

Original Research

Suitability Analysis of Kitchen Waste Compost for Rice Seedling Substrate Preparation

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Abstract

To investigate the impact of kitchen waste compost on the formulation of rice seedling substrate, this study employed indoor seedling tray nursery methods. Six formulations, incorporating kitchen waste compost, peat, and vermiculite as raw materials, were prepared based on volume-specific gravity. The physicochemical characteristics of each seedling substrate were analyzed to assess their influence on rice seedling growth, considering the cost implications of synthesizing different formulations. The findings revealed a significant alteration in both the physicochemical parameters of the seedling substrate and the growth indexes of rice seedlings as the substitution of peat by kitchen waste compost increased. The formulation denoted as WF1 exhibited physicochemical parameters and growth indexes aligning with all applicable standards. Notably, key physicochemical indicators, including pH, electrical conductivity (EC), unit weight, and aeration porosity, increased gradually with the rising proportion of kitchen waste compost. Conversely, growth indicators such as seedling emergence rate, plant height, and stem thickness exhibited a gradual decline. The concentration of malondialdehyde (MDA) and antioxidant enzyme activities in rice seedling roots indicated that an increased presence of kitchen waste compost imposed significant stress on rice seedling growth. From a formulation cost perspective, integrating kitchen waste compost into the rice seedling substrate effectively reduced costs. The WF1 treatment demonstrated a 9.53% reduction in formulation cost compared to the CK treatment. The optimal formulation, consisting of 10% kitchen waste compost, 40% peat, and 50% vermiculite, was identified as better suited for the growth of rice seedlings, achieving a balance between growth performance and cost efficiency. In conclusion, incorporating kitchen waste compost in rice nursery substrate formulation can yield cost-effective solutions while maintaining acceptable growth parameters for rice seedlings.

Keywords: kitchen waste compost, rice, seedling substrate, cost

Introduction

The swift advancement of China's economy has significantly elevated the material well-being of its populace. However, concomitant with this progress, the environmental challenges stemming from the management of kitchen waste (KW) have become progressively conspicuous [1]. The substantial volume and intricate composition of KW constitute two fundamental aspects, presenting a significant impediment to the scientific categorization of waste and the utilization of organic waste resources [2]. Composting is one of the finest ways to use KW in today's modern environment [3]. Compost derived from kitchen waste, commonly referred to as kitchen waste compost (KWC), has not exhibited significant advantages in the prevailing fertilizer market. This circumstance does not foster a conducive environment for incentivizing the growth of enterprises engaged in kitchen waste composting. Consequently, based on our earlier research, we advocated for the utilization of KWC as a substrate for vegetable cultivation, aiming to promote the integration of KWC into agricultural practices.

The adoption of seedling substrates (SS) has substantially enhanced agricultural production efficiency. Substrate seedling nursery practices have proven to significantly elevate crop seedling emergence rates and overall seedling quality. This, in turn, facilitates early crop harvesting, thereby augmenting the economic benefits derived from agricultural production [4–6]. Nevertheless, a primary focus within the study of SS revolves around determining a rational approach for substituting peat in the formulation of SS [7, 8]. Peat is a nonrenewable resource, and over-exploitation endangers the natural environment's safety [8, 9]. Presently, there is widespread acknowledgment that coir stands out as a renewable energy source with substantial potential for replacing peat. However, the higher cost of coir renders it a less favorable choice for businesses engaged in the production of SS [10]. Numerous experts express concern regarding the identification of an efficient and cost-effective renewable material to substitute for peat in SS [11–14]. After years of research, various composting materials, including animal manure compost and straw compost, have been recognized for their potential to replace a portion of peat in the preparation of SS [15, 16]. We conducted an investigation into the incorporation of pig manure compost and chicken manure compost in rice seedling substrates (RSS). Our findings indicated that optimal seedling effects were achieved when replacing peat with chicken manure compost at 20% and pig manure compost at 40%. However, there is limited information on the application of KWC in RSS.

