

The use of un-composted spent mushroom residue as a replacement of peat in substrates for *Gossypium herbaceum* and *Talinum paniculatum*

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Abstract

In order to evaluate the effect of growing media with peat and spent mushroom residue (SMR) on medicinal plants, we cultured *Gossypium herbaceum* and *Talinum paniculatum* seedlings in the substrates with SMR in proportions of 0% (control), 25%, 50%, 75%, and 100%. Results showed that *G. herbaceum* seedlings can survive in all treatments, but *T. paniculatum* seedlings died out in 75% and 100% SMR substrates where higher electrical conductance was found (2.3-2.7 dS m⁻¹). Both growth and biomass mostly declined with the increase of SMR proportion in the growing media for the two species except for root biomass in *T. paniculatum* seedlings between the control and the 25% SMR treatment. Shoot nitrogen (N) and phosphorus (P) concentrations and contents tended to be higher in low- and high-SMR-proportional substrates, respectively. N and P statuses were both diagnosed to be excessive than needed for the two species. Overall, it was not recommended to culture *G. herbaceum* seedlings in the substrates with SMR; instead *T. paniculatum* seedlings can be cultured in the growing media with SMR in volumetric proportion of 25%.

Keywords: commercial weeds; medicinal plants; nutrient availability; nitrogen; phosphorus; spent mushroom residue

Introduction

Peat is an un-renewable resource that has been heavily exploited and made the natural reserve touch the warning-line. Intensive extraction of peat has led to the ecological degradation and stimulation of CO₂ emission that contributes to the global warming (Bustamante *et al.*, 2008). Russia and Finland accounted for over 40% of national peat production worldwide (Kalmari, 1991; Tsvetkov, 2017). Most of extracted peat are used for fuel industry and horticultural substrates. However, a limit has been foreseen for natural reserves if no alternative resource can be emerged.

Spent mushroom residue (SMR) is a by-product of mushroom production. Along with the establishment of huge mushroom industry, a considerable amount of SMR is being produced every year. Turkey, Spain, and China are producing the largest three amounts of SMRs as 0.2, 0.99, and 38.93 million tons, respectively. The increasing demand for mushroom production drives the increase of SMR accumulation, which has led to a new issue of solid waste heap. Piled SMRs can be used as the primary substance for extracting biofertilizers due to their abundant nutritive compounds that were derived from fungus (Elsakhawy and El-

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Rahem, 2020). Another suggested way to reuse SMRs is the outlet as a substrate to amend soils (Li *et al.*, 2020; Marin-Benito *et al.*, 2020). The SMR compost was also suggested to be used as a growing-media that may partly replace peat for horticultural plant production (Caballero *et al.*, 2009; Ribas *et al.*, 2009).

As a possible replacement of peat, composted SMR has several merits, such as restricting pathogens (Chen *et al.*, 2015; Segarra *et al.*, 2007), promoting uptake (Paredes *et al.*, 2016; Sönmez *et al.*, 2016), and benefitting growth (Unal, 2015). As nutrient loss through leaching is an issue that should be considered in potted seedlings with peat (Zhu *et al.*, 2016), no clear evidence has indicated any possible risk that was aroused by inputting SMR. However, the full replacement of peat by SMR compost has not been applicable due to high pH and electrical conductance (EC) (Szmidski and Chong, 1995; Gonani *et al.*, 2011). With SMR addition, it was found that the EC value up to the 2.3 dS m⁻¹ would result in stress on plant growth (Zhu *et al.*, 2019). Even the deep compost cannot fully eliminate these negative impacts; hence only a small part of peats can be replaced by SMR in current growing media (Wei *et al.*, 2020a; Wei *et al.*, 2020b; Wei *et al.*, 2020c). Zhu *et al.* (2019) put forward that SMR can be directly used as un-composted substrates under the condition of partly replacing peats in the growing media for cultivation of pepper (*Capsicum annum* L.) seedlings. The growing media with a quarter of fresh SMR was also successfully used for the cultivation of tree (*Pinus koraiensis*) (Wei *et al.*, 2020a) and shrub (*Aralia elata*) (Wei *et al.*, 2020b) plants that have commercial values. Tests are still scarce on herbaceous plants that are vulnerable to environment changes. Nutritional status of SMR-raised herbaceous plants is not clear in current literature.

Nutrient uptake and utilization are highly important for the culture of valued plants. Recently, the importance to test plant-nutritional budget has further been elevated in studies on horticultural plant culture with modern techniques (Zhao *et al.*, 2017; Xu *et al.*, 2019; Zhao *et al.*, 2019; Zhu *et al.*, 2019; Wei *et al.*, 2020a; Wei *et al.*, 2020b; Wei *et al.*, 2020c; Zhao *et al.*, 2020). They attract high concerns not only because of the relevance of nutrient budget (Zhao *et al.*, 2019; Zhao *et al.*, 2020), but also due to the indication of nutrient status that may forecast seedling quality (Xu *et al.*, 2019). It has been documented that light spectra can modulate nutrient uptake and biomass accumulation (Wei *et al.*, 2020a; Wei *et al.*, 2020c) and biomass accumulation, which will further generate a combined effect to shape nutrient utilization (Zhao *et al.*, 2019; Zhao *et al.*, 2020). In this process, the meantime nutrient availability will cooperate to take part in the regulation of nutrient uptake, allocation, and utilization (Wei *et al.*, 2020b). Both light and fertility have been demonstrated to have significant effect on the production of bioactive materials in horticultural plants (Wei *et al.*, 2020c). Therefore, nutrient uptake and utilization are a synthesized matrix that can be the outcome of substrate property and the indication of by-product outcomes.

