaf and flower tissue following paper waste (10%, 30%, 50% and 100%) addition as compared to control (0% PW) plants

flowers for the three plant species (Table 4). In marigold flowers, phenols' content increased ($P < 0.001$) in plants grown in ≥ 50% PW, whereas antioxidant activity decreased ($P < 0.05$) in 100% PW. However, PW addition into the substrate did not change total phenolics and antioxidant activity of marigold leaves. It is possible that changes in leaves occurred at an earlier growth stage, for example before flowering. Interestingly, the opposite was true for petunia, as total phenolics and antioxidant activity increased ($P < 0.001$) in leaves for plants grown in ≥ 30% PW. In petunia, the color of flowers (white, purple, pink and red) varied the antioxidant status of the flowers, with greater values in red pink, followed by purple and last white flowers (data not shown). The content of phenolics and antioxidant activity in matthiola leaves also increased ($P < 0.001$) as the PW content of the substrate increased (Table 4). A high content of phenols protects tissue oxidation from scavenging free radicals and lipid peroxidation (Scherer et al. 2013). Several parts of a plant can be easily consumed, such as edible flowers; thus, the increased antioxidant capacity of edible parts should be explored further. Several potting plants are used recently for their edible flowers, and petunia and marigold are putative candidates, but more extensive research is needed in that direction. Abiotic stresses can result in overproduction of reactive oxygen species (ROS) that are toxic and cause damage to DNA, lipids, proteins, and carbohydrates. Active oxygen scavenging systems are a defense mechanism against ROS.

Biotic and abiotic stressors activate the gpx-1 promoter of plants leading to the production of H_2O_2 resulting in oxidative stress (Avsian-Kretchmer et al. 2004). The H_2O_2 production increased in marigold, petunia and matthiola grown in PW-based substrates (Fig. 2). MDA production (a measure of lipid peroxidation) also increased in the PW substrates. H_2O_2 production is part of the ascorbate–glutathione cycle with the well-documented role of the key enzymes of ascorbate peroxidase (APX), peroxidase (POD) and SOD (Pasternak et al. 2005). In the current study, SOD antioxidant activity increased in all species, as part of the initial response of the plant to oxidative stress (Fig. 2c). Thereafter, SOD decrease and alternative enzymes (CAT, APX, POD) activity increase are expected. Our findings support that either CAT activity was at initiative stage or alternative enzymes (i.e., APX) might be increased. Thus, the lower H_2O_2 content in plants grown in peat substrate suggests lower oxidative stress. In plants, ROS scavenging takes place with antioxidant enzymes activity increase (Chrysargyris et al. 2017).

Heat maps (Fig. 3) based on the relative expression of phenolics, antioxidants and damage in leaf and flower tissue of plants grown on PW-containing or peat substrate show a differentiation of plant response among species. In marigold, low (i.e., 10%) PW induced leaf and flower phenolics and antioxidants (FRAP, DPPH). In higher PW content, due to the increased stress, hydrogen peroxide and lipid peroxidation were increased, and as a consequence, the SOD activity was increased. In petunia and matthiola, the increased stress caused by the high (50–100%) PW was related to increase of both phenolics and antioxidants (FRAP and DPPH). On top of that, SOD enzyme activity was increased in order to alleviate the lipid peroxidation (increased MDA) caused, resulting in the detoxification of the plant tissue (Fig. 3).

Mineral content fluctuated among species and plant organs [leaves, flowers—only data for leaves are presented (Table 5)]. Matthiola exhibited visual phytotoxicity symptoms (Fig. 1). Marigold, petunia and matthiola N content decreased in plants grown in PW mixtures with a more severe reduction at 100% of PW in marigold. Leaf K content decreased when matthiola was grown in PW media, and this was also evident in petunia for the highest PW content. Sodium content decreased in petunia and matthiola grown in PW media, whereas in marigold, Na content increased in 100% PW, probably due to the mineral availability for absorption by the roots and less antagonism with other cations, such as K, Ca and/or Mg. Interestingly, marigold P content decreased in PW media compared to the control treatment, possibly due to the PO_4^- release into the nutrient solution and immobilization of NO_3^-. Similar observations were found when biochar was used as peat amendment for tomato seedlings (Prasad et al. 2018). However, this mechanism is unknown and further investigation is needed before final conclusions.