Therefore, this experiment was initiated to examine the impact of substituting peat with KWC in RSS. The investigation was carried out using an indoor seedling tray nursery, implementing a replacement gradient of 20% volumetric specific gravity. The objective of this

study is to develop a suitable SS formula, providing a new theoretical foundation to promote rice production and the resource utilization of KW.

Experimental

Materials

The experiment was conducted at the Centre for Artificial Climate and Plant Culture, Institute of Organic Cycling (Suzhou), China Agricultural University. Rice, specifically the NJ 46 variety, was selected as the test crop. The KWC used in the experiment (priced at RMB 0.11/L) was obtained through aerobic fermentation of KW collected from the Huan-Taihu Lake area at the Huan-Taihu Lake Organic Waste Treatment and Utilization Demonstration Centre. The test chicken manure compost (priced at RMB 0.60/L), pig manure compost (priced at RMB 0.35/L), and peat (priced at RMB 0.25/L) were purchased from Greensource Meijia Agricultural Technology Co. Vermiculite used in the experiment (priced at 0.16 RMB/L) was provided by the College of Resources and Environment, China Agricultural University. All substrates were prepared using fresh raw ingredients. Key physical and chemical features of the raw materials are detailed in Table 1.

Methods

Experiment Design

The experiment comprised a total of 8 treatments, each replicated three times. The volume specific gravity of substrate materials corresponding to each treatment is provided in Table 2.

SS Preparation

Following the design outlined in Table 2 for each treatment, air-dried SS raw materials were accurately proportioned and thoroughly mixed in 60 cm × 48 cm × 20 cm plastic pots. Subsequently, samples weighing 500 g were collected from each treatment for testing.

Seeding and Management

The seedling substrates (SS) from each treatment were transferred to rice seedling trays measuring 30 cm × 10 cm × 1 cm. In each tray, 50 pre-soaked and germinated rice seeds were carefully sown, maintaining a distance of 0.2 cm from the substrate surface. Subsequently, the seedling trays were placed in an artificial climate chamber and incubated under conditions of 28°C temperature and 80% humidity for a period of 14 days. Throughout the experimental duration, each treatment received uniform watering, with 1,000 mL of water administered per seedling tray. Additionally, 500 mL of water was replenished every 2 days.

Table 1. Basic physical and chemical properties of the test material.

Indices	Peat	Vermiculite	Chicken manure composting	Pig manure compost	Kitchen waste compost
pH	4.58	6.66	7.01	7.04	8.85
EC/(mS·cm ⁻¹)	0.49	0.13	3.72	4.84	5.12
Bulk density /(g·cm ⁻³)	0.27	0.12	0.34	0.30	0.49
Aeration porosity/%	16.72	22.44	18.76	19.95	26.12
Organic matter/%	36.69	0.07	25.60	21.13	59.44
Total N/%	1.24	0.00	3.07	2.45	2.76
Total P/%	0.79	0.00	1.17	1.09	0.98
Total K/%	0.87	0.00	2.14	1.78	0.40

Table 2. Volume specific gravity of substrate materials corresponding to each treatment.

Treatment	Chicken manure compost	Pig manure compost	KWC	Peat	Vermiculite	Percentage of peat replaced
CK	0	0	0	50	50	0
CF	10	0	0	40	50	20
PF	0	20	0	30	50	40
WF1	0	0	10	40	50	20
WF2	0	0	20	30	50	40
WF3	0	0	30	20	50	60
WF4	0	0	40	10	50	80
WF5	0	0	50	0	50	100

Indicators and Methods

Physicochemical Properties

Referring to the agricultural industry standard “NY/T 2118-2012” for determining sample substrate unit weight and aeration porosity, the procedure involves employing a ring knife with a bottom cover of 200 mL volume. The determination process is outlined as follows:

1. Weigh the ring knife and record the weight as M₀.
2. Load fresh substrate samples uniformly into the ring knife, weigh the ring knife and the substrate together, and record the weight as M₁.
3. For air-dried substrate samples in a compact state, load them into the ring cutter and secure with a perforated lid. Subsequently, soak the assembly in water for 24 hours and weigh it as M₂.
4. Place the ring cutter on a funnel lined with filter paper, allow it to drain naturally for 3 hours, and weigh it as M₃.

