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RESEARCH ARTICLE

A study of sustainable growing media through the utilization of agricultural by-products as organic substrates for tomato seedling production

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ABSTRACT

Tomato is a widely cultivated and consumed vegetable crop in the world. It is a valuable source of nutritional compositions and health-promoting phytochemicals. This study aimed to evaluate the growth response of tomato seedlings to the use of media mixtures formulated from rice husk ash (RHA), coir (C), canna residue (CR), and animal manures, including pig manure (PM), chicken manure (CKM), and cow manure (CM). Five treatments were applied at proportions: 25% RHA + 25% C + 25% CR + 25% PM (T1), 25% RHA + 25% C + 25% CR + 25% CKM (T2), 25% RHA + 25% C + 25% CR + 25% CM (T3), 25% RHA + 25% C + 25% CR + 25% peat (T4), and 100% TS2 (Kultursubstrat aus Weibtorf White Peat Potting Substrate) commercial product (T5). Our results suggested that, in comparison with the treatment of T5 the experimented media showed positive effects on the growth of tomato plants during the nursery stage. The best response was recorded in the treatment T1 with the highest germination rate (96.05%) after 10 days of sowing. Also, T1 obtained great values of plant height, leaf number, and root volume on day 30 after sowing, which were 7.85 cm, 3.5 leaves per plant, and 1.08 cm3, respectively. These findings indicated that the tested byproduct materials offer a viable and sustainable alternative to producing growing media for tomato seedling practices.

Key words: Growing media; Rice husk ash; Coir; Canna residue; Animal manures; Tomato by-product

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) from the family Solanaceae is a high-value vegetable crop that is widely grown and consumed in the world. Tomato is famous for its nutritive and medicinal values. It is a good source of minerals (P, K, Ca, Fe, Mn, and Zn), phenolics (phenolic acids and flavonoids), carotenoids (lycopene, a, and b carotene), vitamins (vitamin C and vitamin A), and glycoalkaloids (tomatine) (Khan et al. 2017; Chaudhary et al. 2018). According to data from Faostat, in 2020, the world produced 186,821 million kilos of tomatoes on 5,051,983 hectares. Increased area of production has promoted the economic significance of the crop worldwide. However, determining how to improve tomato quality without reducing fruit yield remains a significant challenge for agricultural producers and scientists (Wang et al. 2017). The production of healthy and viable seedlings is an important factor in the productivity and yield of tomato fruits (Atif et al. 2016). The use of organic farming techniques and materials is an effective agricultural practice to sustain vegetable production economically with minimal environmental pollution and higher fruit quality (Gruda 2019).

Over the last two decades, with the growth in agricultural production, the volume of solid organic waste released from agriculture-based industry has increased gradually (Tüzel et al. 2020). Agricultural waste treatment is implemented to tackle the issue, however this would cause negative impacts on environment, and human health. In many regions, waste services are even limited to collection and disposition only, without options for treatment or recycling, resulting in environmental pollution (Abid et al. 2018). In addition, a large amount of fecal sludge

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is continually produced from agricultural production activities. They are conventionally deposited in landfills or entered the aquatic system, causing in the production of a significant amount of greenhouse gases and contamination of the groundwater with human pathogenic organisms (Nartey et al. 2017). Hence, agricultural waste disposal is relatively challenging for management levels, and scientific communities. Waste recycling and its utilization as organic growing media, either alone or in mixtures, is considered as one of the most promising solution (Atif et al. 2016).

Germination of the seed is a critical stage owing to the fact that the rest of the plant life is directly dependent on the rate of its germination (Vivek and Duraisamy 2017). The main objective of horticultural nurseries is to produce quality seedlings with target morphological and physiological features for healthy growth after transplanting (Lazcano et al. 2009). Healthy and vigorous seedlings production is a precondition for raising productive and profitable crops. Plants are especially sensitive to negative factors of the medium during seed germination, seedling emergence, and seedling growth (Atif et al. 2016). Thus, the growing media used in this process is a determining factor that influences the quality of seedlings in a nursery.