Gossypium herbaceum L. is a species of cotton with significant value in medicinal uses, such as women's menstrual cycle pains and irregular bleeding (Huang *et al.*, 2020). *Talinum paniculatum* (Jacq.) Gaertn. 1971 is a highly valued plant that is used for traditional medicine due to anti-oxidative bioactive substances from extracts (Tolouei *et al.*, 2019). Both species are found in natural habitats. Mushroom is widely produced in these regions and SMR has been but issue as solid piles. They are highly fragile at the early stage of artificial culture which arouses a challenge to use suitable growing media. In this study, fresh SMR was used as part of growing media mixed peat to culture *G. herbaceum* and *T. paniculatum* seedlings. It was hypothesized that: (i) the fresh SMR would not cause harmful impact on plants at the low proportion in the growing media; (ii) growth and nutrient uptake would be both maximized at the ratio of SMR involvement around a quarter in volume. According to Zhu *et al.* (2019), high proportion of SMR input may result in large range of mortality for pepper plants. We cannot assume this happen considering the difference between species attributes. However, we can accept the fact if unexpected mortality happened in our experiment.

Materials and Methods

Plant materials and growth condition

Seeds of *Gossypium herbaceum* and *Talinum paniculatum* were sent to the Laboratory of Combined Manipulations of Illumination and Fertility on Plant Growth (Zhilunpudao Agric. S&T Ltd., Changchun, China) (43°58' N, 125°24' E) in Changchun city, Northeast China. Seeds were sterilized by soaking in 0.5% (w/w) potassium permanganate for 30 min and soaked in water at the room temperature for 12 h. Seeds were sown in fine-ground peat which were moved to sowing trays and sealed with plastic fiber film. Seeds were germinating at the temperature of 24 °C in the relative humidity of 90%. Germinated embryos were transplanted to plants trays which have 32 (4×8) cavities (13cm depth and 7cm top-diameter) that were filled with substrates of peat and SMR. Light was supplied by high pressure sodium lamps with the spectrum of 43.9% red (600-700 nm), 54.7% green (500-600 nm), and 1.4% blue (400-500 nm) in a daily photoperiod of 16 h. This illumination condition was successfully used for plant culture in previous studies (Wei *et al.*, 2017; Zhao *et al.*, 2017; An *et al.*, 2018; Zhu *et al.*, 2019). Seedlings were watered by sub-irrigation through placing trays in tanked water that were refilled every two days. This watering regime has been proven to enable the desired irrigation availability in the similar cultural system (Zhao *et al.*, 2019; Wei *et al.*, 2020a; Wei *et al.*, 2020b). During the experiment, temperature was 16.8/31.7 °C (night/day) and the relative humidity (RH) ranged between 49% and 94%.

Substrate treatment

Substrates treatments varied by the proportion of SMR in growing-media as 0% (control), 25%, 50%, 75%, and 100% (v/v) with peat mixed together. The peat used in this study was adapted that from Zhu *et al.* (2019), which can solely be used as growing media for the culture most horticultural plants. Spent mushroom residue was obtained from a local mushroom factory in Changchun from the cultivation of *Pleurotus eryngii*. The raw materials to generate SMR included 20% cottonseed hull, 20% wood bits, 24% corncobs, 20% brans, 5% corn flour, 2% lime carbonate, 1% gypsum powder, and 8% bean pulp (Zhu *et al.*, 2019). After the harvest of mushrooms, SMR was immediately moved out of plastic coating, crushed to pieces, and air-dried at indoor temperature until the weight was constant. A pile of peat was mixed by SMR and both were mixed to the aimed volumetric proportion. Mixed substrates were used to fill planting cavities in every tray. Filled trays received full watering and a second portion of substrate was added to the surface gap caused by wetted compression. Chemical properties of the five substrates are shown in Table 1. Each treatment was replicated for three times with one planting tray as a replicating unit.

Table 1. Chemical properties of the substrates with fresh spent mushroom substrate mixed with commercial peat in different proportions (v/v)

Treatment	NH ₄ ⁺ -N (mg kg ⁻¹)	NO ₃ ⁻ -N (mg kg ⁻¹)	PO ₄ ³⁻ -P (mg kg ⁻¹)	pH	EC (dS m ⁻¹)
0%	124.74 ± 4.92a	152.51 ± 8.63a	232.29 ± 18.26e	4.29 ± 0.05d	0.31 ± 0.20c
25%	121.75 ± 2.02a	137.63 ± 3.56a	364.88 ± 3.45d	4.48 ± 0.06cd	0.99 ± 0.12b
50%	113.33 ± 1.66a	49.11 ± 4.08b	510.52 ± 8.78c	4.66 ± 0.05c	1.54 ± 0.23b
75%	74.35 ± 10.79b	36.96 ± 5.70b	637.86 ± 10.43b	5.10 ± 0.19b	2.35 ± 0.29a
100%	19.52 ± 8.18c	11.07 ± 4.13c	910.01 ± 13.67a	5.66 ± 0.08a	2.74 ± 0.09a
M.S.	5976.84	12078.55	20423.17	0.94	2.94
Fvalue	124.79	353.14	1274.12	79.51	66.17
Pt > F	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Different letters in a column stand for significant difference among SMR treatments was tested by Tukey method at 0.05 level.