The calculation formula for determining the unit weight and aeration porosity index is as follows:

$$\text{Unit capacity } (\gamma) = (M_1 - M_0) / 200$$

$$\text{Aeration porosity (AP)} = (M_2 - M_3) / 200$$

The pH and EC values, as well as the concentrations of alkaline dissolved nitrogen, effective phosphorus, quick-acting potassium, and organic matter in the sample substrates, were determined following the methodology outlined by Liu et al. [2]

Growth Indicators

Five days post-sowing, the count of emerged rice seedlings was recorded, and the seedling emergence rate was subsequently calculated. After fourteen days, 15 seedlings were randomly selected from each seedling tray, and their plant heights and stem thicknesses were measured using a straightedge and a vernier caliper, respectively. The above- and below-ground fresh weights of rice seedlings from each treatment were measured using an electronic balance. Following the enzyme deactivation at 90°C and the drying of seedlings to a constant weight at 60°C, the corresponding dry weight was calculated, and the seedling growth index was computed. The seedling growth index was determined using the following formula:

$$\text{Seedling growth index} = \left(\frac{\text{Stem thickness}}{\text{Plant height}} + \frac{A}{B} \right) \times (A + B)$$

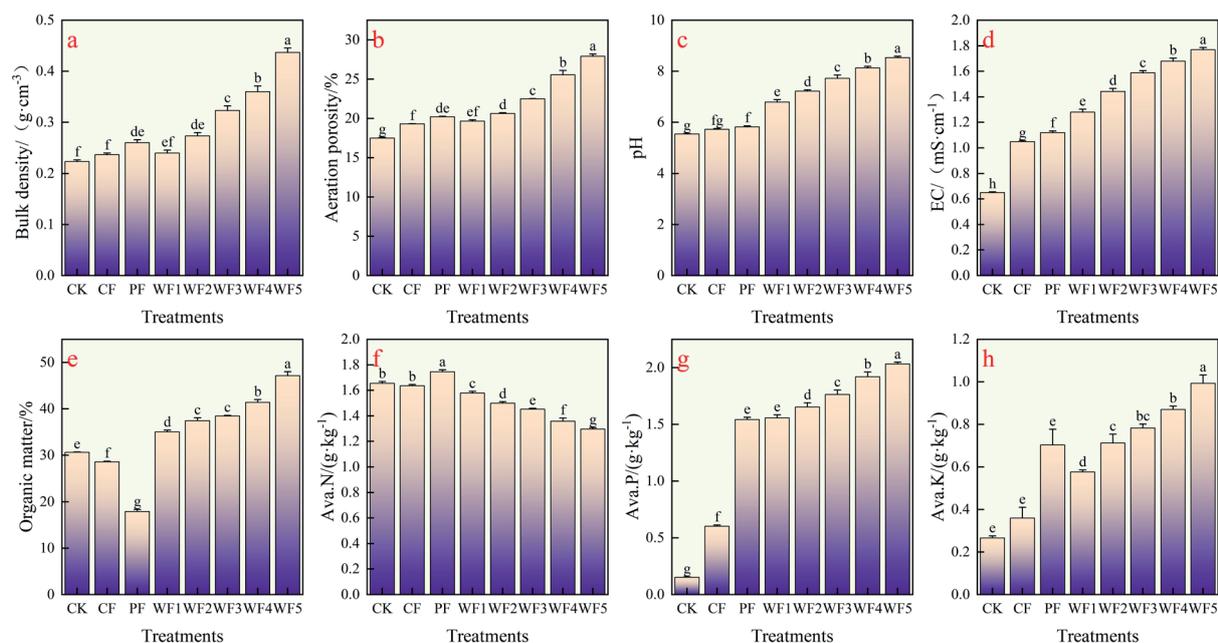


Fig 1. Physicochemical properties of RSS in different treatments. Note: Different lowercase letters represent significant differences $p < 0.05$. Same below.