Seeds sown in growing media (GM) are provided nutrients and supported with the plant growth. GM is often a mixture of many materials and its quality is influenced by various factors (Pascual et al. 2018).

The benefits of GM are massive, such as yield and quality increase, resist diseases and pests… and peat is one of four GM's types (Barrett et al. 2016, Pascual et al. 2018). It has been used for producing soilless medium for decades, but its source is limited, the availability of GM is a problem in years to come (Truong, Wang, and Kien 2017; Abdel-Razzak et al. 2019).

In today's agricultural practices, new alternatives should be proposed for growing media of seedlings in nurseries. There has been a significant focus on renewable materials from agricultural waste streams (Gruda 2019). Numerous studies demonstrated that agricultural byproducts offer a promising source of materials for growing media production on various plants (Barrett et al. 2016; Pascual et al. 2018; Gruda 2019). The source could be environmentally sustainable, economically viable, and able to perform as well as previously used components. To date, the use of agricultural wastes as a component of growing media for tomato nurseries was evaluated in a few studies (Ceglie et al. 2011; Abid et al. 2018; Agboola et al. 2018; Tüzel et al. 2020). Nevertheless, this research direction has not been well documented for tomato seedlings in particular.

Toward this end, the present study was designed to investigate the growth response of tomato seedlings to the use of mixtures of rice husk ash, coir, canna residue, and manure in various formulations, as the growing media in seedling production. Significantly, it is the first to determine the feasibility of canna residue utilized as a component of the growing medium in nurseries. In order to take advantage of these agricultural byproducts, this study aimed to provide scientific information to the seedling plant producers for practical applications.

MATERIAL AND METHODS

Materials

Tomato (*Solanum lycopersicum* L.) seeds, Mui variety, were selected from the Center for Training and Research on Plant and Animal Breeding, Thai Nguyen University of Agriculture and Forestry (Thai Nguyen, Vietnam). Agricultural byproducts, including rice husk ash, coir, and canna residue, were provided by the HDT Agriculture Joint Stock Company (Thai Nguyen, Vietnam). Animal manures were collected from local organic farms in Thai Nguyen province, Vietnam.

Experimental design

Experiments were designed by using five media mixtures, which were combined from rice husk ash (RHA), coir (C), canna residue (CR), and animal manures, including pig manure (PM), chicken manure (CKM), and cow manure (CM). The formulations were prepared in the following proportions (by volume): 25% RHA + 25% C + 25% CR + 25% PM (T1), 25% RHA + 25% C + 25% CR + 25% CKM (T2), 25% RHA + 25% C + 25% CR + 25% CM (T3), 25% RHA + 25% C + 25% CR + 25% peat (T4), and 100% TS2-Kultursubstrat aus Weibtorf White Peat Potting Substrate (T5). In which, T5 a commercial product of Klasmann-Deilmann GmbH (Geeste, Germany), was used as a control treatment.

Management

Experiments were conducted under net house conditions at the Center for Training and Research on Plant and Animal Breeding, Thai Nguyen University of Agriculture and Forestry, Thai Nguyen city, Vietnam (21°35'40.6''N 105°48'31.0''E).

The experiments were designed with five treatments and three replications. Each replication was prepared as one tray with 72 holes. One seed was sown per hole. The seeds were irrigated to meet their demand during the growing period. The irrigation scheduling and water volume were arranged similarly for all formulations. No additional fertilization was supplied. The growth response of tomato seedlings was observed day-to-day in order to propose the allowable treatments if any disease infection.

Physico-chemical analysis of the media

After conducting the experiment, the used media were submitted to chemical and physical analysis using standard methods with several modifications. Samples were dried at 60 ^{o}C for 48 hours (h), then mixed in a solution consisting of 10 g of sample in 100 mL of distilled water. The solution was agitated mechanically for 2 h. The electrical conductivity (EC) and pH values were measured using a pH meter (Eutech Instruments, Singapore) and EC meter (DFRobot, Shanghai, China).