Table 5 Leaf macronutrients analysis for marigold, petunia and matthiola plants grown in substrate medium consisting of different ratios of peat (P) and paper waste (PW)

	Mixtures	N (g/kg)	K (g/kg)	P (g/kg)	Na (g/kg)
Marigold	P:PW (100:0)	40.53^{a,Y}	28.49^{ab}	5.31^{a}	0.96^{b}
	P:PW (90:10)	31.19^{b}	26.15^{b}	4.37^{b}	0.74^{c}
	P:PW (70:30)	28.40^{b}	28.46^{ab}	2.89^{c}	0.91^{bc}
	P:PW (50:50)	27.30^{b}	28.99^{ab}	3.21^{c}	0.94^{b}
	P:PW (0:100)	20.62^{c}	29.95^{a}	4.35^{b}	1.16^{a}
Petunia	P:PW (100:0)	29.42^{a,Y}	29.40^{a}	4.06^{a}	8.67^{a}
	P:PW (90:10)	21.04^{b}	30.20^{a}	2.71^{b}	6.96^{b}
	P:PW (70:30)	14.63^{c}	27.72^{a}	2.50^{b}	6.04^{bc}
	P:PW (50:50)	13.38^{c}	28.37^{a}	2.35^{b}	5.75^{c}
	P:PW (0:100)	11.48^{c}	20.94^{b}	2.77^{b}	4.58^{d}
Matthiola	P:PW (100:0)	29.90^{a,Y}	26.64^{a}	2.53^{a}	7.40^{ab}
	P:PW (90:10)	17.83^{b}	21.10^{b}	1.84^{b}	6.25^{bc}
	P:PW (70:30)	13.67^{b}	21.89^{b}	0.88^{d}	5.25^{c}
	P:PW (50:50)	14.14^{b}	21.10^{b}	1.33^{cd}	4.95^{d}
	P:PW (0:100)	15.73^{b}	21.11^{b}	1.66^{bc}	7.69^{a}

^{Y}For each value $n=4$. Values in rows followed by the same letter are not significantly different, $P \leq 0.05$

Several potting mixes are coming from single or combined, raw material or composted waste by-products including spent mushroom compost, paper mill sludge, corrugated cardboard, apple-mill waste, citrus peels, wood chips from pallets, pulverized glass and different types of tree barks (Chong 2005), sugarcane bagasses sewage sludge (Jayasinghe 2012), municipal solid waste compost (Chrysargyris and Tzortzakis 2015), paper waste and olive mill waste (Chrysargyris et al. 2018), biochars (Prasad et al. 2018) which fascinated research and scientific interest but they were not deliberated acceptable as attractive growing media for containers (Chong 2005). Possible, other than bark, which is one of the most attractive and often-used growing media for substrates (Davidson et al. 2000), the use of waste by-products in nurseries growing media is not well characterized or scientifically recorded. Different ratios have been examined, and often the amounts exceeding 50% and sometimes up to 100% by volume that could likely cause increased EC and pH values, sometimes toxic, could be managed after successive irrigation practices as the media salts can leach quickly from the container to the initial levels (~ 1.0 dS/m) (Chong 2005). The content of soluble salts in paper sludge commonly ranges from 0.8 to

2.0 dS/m and has been successfully applied as rooting media (Chong 2005), similar to our findings. Further, different plant species may withstand and use more effectively plant available water (Evanylo and Lee Daniels 1999). To date, there have been relatively limited research and few practical tests on using composted and non-composted paper wastes for use in growing media.

Conclusions

Applications of waste from various industrial sectors either as fertilizer and/or as soil amendments in agriculture have become attractive. The recent and increasing interest on smart waste management and recycling paved the way for research and applications on the use of organic materials and composts in the potting industry. Alternatives to peat are seeking for the intensive seedling and potting production and PW is a promising candidate, as the scope of our study was to examine the use of PW as growing media for partial peat replacement for ornamental potting crops by controlling plant mineral requirements with appropriate fertigation (using a complete nutrient solution). The present study suggests that up to 30% of PW can substitute peat for marigold and petunia, but not for matthiola, as substrates need further physicochemical properties improvements. This would be economically and environmentally very interesting and attractive, since it achieves an important volume of peat replacement, before bedding plants are transplanted out of the greenhouse. The possibility of plant recovering after transplantation into the soil could be examined in future studies. Moreover, the present findings strengthen the importance of controlling the fertigation during plant growth, as this can bypass several limitations that a growing media or composting process might have.

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