Where, *A* represents dry weight below ground and *B* represents dry weight above ground.

Seedling Root Biochemical Indicators

On the 14th day post-sowing, root biochemical indexes were assessed for 15 randomly selected seedlings from each seedling tray. Malondialdehyde (MDA) content was determined using the thiobarbituric acid method, peroxidase (POD) activity was measured through the guaiacol method, catalase (CAT) activity was assessed via the spectrophotometric method, and superoxide dismutase (SOD) activity was determined using the nitrogen blue tetrazolium photochemical reduction method in the root system of rice seedlings.

Data Statistics and Analysis

Using DPS 18.1 software [17], the trial's raw data were submitted to one-way ANOVA after being tallied using Excel 2019. The images were drawn with Origin pro-2021.

Results

Physicochemical Properties

The physicochemical characteristics of RSS exhibit discernible alterations, as illustrated in Fig. 1, irrespective of the type of organic fertilizer used to substitute for peat. In adherence to the principle of local adaptation, this study was conducted in accordance with agricultural local standards in Suzhou City,

specifically following the “DB3205/T 212-2014 Rice Factory Substrate Seedling Transplanting Technical Regulations.” The technical indicators specified in this regulation were employed to compare the physicochemical properties of various RSS. Although the current RSS lacks specific agricultural industry standards, the study adhered to the criteria outlined in DB3205/T 212-2014. According to this standard, the physicochemical properties of RSS must meet the following specifications: bulk density of 0.10 g/cm³, aeration porosity of 40%, pH of 6.5, EC value of 1.3 mS/cm, and organic matter content of 15%. Regarding bulk density, aeration porosity, EC value, and organic matter content, all treatments were found to be in compliance with the stipulated standard requirements. However, the pH values of CK, CF, and PF deviated from the permitted range defined by the standard. Previous research has indicated that maintaining a pH value within the range of 5.5-6.5 creates a more favorable acid-base environment for the optimal growth of rice seedlings [18]. The pH, bulk density, aeration porosity, EC value, and organic matter content of RSS exhibited a more noticeable increasing trend as the percentage of organic fertilizer replacing peat increased. Notably, when KWC replaced peat at a 60% level, the pH of RSS reached 7.73, surpassing the standards outlined in DB3205/T 212-2014. Similarly, the EC value of RSS measured 1.44 mS/cm when the replacement rate of peat by KWC reached 40%, exceeding the requirements stipulated in DB3205/T 212-2014. While DB3205/T 212-2014 lacks detailed regulations on the nutrient index of RSS, Fig. 1 provides valuable insights. It is evident that as the amount of peat replaced by KWC increases, the organic matter, available potassium (Ava.K),

Table 3. Seedling growth indicators of different rice nursery substrates.

Treatments	Seedling rate/%	Height/cm	Stem thickness/mm	Fresh weight above ground/mg	Fresh weight below ground/mg	Dry weight above ground/mg	Dry weight below ground/mg	Seedling growth index
CK	100.00±0.00a	13.47±0.18ab	0.65±0.03a	51.52±3.62ab	104.33±2.03b	20.73±0.15a	4.50±0.17cd	6.69±0.30bc
CF	96.67±3.33a	14.27±0.67a	0.67±0.05a	53.56±3.78ab	126.60±3.75a	21.17±0.17a	5.10±0.06b	7.56±0.15b
PF	100.00±0.00a	13.20±0.53b	0.68±0.01a	59.66±5.16a	129.00±5.51a	22.33±0.18a	5.60±0.12a	8.45±0.23a
WF1	96.67±3.33a	12.20±0.15c	0.69±0.01a	48.56±3.44b	130.15±2.65a	21.43±0.18a	5.87±0.18a	9.02±0.27a
WF2	96.67±3.33a	10.46±0.12d	0.68±0.02a	37.15±3.23c	110.24±2.89b	17.73±0.24b	4.67±0.18cd	7.35±0.33bc
WF3	93.33±3.33a	9.37±0.15e	0.62±0.03a	34.35±0.44c	86.67±3.33c	15.90±0.17c	4.10±0.06d	6.49±0.07c
WF4	63.33±3.33b	7.50±0.12f	0.57±0.03ab	27.24±3.82c	76.67±3.33cd	14.23±0.09d	3.13±0.20e	5.14±0.35d
WF5	53.33±3.33c	5.50±0.17g	0.47±0.09b	27.44±0.39c	66.09±1.53d	12.17±0.12e	2.50±0.12f	4.27±0.42e