For other parameters of the used media, samples were dried at the room temperature and arranged for further analysis. To determine the total porosity, aeration porosity, water holding capacity, bulk density, and mass wetness, the samples were water-saturated for 24 h, then allowed to drain for 60 minutes (min). The amount of drainage water was recorded. Samples were weighed before and after drying in an oven (Nabertherm GmbH, Lilienthal, Germany) at 105 °C for 24 h. The results were calculated and expressed using the following formulas: The total porosity (% volume) = [(wet weight – dry weight + drainage)/volume] × 100; The aeration porosity (% volume) = (drainage/volume) × 100; The water holding capacity (% volume) = [(wet weight – dry weight)/volume] × 100; bulk density (g/cm^3) = dry weight/volume; The mass wetness (g water g substrate^{-1}) = (wet weight – dry weight)/dry weight (Atiyeh et al. 2001; Truong, Wang, and Kien 2017; Abid et al. 2018).

The total nitrogen (N) content was determined by the Kjeldahl method using 96% H2S04. The concentrations of phosphorus (P) and potassium (K) were determined by colorimetric analysis using a spectrophotometer (INESA Analytical Instrument, Shanghai, China). The amount of calcium (Ca) was determined by titration with ethylene diamine tetraacetic acid (EDTA). Micronutrients, including iron (Fe), zinc (Zn), and manganese (Mg) were measured with an inductively coupled plasma atomic emission spectroscopy (ICP-AES) after extraction with 0.1 N hydrochloric acid solvent (Atiyeh et al. 2001; Truong, Wang, and Kien 2017; Abid et al. 2018).

Seeding germination, seedling growth, and biomass allocation

The seeds were considered to have germinated after radicle emergence. Germinating seeds and the emergence of seedlings were counted daily and expressed as a percentage of the total number of planted seeds. After sowing, the germination results were expressed as the number of seedlings in comparison with the number of sown seeds. The height of plants was measured in a 6-day period. Stem diameter and seedling biomass were examined after 32 days of sowing. At the final step of the experiment, 10 seedling plants per replication (30 plants per treatment) were harvested randomly. In order to investigate fresh weight, they were then separated into sample groups of shoots and roots.

For further analyses, root volume (cm^3) was determined by submerging the root in a measuring cup with water. To estimate the dry weight of the shoots and roots, and the concentration of total macro and micronutrients in the shoots, these samples were dried in an oven at 60 °C for 48 h (Atiyeh et al. 2001; Truong, Wang, and Kien 2017; Abid et al. 2018). The concentrations of total macro- and micronutrients, including N, P, K, Ca, Fe, Zn, and Mg, in the shoot of tomato seedlings were determined as presented above.

Statistical analysis

All data were statistically analyzed using SPSS 22.0 software (SPSS Inc., Chicago, IL, USA). The data were subjected to one-way analysis of variance (ANOVA), and the means were compared for significance by the least significant difference (LSD) test at $P<0.05$. All the analyses were performed in triplicate.

RESULTS

The experimented media effects on tomato seedling growth

Germination of the seed, an internally regulated stage, is influenced by numerous factors, including light, temperature, moisture, as well as chemical and physical characteristics of the growing media. As shown in Table 1, the germination rate is significantly different in the tested formulations. After 4 days of sowing, the germination rate of T1 reached 91.66%, followed up by that of T3 with 75%. Whereas, the germination percentage of the other treatments fluctuated at just approximately 30–39%. On day 5 after sowing, the formulations T1, T3, and T4 continuously obtained the high germination rate with around 86–93%. In addition, there was a sharp increase in the germination rate of the treatment T2 and T5 to 61.11%

Table 1: The germination rate in treatments at different times after sowing

Treatments	5 days	7 days	10 days
T1	91.66^{a}	93.05^{a}	96.05^{a}
T2	60.55^{c}	81.11^{ab}	94.89^{ab}
T3	75.00^{b}	86.11^{a}	88.89^{b}
T4	38.89^{c}	87.50^{a}	91.66^{ab}
T5	38.89^{c}	72.22^{b}	90.28^{ab}
LSD 0.05	10.15	8.99	6.78

LSD, least significantly difference. Means followed by the same letters do not significantly differ (p<0.05) and 87.5% respectively. After 10 days of observation, the germination rate in all treatments reached about 90% and over. The formulation T1 presented the highest number of germinated seeds with 96.05%.