Plant culture, sampling, and chemical analysis

Seedlings were cultured for four months until some trayed seedlings died out in the 100% SMR treatment (Figure 1). Ten living seedlings were sampled from one planting tray and measured for their height and root-collar diameter (RCD). Height was measured as the length from root-collar scar to the tip of shoot. RCD was measured as the diameter of the stem 3 cm above the root-collar scar. Each sampled seedling was divided into shoot and root parts and both were dried in a ventilated oven at 70 °C for 72h. Dried samples were ground and determined for nitrogen (N) and phosphorus (P) concentrations. A sample in the weight of about 0.2 g was digested in 5mL mixture of hydrogen peroxide and sulfuric acid. The digested solution was diluted to 50 mL. Total N concentration was determined Kjeldahl method (Salifu and Timmer, 2003). Total P concentration was determined by the Molybdenum-anticolorimetry method (Zhao *et al.*, 2020).

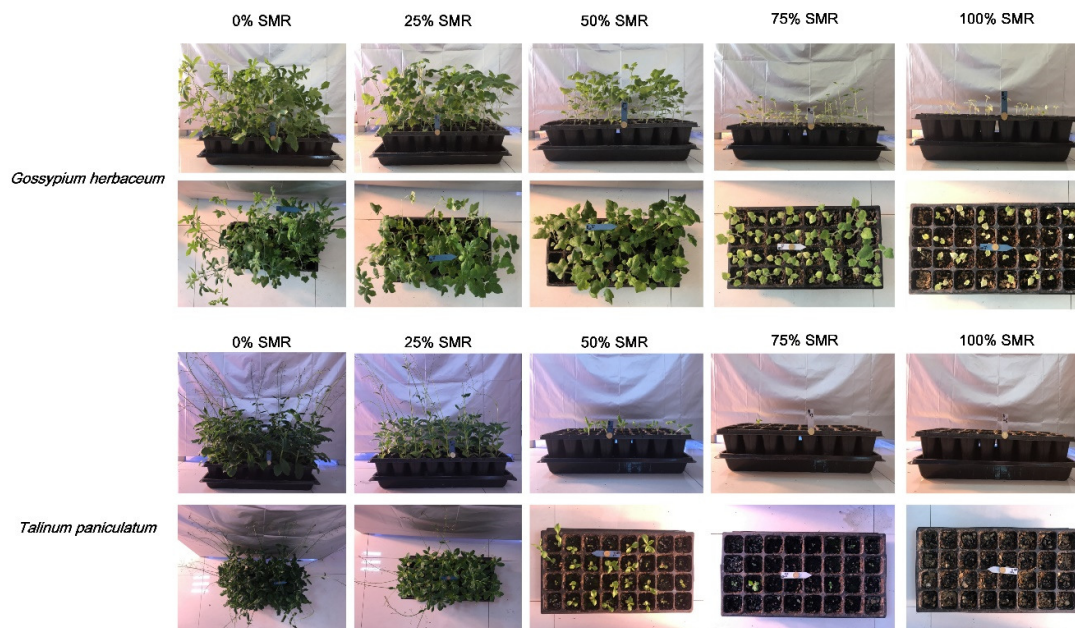


Figure 1. Typical outcome of *Gossypium herbaceum* and *Tlinum paniculatum* seedlings exposed to growing media with peat and spent mushroom residue (SMR) in proportions of 0, 25%, 50%, 75%, and 100%

Statistical analysis

Statistical analysis was made by SPSS software (IBM, New York, U.S.A.). All data were tested for their normal distribution and no data transformation was necessary. Data were analysed by a two-way analysis of variance (ANOVA) with two species (*G. herbaceum* and *T. paniculatum*) and five treatments (0%, 25%, 50%, 75%, 100% proportion of SMR in the growing media) as fixed factors. Because *T. paniculatum* seedlings died out in 100% SMR treatment and the number of survived ones in the 75% SMR treatment was fewer than 10, data were analysed by a factorial analysis of 2×3 factors arrangement with two species in 0%, 25%, and 50% SMR treatments. When significant effect was indicated by ANOVA ($\alpha=0.05$), data in response to the six combined treatments were compared by a one-way ANOVA plus two other treatments of 75% and 100% SMR on *G. herbaceum* seedlings. This analysis of combined treatments with hanging-up new comers was also used in the study on soil amendment (Wei *et al.*, 2012). The significant difference in comparison was tested by Tukey method at 0.05 level. Vector diagnosis was used to evaluate nutritional status for N and P according to the methodology by Salifu and Timmer (2003). This technique has been widely used for the diagnosis of nutrient status in plants subjected to light and substrate combination (Li *et al.*, 2018; Wei *et al.*, 2020a; Wei *et al.*, 2020b).