Note: Different lower case letters in the same column represent significant differences, $p < 0.05$.

and available phosphorus (Ava.P) content in the various treatments exhibit a substantial rise. Notably, the Ava.P content in the WF1 treatment is significantly higher than that in CK, CF, and PF.

Growth Indicators

As depicted in Table 3, a significant reduction in the emergence rate of rice seedlings was observed when the substitution of peat by KWC reached 80%. The introduction of KWC had a notable adverse impact on the height of rice seedlings. Specifically, at a 20% replacement rate of KWC for peat, the seedling height decreased by 9.43% compared to that of CK, and a consistent reduction trend in seedling height was evident with increasing KWC substitution. According to the guidelines in DB3205/T 212-2014, seedlings should achieve a height of 12 cm to 17 cm after 12-14 days, and the seedling emergence rate should not fall below 85%. It is evident that substituting 20% of peat with KWC is sufficient to meet these standard requirements.

With the exception of WF5, none of the treatments displayed significant variations in seedling stem thickness. In terms of biomass, both the fresh and dry weights of rice seedlings above and below the ground decreased significantly with an increasing replacement of KWC. The below-ground biomass of seedlings with 20% peat replaced by KWC exhibited a significant increase compared to CK, akin to the performance of CF and PF. Regarding above-ground biomass, WF1 did not show a promotional effect relative to CK, unlike CF and PF.

The comprehensive evaluation of the seedling growth index for various RSS treatments revealed that PF and WF1 performed the best. The seedling growth index of WF1 increased by 34.83% compared to CK. However, a significant decreasing trend in the seedling growth index was observed as the amount of KWC substitution increased.

Seedling Root Biochemical Indicators

The incorporation of organic fertilizers, especially KWC, led to a notable elevation in the EC value of RSS. This increase, particularly in the case of KWC, can have detrimental effects on plant seedling growth due to the elevated salt content in the raw material. The assessment of biochemical indicators in the root system of rice seedlings demonstrated a significant rise in the MDA content as the proportion of KWC increased. This indicates that the addition of KWC induced damage to membrane lipids in the root system of seedlings compared to other treatments.

To mitigate the stressors associated with the addition of organic fertilizer, there was a significant increase in rice root CAT activity, POD activity, and SOD activity. Notably, as the amount of KWC increased, CAT activity and SOD activity exhibited a significant rise. In the case of 100% KWC replacing peat, CAT, POD, and SOD