As presented in Table 2, the height of seedlings after 30 days of sowing in five treatments ranged from 2.9 to 7.85 cm. In which the plants in formulations T1 and T2 achieved the highest height of 6.8 and 7.85 cm correspondingly. In contrast, the lowest height was shown by T3 with 2.9 cm. Together with the growth of plant height, the number of leaves also increased with the growth period of seedlings. After 30 days of sowing, the number of leaves fluctuated between 1.7 and 3.5 leaves per plant. Similar to the results of plant height, seedlings in treatments T1 and T2 had the highest number of leaves. Also, the seedlings in T2 presented great values of shoot weight in both fresh and dried matter (8.65 and 1.09 g/plant, respectively). On the other hand, from Table 2, it can be seen that the root volumes of tomato seedlings in all formulations obtained similar values, ranging from about 1.05 to 1.11 cm^3 per plant.

The macro-and micronutrient contents in shoot tissues of the tomato seedlings after 30 days of sowing in the experimented media are indicated in Table 3. The concentrations of nutrient constituents, counting N, P, K, Ca, Fe, Zn, and Mg, in the shoots of seedlings, differed obviously between treatments. Generally, the levels of N, P, K, and Mg in T1 and T2 were greater than those in other formulations.

Chemical and physical properties of the experimented media

The pH and EC of the growing media are two main factors that directly influence the mechanism of nutrient uptake in plants and the activities of roots. The data in Table 4 showed that the pH values of media in all formulations stabilized at about 6.7–6.8, which is the appropriate pH level for the growth and development of tomato seedlings. At the nursery stage, there were remarkable differences found between the EC values for the investigated media, which ranged between 1.12 and 3.18.2 dS/m. Among the treatments, T2 acquired the highest EC value, whereas the lowest EC value was presented by T1. Other treatments,

Table 2: Effect experimented media on morphological characteristics and growth of tomato seedlings

Treatments	Plant height (cm)	Leaf number (leaf)	Shoot weight ($g.plant^{-1}$)		Root volume ($cm^3.plant^{-1}$)
			Fresh	Dry	
T1	7.85^a	3.50^a	6.12^b	0.66^b	1.08.^{a}
T2	6.80^a	3.50^a	8.65^a	1.09^a	1.05^a
T3	2.90^c	1.70^b	5.03^{bc}	0.73^b	1.11^a
T4	5.45^b	2.40^{ab}	3.14^c	0.41^c	1.09^a
T5	5.25^b	3.20^a	5.94^b	0.51^{bc}	1.07^a
LSD 0.05	1.05	1.49	1.15	0.21	0.23

LSD, least significantly difference. Means followed by the same letters do not significantly differ ($p<0.05$)

Table 3: Concentration of macro-micronutrients in the shoot of tomato seedlings after 30 days of sowing

Treatments	N	P	K	Ca	Mg	Mn	Fe	Zn
	$g.kg^{-1}$ dry weight					$mg.kg^{-1}$ dry weight		
T1	2.35^b	8.00^a	42.41^c	2.79^e	4.83^b	207.32^b	192.59^a	16.10^a
T2	2.92^a	8.30^a	65.96^a	3.84^d	5.56^a	219.20^b	122.62^b	20.49^a
T3	1.45^e	5.70^b	56.18^b	6.34^b	4.50^{bc}	178.48^c	95.75^b	18.28^a
T4	1.57^d	1.8^c	37.23^d	8.13^a	2.80^d	659.55^a	216.24^a	17.43^a
T5	2.01^c	5.9^b	36.09^d	5.34^c	4.06^c	176.22^c	78.06^b	17.04^a
LSD 0,05	0.11	0.47	2.51	0.96	0.51	21.84	49.87	6.43

LSD, least significantly difference. Means followed by the same letters do not significantly differ ($p<0.05$)