Results

Responsive performance

Seedlings of *G. herbaceum* generally showed better responses of survival and growth to SMR substrates than those of *T. paniculatum* (Figure 1). Shoots of *G. herbaceum* seedlings subjected to the 100% SMR treatment failed to initiate the second flush and showed yellow leaves in most surviving individuals. Survival of *G. herbaceum* seedlings in the 75% SMR treatment was higher but parts of individuals had yellow leaves. Seedlings of *T. paniculatum* died out in the 100% SMR treatment and most individuals died in the 75% SMR treatment. Although over half of *T. paniculatum* seedlings survived in the 50% SMR treatment, leaves of living individuals did not look green as expected.

Shoot growth

Factors of species and SMR treatment had an interactive effect on height growth and RCD (Table 2). *Talinum paniculatum* seedlings showed highest plant height in the control ($F_{7,16}=49.37$; $P<0.0001$) (Figure 2A). Root-collar diameter of *G. herbaceum* seedlings in the control was also as high as that of *T. paniculatum* ($F_{7,16}=98.40$; $P<0.0001$) (Figure 2B). Both height and RCD generally showed a decreasing trend with the increase of SMR ratio in the growing media. Both height and RCD were lower in the 50% SMR treatment than those in the control in *T. paniculatum* seedlings. Height and RCD were lower in the 75% and 100% SMR treatments than those in the control in *G. herbaceum* seedlings.

Table 2. *F* and *P* values from analysis of variance (ANOVA) of species, spent-mushroom residue ratio (SMR), and their interaction on seedling growth, biomass and nutrient uptake

Parameters	ANOVA	Species	SMR	Species × SMR
Seedling height	<i>F</i> value	11.04 ¹	70.91	18.19
	<i>P</i> value	0.0061	<0.0001	0.0002
RCD ²	<i>F</i> value	6.39	234.18	11.83
	<i>P</i> value	0.0265	<0.0001	0.0015
Shoot biomass	<i>F</i> value	1.21	197.69	13.26
	<i>P</i> value	0.2921	<0.0001	0.0009
Root biomass	<i>F</i> value	58.58	86.14	48.83
	<i>P</i> value	<0.0001	<0.0001	<0.0001
RS ³	<i>F</i> value	35.58	100.13	84.68
	<i>P</i> value	<0.0001	<0.0001	<0.0001
Shoot N ⁴ concentration	<i>F</i> value	2.58	1.29	7.45
	<i>P</i> value	0.1344	0.3100	0.0079
Root N concentration	<i>F</i> value	78.14	2.57	34.45
	<i>P</i> value	<0.0001	0.1180	<0.0001
Shoot P ⁵ concentration	<i>F</i> value	209.68	34.13	25.38
	<i>P</i> value	<0.0001	<0.0001	<0.0001
Root P concentration	<i>F</i> value	147.91	392.38	284.67
	<i>P</i> value	<0.0001	<0.0001	<0.0001
Shoot N content	<i>F</i> value	14.09	289.24	66.71
	<i>P</i> value	0.0028	<0.0001	<0.0001
Root N content	<i>F</i> value	6.66	79.44	49.10
	<i>P</i> value	0.0241	<0.0001	<0.0001
Shoot P content	<i>F</i> value	58.29	413.00	84.80
	<i>P</i> value	<0.0001	<0.0001	<0.0001
Root P content	<i>F</i> value	43.75	82.08	43.57
	<i>P</i> value	<0.0001	<0.0001	<0.0001

Note: ¹ value in bold font indicate significant effect; ² RCD, root-collar diameter; ³ RS, root to shoot biomass ratio; ⁴ N, nitrogen; ⁵ P, phosphorus.

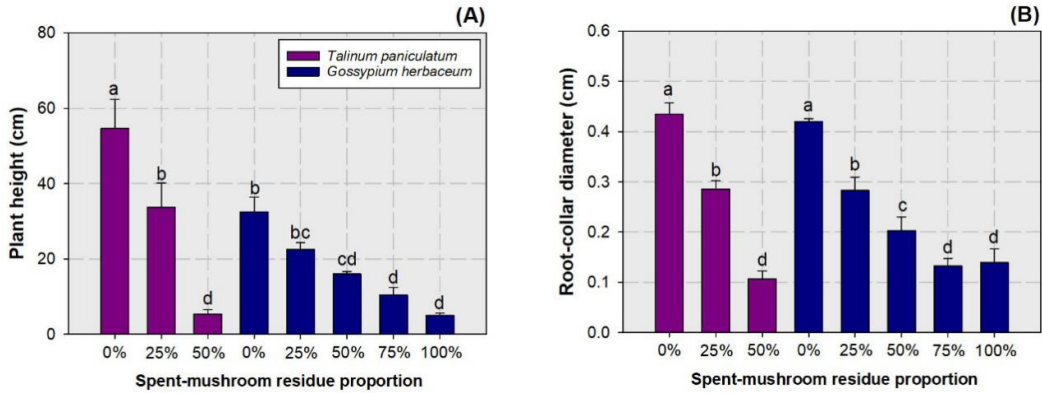


Figure 2. Plant height (A) and root-collar diameter (B) in *Gossypium herbaceum* and *Talinum paniculatum* seedlings exposed to growing media with peat and spent mushroom residue (SMR) in proportions of 0%, 25%, 50%, 75%, and 100% for *G. herbaceum* and 0%, 25%, and 50% for *T. Paniculatum*. Error bars label standard errors. Different letters indicate significant difference at 0.05 level according to the Tukey test.