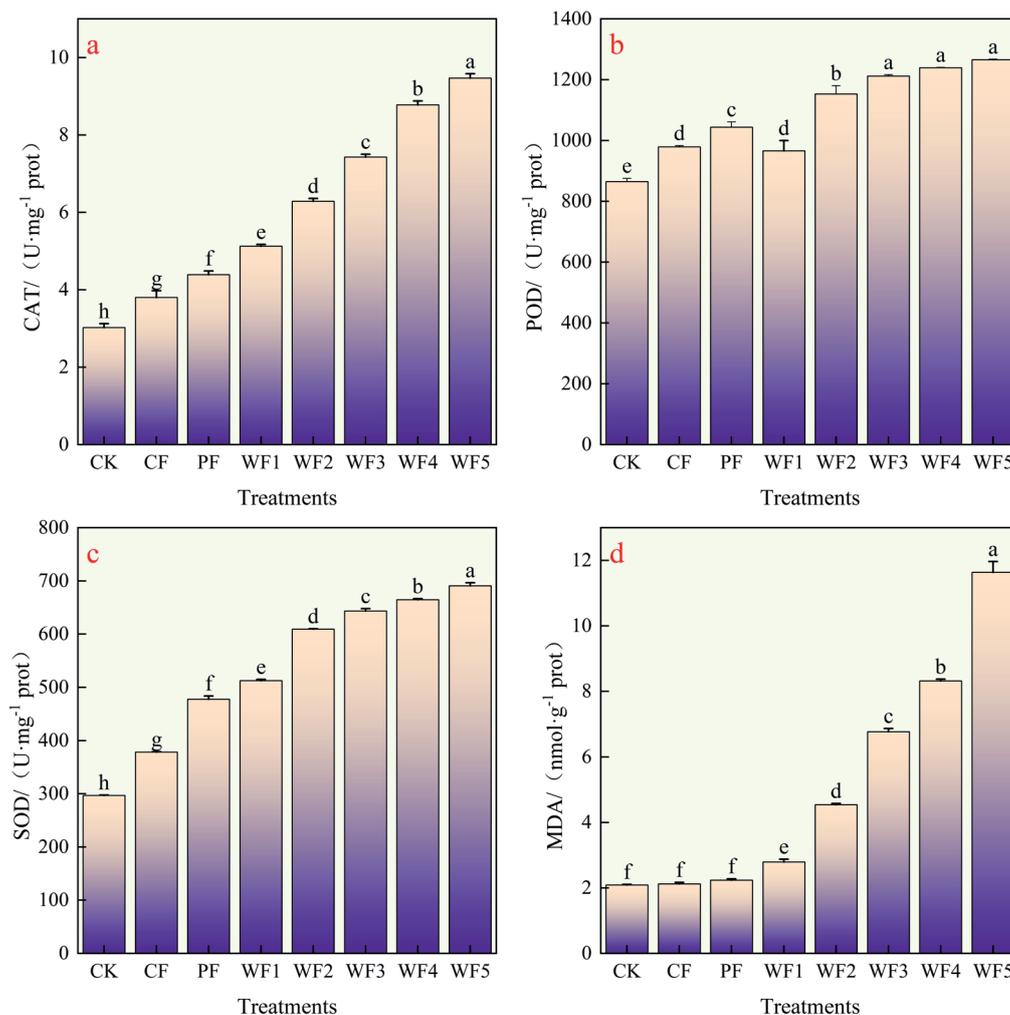


Fig. 2. Biochemical indices of rice root system in different SS.

Table 4. Cost of formulating different rice nursery substrates.

Treatments	Cost (yuan/L)
CK	0.21
CF	0.24
PF	0.25
WF1	0.19
WF2	0.18
WF3	0.16
WF4	0.15
WF5	0.14

activity increased by 213.23%, 46.37%, and 132.77%, respectively, compared to CK. Relative to CF and PF, the incorporation of KWC led to more pronounced membrane lipid peroxidation and greater antioxidant enzyme activity in the root system of rice seedlings in response to growth stress.

Cost Analyses

The formulation cost is intricately tied to the producer's selection of raw materials, thereby influencing the product's competitiveness in the market. As depicted in Table 4, the formulation cost of the required RSS steadily decreases as peat is progressively replaced by KWC. For instance, when KWC substitutes 20% of the peat, the formulation cost is RMB 0.19/L, representing a 9.53% reduction compared to CK. Conversely, when pig manure compost replaces 40% of the peat in RSS formulation, the cost is 31.58% higher than WF1 and 19.05% more than CK, while the formulation cost with chicken manure compost remains comparable. From a cost perspective, substituting peat with KWC proves more favorable for RSS producers compared to pig manure compost and chicken manure compost.

Discussion

One of the prevailing challenges in current SS research is the reduction of peat consumption.