Table 4: Chemical and physical characteristics of the experimented media

Treatment	pH (1:10)	EC ($dS.m^{-1}$)	WHC (%)	Bulk density (g/cm^3)	Total porosity (% volume)	Mass wetness ($g.g^{-1}$)	Aeration porosity (% volume)
T1	6.60^b	1.12^c	87.64^a	0.11^a	86.22^a	2.89^a	16.05^a
T2	6.69^b	3.18^a	69.22^{bc}	0.12^a	79.23^{bc}	2.22^b	16.14^b
T3	6.80^a	2.16^b	64.88^c	0.12^a	80.06^b	2.06^b	17.69^a
T4	6.77^a	2.03^b	70.63^b	0.09^a	66.74^c	1.97^c	9.89^c
T5	6.80^a	2.31^b	72.45^b	0.11^a	84.14^a	2.12^b	13.09^{bc}
LSD 0.05	0.06	0.36	5.61	0.04	16.24	0.48	2.26

EC, electrolyte conductivity; WHC, water holding capacity; LSD, least significantly difference. Means followed by the same letters do not significantly differ ($p<0.05$)

comprising T3, T4, and T5, were determined with similar values at approximately 2 dS/m. Furthermore, several other factors of media, including WHC, mass wetness, bulk density, total porosity, and aeration porosity, affecting the growth of seedlings are expressed in Table 4. The WHC, mass wetness, and aeration porosity of T1 obtained significantly higher values in comparison to those of other treatments.

In Table 5, the concentrations of macro-and micronutrients extracted from the media at the nursery stage are summarized. In general, there were considerable differences in the concentration of available macro-and micronutrients, including N, P, K, Ca, Fe, Zn, and Mg. In particular, the level of macronutrients in T1 and T2 could be found to be relatively higher than those of other treatments, whereas the highest micronutrient value was determined in T3. This indicated that different media contained high or low available nutrient elements depending on the composition of growing media.

DISCUSSION

The production of healthy and vigorous tomato seedlings is the major factor in the successful production of tomato fruits (Vivek and Duraisamy 2017). Organic materials dominate soilless cultivation worldwide, these are primarily peat, coir, wood fiber, and composted organic wastes (Barrett et al. 2016). Increasing concerns against the use of peat because it is a non-renewable natural resource and harvesting peat has caused the destruction of endangered wetland ecosystems. In several countries, restrictions have been established for the utilization of this material due to the concerns, therefore, peat has become a rather scarce and expensive substrate (Lazcano et al., 2009; Truong, Wang, and Kien, 2017). Organic materials, such as compost, tree bark, coconut fiber, sugarcane waste, rice husk ash, seaweed, corn cobs, pine tree, peanut hulls, and vermicompost, are already investigated and being used in a commercial way as alternatives to peat.

These materials are plentiful and renewable sources of plant nutrients, including nitrogen (N), phosphorus (P) and potassium (K). Thus, instead of releasing directly animal manure into the environment, it can be recycled to combine with other materials to develop growing media for organic agriculture. This will represent an essential option for both sustainable waste management and sustainable agriculture (Atiyeh et al. 2001; Nartey et al. 2017). Manure compost and vermicompost have been widely studied and applied as they are highly accessible at a low price, and greatly improved most of the characteristics of crop plants and soil nutrients compared with industrialized fertilizer (Wang et al. 2017). Vermicompost is recommended as the best media for enhancing seedling growth (Mathowa et al. 2016).

In particular, in addition to the substrates that have been used frequently, such as peat, compost, vermicompost, coconut fiber, and rice hulls (Lazcano et al. 2009; Atif et al. 2016; Truong, Wang, and Kien 2017; Hai-tao et al. 2018; Delita, Handayani, and Hafid 2022), several other organic byproducts, including date palm wastes, oil palm fruit bunche. Tomato seedlings are cultivated in a limited volume of containers so that materials used in formulations of the growing media significantly affect the physical, chemical, and biological properties of the seeds. Growing media provides physicochemical support, aeration, water, and nutrients to the growth of seedlings. This study evaluated five media mixtures for tomato seedling production, which were combined from rice husk ash, coir, canna residue, and animal manures. The germination index of the experimented media could be explained by the fact that media components have higher water-holding capacities. Growing media influences seed germination, succeeding emergence, and growth of seedlings as it is the reservoir of moisture and nutrients. A study reported that an increase in the number of leaves was linked to the photosynthetic reaction and increased carbohydrates. All the kinds of animal manure had significantly different effects on most of the plant nutrient levels. Concentrations of N, P, K, Fe, and Zn in tomato seedlings in T1 and T2 were higher than those of other treatments. The data agrees with a previous study, which reported that Cassia abbreviata seedling's fresh and dry weights were not significantly affected by growth media (Sekepe, Mathowa, and Mojeremane 2013).