Biomass accumulation and allocation

Factors of species and SMR treatment had an interactive effect on biomass accumulation in shoot and root and allocation between root and shoot (Table 2). Shoot biomass was lower in SMR treatments from 25% up to 100% compared to the control for both species ($F_{7,16}=18.98$; $P<0.0001$) (Figure 3A). In *G. herbaceum* seedlings, shoot biomass was also lower in the 75% and 100% SMR treatments relative to the control. In *T. paniculatum* seedlings, root biomass in the 25% SMR treatment was not statistically different from that in the control. Root biomass was lower in the 75% and 100% SMR treatments compared to the control for *G. herbaceum* seedlings ($F_{7,16}=77.88$; $P<0.0001$) (Figure 3A).

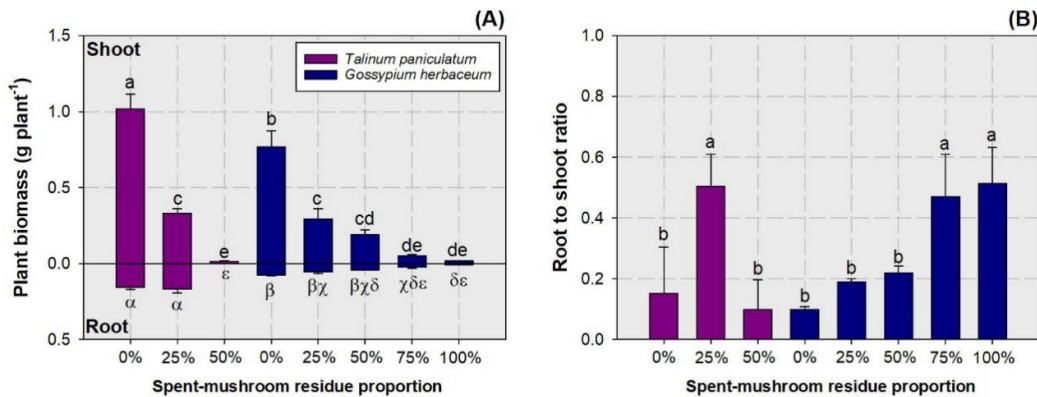


Figure 3. Plant biomass accumulation (A) and root to shoot biomass ratio (B) in *Gossypium herbaceum* and *Talinum paniculatum* seedlings exposed to growing media with peat and spent mushroom residue (SMR) in proportions of 0%, 25%, 50%, 75%, and 100% for *G. herbaceum* and 0%, 25%, and 50% for *T. Paniculatum*. Error bars label standard errors. Different letters indicate significant difference at 0.05 level according to the Tukey test. Lower case letters label difference for shoot and roman letters for root.

Factors of species and SMR treatment had an interactive effect on root to shoot biomass ratio (R/S) (Table 2). In *T. paniculatum* seedlings, R/S was higher in the 25% SMR treatment than that in the control and in the 50% SMR treatment ($F_{7,16}=18.98$; $P<0.0001$) (Figure 3B). The R/S tended to rise with the increase of SMR proportion in the substrates. The R/S was higher in the 75% and 100% SMR treatments than that in the control.

Nitrogen and phosphorus concentrations

Factors of species and SMR treatment had an interactive effect on N and P concentrations in shoot and root parts in both species (Table 2). Nitrogen concentration declined with the increase of SMR proportion in growing media in *T. paniculatum* shoots ($F_{7,16}=5.70$; $P=0.0019$) (Figure 4A). Shoot N concentration was not different in the SMR treatments from that in the control. Root N concentration was highest in controlled *G. herbaceum* seedlings followed by that in same species of seedlings subjected to the 25% and 50% SMR treatments ($F_{7,16}=38.71$; $P<0.0001$) (Figure 4B). Root N concentration was higher in the 25% and 50% SMR treatments compared to the control for *T. paniculatum* seedlings. Controlled *T. paniculatum* seedlings and *G. herbaceum* seedlings in the 75% SMR treatment had the lowest root N concentration. Whole-plant N concentration was highest in controlled *T. paniculatum* seedlings and *G. herbaceum* seedlings exposed to the 25% and 50% SMR treatments ($F_{7,16}=5.53$; $P=0.0022$) (Figure 4C). *Talinum paniculatum* seedlings in the 50% SMR treatment and *G. herbaceum* seedlings in the 75% SMR treatment had the lowest whole-plant N concentration.