A statistical analysis of 142 patented SS compositions revealed that prominent alternatives to peat include animal manure compost, mushroom residue, and coconut husk [19]. While considering alternatives, it is crucial to acknowledge the ongoing use of peat in nursery soils at the market level. Additionally, the increasing use of black soil for SS production in Northeast China has raised concerns about its impact on the regional food production chain [20]. This dilemma underscores the urgency for researchers to identify marketable alternatives to peat. In this study, we replaced peat in RSS with KWC, and the results indicated that the combination of “10% chicken manure compost + 40% peat + 50% vermiculite” and “20% pig manure compost + 30% peat + 50% vermiculite,” previously identified for better seedling effects, served as the control.

The incorporation of chicken manure compost, pig manure compost, and KWC as peat substitutes induced significant changes in the physicochemical parameters of RSS. This is attributed to the inherent differences in the physicochemical properties of peat and the three organic fertilizers. Notably, KWC exhibited pH and EC levels 93.23% and 944.89% higher than peat, respectively, with pH and EC being critical factors affecting substrate environment and seedling growth. A prior study on vegetable seedling substrates revealed that the addition of sulfur could effectively lower substrate pH, positively impacting crop growth indexes. Whether this method is suitable for RSS warrants further investigation.

In terms of seedling growth index, the maximum was reported in all treatments with 20% replacement of peat by KWC. The growth indices of rice seedlings showed a consistent decline as the proportion of KWC increased, a trend corroborated by biochemical indicators in the root system. KWC cannot fully replace peat, and the recommended replacement proportion, similar to chicken manure compost, is 20%, substantially lower than the 40% recommended for pig manure compost. The composition of kitchen waste compost is more complex and variable than that of chicken or pig manure compost, influenced by factors such as geographical location, seasons, food cultures, and socio-environmental conditions [21]. The use of fermented KWC from the Taihu Lake region in this study emphasizes the importance of standardized and industrialized processes. While other studies have employed KWC from different sources, the variability in composition highlights the challenges in establishing generalized applications for small-scale household compost in large-scale agricultural production.

The study introduces a novel perspective by examining the cost of RSS formulation. Notably, KWC emerges as the most cost-effective material among the five studied, with a cost price of RMB 0.11/L, significantly lower (56.00%, 81.67%, and 68.57%) than peat, chicken manure compost, and pig manure compost,

respectively. The cost analysis demonstrates that RSS incorporating KWC are economically advantageous. Among the treatments, WF1, with a preparation cost of 0.19 RMB/L, stands out as the most effective and cost-efficient, being 9.53% less than CK. This underscores the dual benefits of substituting 20% volume-specific gravity peat with KWC – improving rice seedling impact and reducing substrate preparation costs.

Conclusions

In conclusion, the physicochemical properties of the seedling substrate formulated with “10% kitchen waste compost + 40% peat + 50% vermiculite” demonstrated superior suitability for rice seedling growth compared to other treatments in this experiment. This formulation not only exhibited enhanced seedling performance but also contributed to a notable reduction in the overall formulation cost of the rice seedling substrate.

The comprehensive evaluation of various treatments highlighted the distinctive advantages of the “10% kitchen waste compost + 40% peat + 50% vermiculite” formulation. The optimized combination of these components proved to be the most effective in promoting favorable conditions for rice seedling development. This conclusion is reinforced by the observed benefits in seedling growth indices, physicochemical parameters, and cost efficiency.

Therefore, based on the findings of this study, it can be unequivocally stated that the fundamental formulation for the creation of rice seedling substrate with optimal characteristics is “10% kitchen waste compost + 40% peat + 50% vermiculite.” This formulation not only aligns with the specific requirements for promoting rice seedling growth but also offers a cost-effective solution for rice nursery substrate production. The implications of this research extend to both academia and industry, providing a valuable contribution to the ongoing efforts to optimize seedling substrate formulations for sustainable and efficient agricultural practices.

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Conflict of Interest

The authors declare no conflict of interest.

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