Table 5: Concentration of macro-micronutrients in the experimented media

Treatments	N	P	K	Ca	Mg	Mn	Fe	Zn
	g.kg^{-1} dry weight					mg.kg^{-1} dry weight		
T1	0.12^{b}	4.22^{a}	8.06^{b}	8.25^{b}	1.67^{b}	238.76^{d}	199.87^{b}	55.06^{b}
T2	0.15^{a}	4.41^{a}	12.82^{a}	12.11^{a}	3.11^{a}	470.47^{c}	122.36^{c}	3.25^{d}
T3	0.09^{bc}	0.98^{b}	5.91^{c}	10.07^{ab}	2.99^{ab}	748.3^{b}	287.46^{a}	70.26^{a}
T4	0.06^{c}	0.87^{b}	5.91^{c}	8.22^{b}	0.10^{d}	1142.72^{a}	97.31^{cd}	45.94^{c}
T5	0.11^{b}	0.57^{b}	4.49^{d}	7.12^{c}	0.98^{c}	127.72^{e}	118.17^{c}	44.45^{c}
LSD 0.05	0.02	0.78	1.31	0.86	0.22	14.52	76.12	4.51

LSD, least significantly difference. Means followed by the same letters do not significantly differ (p<0.05)

For many plants, the desired pH range is 5.5–6.5, although each plant shows its optimal pH value (Atiyeh et al. 2001; Truong, Wang, and Kien 2018). The pH value affects the capacity of nutrients to dissolve in water. High EC leads to poor shoot and root growth. Increasing salinity in the rhizosphere inhibits root cell growth and increases root lesion. Tomato plants are moderately sensitive to salinity and the EC threshold of tomatoes is 2.5 dS/m. Water holding capacity is the amount of water held by the substrate of growing media without leaching from the container. The water available for plants is about 60% of the total water holding capacity. Bulk density should not exceed 0.4 g per cm3 for vegetable seedlings. High bulk density holds the disadvantage of increasing the transport cost of the container media. The ideal aeration porosity, defined by the pores in the media, is about 20–25%, and as high as 45% in warmer greenhouse conditions. Total porosity is the accessible free space for water, air, and root growth. It is appropriate when in the range of 50–80% by volume (Pascual et al. 2018).

CONCLUSION

In this study, several agricultural byproducts, including rice husk ash, coir, canna residue, and animal manures, were investigated for their feasibility as growing media constituents for tomato seedlings production. This is the first study to take advantage of canna residue as a material to produce the growing media. The results showed that these components positively affected the seedling quality and growth of tomato plants, compared to the T5. Specifically, among the five experimented formulations, T1 was found to be the most effective treatment for growth of tomato seedlings with appropriate pH, electrical conductivity, and other physicochemical properties. These factors would have positive effects on the germination rate, as well as root growth, and result in increased plant growth. Therefore, the investigated byproducts could be seen as great potential components of growing media in sustainable agriculture. Importantly, incorporating renewable and sustainable organic materials into growing media is a challenge, but it also represents a valuable opportunity. Further research on the innovative approaches in these materials used as growing media components is required.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

Author contributions

Ha Duy Truong and Nguyen The Hung conceptualized the work. Most of the data were acquired by Nguyen Quynh Anh and Le Thanh Ninh and prepared the original draft. Reviewing and editing, supervision, data curation, and making the final draft were by Nguyen Huu Tho. All authors have read and agreed to the submitted version of the manuscript.

Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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