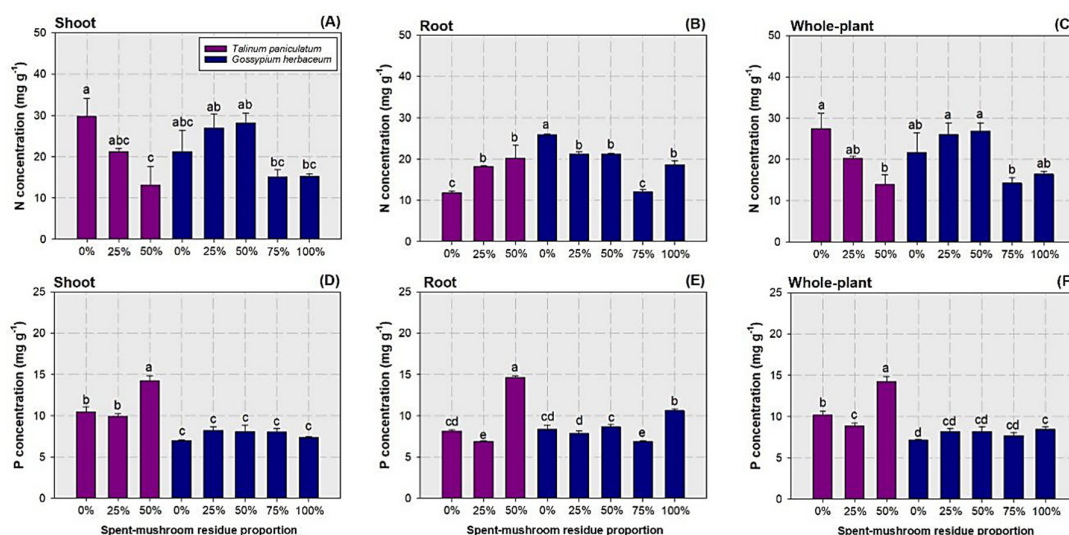


Figure 4. Concentrations of nitrogen (N) (top) and phosphorus (P) (bottom) in shoot (left), root (middle), and whole-plant (right) in *Gossypium herbaceum* and *Talinum paniculatum* seedlings exposed to growing media with peat and spent mushroom residue (SMR) in proportions 0%, 25%, 50%, 75%, and 100% for *G. herbaceum* and 0%, 25%, and 50% for *T. Paniculatum*. Error bars label standard errors. Different letters indicate significant difference at 0.05 level according to the Tukey test.

Shoot P concentration was highest in *T. paniculatum* seedlings subjected to the 50% SMR treatment, followed by that in the same species of seedlings subjected to the control and the 25% SMR treatment ($F_{7,16}=65.99$; $P<0.0001$) (Figure 4D). Shoot P concentration in *G. herbaceum* seedlings was lower than that in *T. paniculatum* seedlings without significant difference among SMR treatments. Root P concentration was also highest in *T. paniculatum* seedlings subjected to the 50% SMR treatment and that in *G. herbaceum* seedlings subjected to the 100% SMR treatment was the second highest ($F_{7,16}=297.14$; $P<0.0001$) (Figure 4E).

Root P concentration in *T. paniculatum* seedlings subjected to the 25% SMR treatment and that in *G. herbaceum* seedlings subjected to the 75% SMR treatment showed the lowest level. Whole-plant P concentration was highest in *T. paniculatum* seedlings subjected to the 50% SMR treatment and lowest in *G. herbaceum* seedlings subjected to the control (Figure 4F).

Nitrogen and phosphorus contents

Factors of species and SMR treatment had an interactive effect on N and P contents in shoot and root parts in both species (Table 2). Shoot N content declined with the increase of SMR proportion in the growing media for both species ($F_{7,16}=178.78$; $P<0.0001$) (Figure 5A). However, root N content was highest in *T. paniculatum* seedlings subjected to the 25% SMR treatment, followed by that in controlled *T. paniculatum* seedlings and *G. herbaceum* seedlings ($F_{7,16}=70.05$; $P<0.0001$).

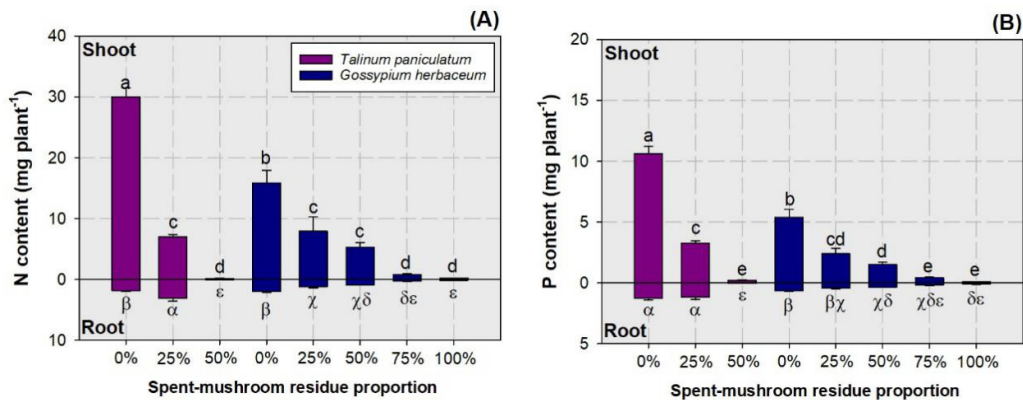


Figure 5. Contents of N (A) and P (B) in shoot and root parts of *Gossypium herbaceum* and *Talinum paniculatum* seedlings exposed to growing media with peat and spent mushroom residue (SMR) in proportions of 0%, 25%, 50%, 75%, and 100% for *G. herbaceum* and 0%, 25%, and 50% for *T. Paniculatum*. Error bars label standard errors. Different letters indicate significant difference at 0.05 level according to the Tukey test. Lower case letters label difference for shoot and roman letters for root.

Shoot P content also declined with the increase of SMR proportion in the growing media ($F_{7,16}=257.22$; $P<0.0001$) (Figure 5B). Root P content was highest in *T. paniculatum* seedlings subjected to the control and the 25% SMR treatment ($F_{7,16}=72.18$; $P<0.0001$). Root P content declined with the increase of SMR proportion in the growing media.

Diagnosis of nitrogen and phosphorus statuses

Compared to the control, SMR treatments resulted in the symptom of nutrient excess for both species, but the cause of nutrient excess was various (Figure 6). In *T. paniculatum* seedlings, both proportions of 25% and 50% SMR in the growing media resulted in antagonistic N excess because of multiple declines in biomass, N content and concentration (Figure 6A). In *T. paniculatum* seedlings, the lower SMR proportion of 25% also resulted in antagonistic P excess, but the higher proportion of 50% led to toxic P accumulation due to the increase of P concentration relative to the control (Figure 6B). In *G. herbaceum* seedlings, lower SMR proportions of 25% and 50% resulted in the toxic N accumulation but higher proportions of 75% and 100% resulted in antagonistic N excess (Figure 6C). The P status was indicated to be toxic accumulation in *G. herbaceum* seedlings subjected to all SMR treatments (Figure 6D).

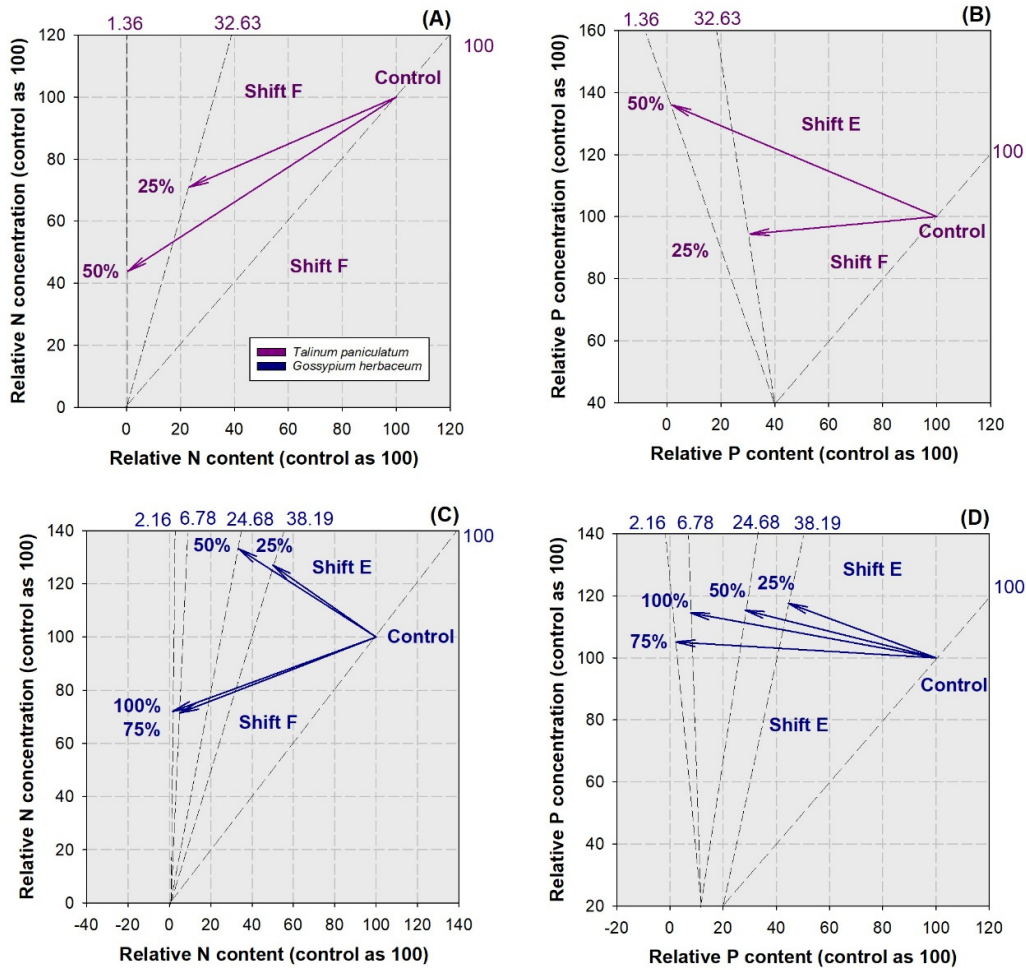


Figure 6. Vector diagnosis of N and P statuses in shoots of *Gossypium herbaceum* and *Tlinum paniculatum* seedlings exposed to growing media with peat and spent mushroom residue (SMR) in proportions of 0, 25%, 50%, 75%, and 100%. Shifts interpretations are adapted from Salifu and Timmer (2003). Shift E stands for nutrient excess caused by toxic accumulation. Shift F stands for antagonistic excess.

Discussion

As we indicated, the high proportion (over 50%) of SMR in the growing media generated negative impacts on plant growth of the two species. This negative influence had a species-specific response that *G. herbaceum* seedlings can endure SMR at a high proportion with weakened growth, but *T. paniculatum* seedlings cannot endure SMR at the proportion from 75% to 100%. High EC in SMR-enriched growing media was caused by high levels of ions and salts (Medina *et al.*, 2009). According to the negative response of *T. paniculatum* seedlings to the high-proportion SMR substrates, this species is more sensitive to salt stress; hence occurred higher mortality than in *G. herbaceum* seedlings. Distinctly negative attributes to high salt stress also occurred on other plant species. Medina *et al.* (2009) reported that tomato plants are less sensitive to salt than pepper and courgette when cultured with the growing media with SMR. Therein, only tomato plants out of all species tested can endure high proportion of SMR.

Both species showed a decrease in shoot growth in response to the increase of SMR in the growth media. Controlled seedlings without any SMR addition showed the best responses in growth and biomass

accumulation. These results suggest that the two economical plants we used were unsuitable to be cultured by the growing media with SMR. Nevertheless, results from Zhu *et al.* (2019) did not concur with ours because 25%-SMR increased shoot growth in pepper seedlings. Root biomass in our plants was not changed in 25%-SMR as it was for shoot biomass. More biomass was allocated to roots in high proportions of SMR for *G. herbaceum* but in the low proportion (no higher than 25%) for *T. paniculatum*. In accordance with our findings, pepper plants were also found to have more biomass allocated to roots by more SMR used in the growing media (Zhu *et al.*, 2019). Therefore, biomass allocation to roots functioned as a mechanism to account for the difference of sensitivities of the two plant species to the proportion of SMR. The ability to make biomass translocation to roots explained at least parts of the reason that *G. herbaceum* can survive when facing high SMR proportion.

Regarding the species-specific response to the mixture with SMR, we cannot accept our first hypothesis even at low proportion. However, if the promotion of shoot growths was not the main object in the cultural system, the growing media with 25% SMR and 75% peat can be used, but not recommended, for the two species. The only merit of 25%-SMR substrates for dry mass production can be confirmed through our results was that high biomass-allocation to roots benefits the under-ground biomass pool in *T. paniculatum* if being cultured as a traditional source of medicine.

The high N concentration in shoots was driven by high NH_4^+ -N and NO_3^- -N concentrations in the substrates with low SMR proportions. In contrast, higher proportion of SMR increased the concentration of available P. Hence, seedlings tended to have higher P concentration in substrates with higher SMR proportions. These results about P budget concur with those of P uptake and utilization in horticultural plants (Medina *et al.*, 2009; Zhu *et al.*, 2019). Because of the decline of biomass with the increase of SMR in the growing media, N and P contents also showed a decreasing trend along the gradient of SMR proportion from low to high. After all, both species in our study showed excessive symptoms of N and P to any proportional addition of SMR to the growing media. This was mainly caused by the decline of biomass in SMR-amended substrates. Therefore, we cannot accept our second hypothesis, but we concur with our preceding findings that the two species are not suitable to be cultured by the growing media.

Conclusions

Although we conducted this study on *Talinum paniculatum* and *Gossypim herbaceum* seedlings with empirical manipulations according to existed experiments, our results do not concur with most of findings in the horticultural plants. *Talinum paniculatum* is not suitable to be cultured by the growing media with SMR mainly due to depressed growth, decreased biomass accumulation, and subsequently nutrient excess. However, it can be suggested to culture *T. paniculatum* seedlings with growing media of 25% SMR regarding more biomass allocated to root as an invest of source to commercial organ in this species. Our results can be a set of theoretical references for the environmental advice to eliminate the possible contamination of solid water accumulation. Our findings about biomass production and allocation can also be used as the evidence for the culture of medicinal plants if dry mass production was set as the aim to enlarge the reserve for medical components.

Authors' Contributions

Conceptualization: HZ and YL; Data curation: HZ and AJ; Formal analysis: JT and YL; Funding acquisition: YL and HZ; Investigation: SZ and AJ; Methodology: YL; Project administration: YL; Resources: YL; Software: AJ and JT; Supervision: YL; Validation: HZ and SZ; Visualization: HZ; Writing - original draft: HZ; Writing - review and editing: YL. All authors read and approved the final manuscript.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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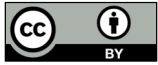
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