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EFFECTS OF PRESS-FORMED CROP RESIDUE RICE SEEDLING TRAY ON THE PHYSIOLOGICAL CHARACTERISTICS OF MACHINE-TRANSPLANTED RICE SEEDLINGS

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Abstract

This study aims to analyze the intrinsic relationship between substrate type and the physiological characteristics of seedlings. It also aims to evaluate the applicability and universality of seedling substrates. Natural soil (CK) and a commercial mixed substrate (T1) were used as controls, while bulk straw substrate (T2) and straw seedling board substrate (T3) were taken as research objects. The effects of straw seedling substrate, specifically plate straw seedlings without a plastic plate, on the growth characteristics and seedling quality of rice seedlings were studied. Results showed that the bulk densities of the T2 and T3 were significantly lower than those of the control by 74.11% and 59.82%, respectively ($p<0.05$). Aeration pores, water holding pores, and nutrient contents were significantly higher in the test groups than in the controls ($p<0.05$), and the raising process was simple. The growth characteristics of seedlings and roots grown in T2 and T3 were significantly better than those of the control treatment ($p<0.05$). Roots were agglomerated and the leaf age, plant height, amount of dry matter in the above-ground parts, and stem base width of the test groups were significantly higher in the test groups than in the control treatment. The physiological indicators of the seedlings suggested that the respective SOD and POD contents of seedlings raised in T3 were 40.80% and 16.76% higher than those of seedlings raised in T1. However, the MDA content of this group was lower than that of the control, which indicates that T3 improves the stress resistance of rice. The binding ability and contents of total nitrogen, soluble sugar, starch, and chlorophyll of the T3 and T2 were higher than those of CK and T1. The findings suggest that seedlings raised in the straw seedling substrates have strong growth potential, which is conducive to their growth in the field after machine transplantation, and lays a solid foundation for research on high-yield agriculture.

Key words: Straw substrate; Rice; Seedling raising; Physiological characteristics.

Introduction

The rice transplanting technology in China has been studied for over 50 years (Qian *et al.*, 2009). In 1995, the area for rice transplanting in the entire country accounted for only 2.3% of the total rice planting area; currently, the former accounts for approximately 38.0% of the latter (Liu *et al.*, 2015). Rice transplantation requires nutrient-rich soil, which means a large amount of soil is utilized every year. This practice has seriously damaged the characteristics of farmland soil. In addition, rice transplantation requires intensive labor to manufacture, transport, and store the seedling bed soil every year, and fertilization of the bed soil is often non-uniform. The quality of soil nutrients cannot be guaranteed, and low levels of nutrients may affect the yield of machine-transplanted rice. Given the continuous expansion of the rice planting area, commercialized unified breeding and unified machine insertion are expected become inevitable trends in rice production. However, the preparation of healthy soil has become a major obstacle in promoting rice transplantation in large areas. Utilizing natural resources and industrial and agricultural waste to develop rice seedling substrates has become a research hotspot in attempts to solve problems associated with rice transplantation, including difficulty in nutrient soil unloading and damage to the surrounding vegetation and environment.

Agricultural waste resources are abundant in China. The annual crop straw yield of the country can exceed 1.04 billion tons a year. According to data from the Ministry of Agriculture, the comprehensive utilization rate of this resource is only 80%, which means 200 million tons of straw is discarded or burned annually, causing serious resource wastage and environmental pollution. Using organic waste to develop seedling substrates can replace the need for common soil in large-scale industrial rice raising. Through this approach, the difficulty of soil unloading is relieved, and issues related to resource wastage and environmental pollution are resolved. Such initiatives have important economic and ecological benefits.

Research on rice seedling substrates mainly focuses on the production of seedling substrates by industrial and agricultural wastes, such as edible fungus residue, carbonized chaff, peat, and organic fertilizers (Lu *et al.*, 2012; Lian *et al.*, 2013; Sui *et al.*, 2014; Heng *et al.*, 2014). The positive effect of rice seedling substrate on seedling quality has been reported. However, seedling substrates, whether soil or other media, continue to require the use of plastic seedling baseplates. Every year, billions of plastic seedling baseplates are utilized, and this practice has brought about adverse impacts to the environment. To eliminate the use of plastic trays, in this work, our research group developed and produced a straw-pressed seedling tray. This study uses straw-pressed seedling trays developed by our research group as the research object and natural soil (CK) and commercial mixed substrate (T1) seedlings as controls. This study aims to analyze the effects of straw-pressed seedling trays on the physiological characteristics and quality of rice seedlings and investigates the intrinsic relationship between the characteristics of pressed-formed seedling trays and seedlings. Furthermore, the applicability and universality of the proposed straw-pressed seedling trays are evaluated. Results will provide a reference for promoting and applying straw rice seedling trays and improving the level of mechanization of rice planting.

Materials and Methods

Experimental sites and materials: An experiment on substrate seedling raising was conducted at the plantation of Anhui Science and Technology University (N32°52′38″, E117°31′35″) from May 2018 to June 2018. The tested rice was Quan 9 You 063, a hybrid rice variety considered suitable for planting in Anhui, Henan, Jiangsu, and Zhejiang.

Experimental design: Based on the type of rice seedlings in China, four rice seedling media were set up, namely, CK, T1, bulk straw substrate (T2), and straw seedling board (T3). CK was taken from the plough layer (0–20 cm) at the base of Anhui Science and Technology University. After air-drying and grinding, the soil was passed through a 5 mm sieve. T1included grass charcoal, perlite, and vermiculite, among others, all of which were purchased from Bengbu Zhonglin Biological Products Co., Ltd. The straw rice bulk seedling substrate and straw-pressed seedling trays were developed and produced by our team.

The substrate raising experiment was carried out on May 12, 2018. CK, T1, and T2 were raised on hard plastic seedling trays (size: 58 cm × 28 cm × 3 cm). T3 was placed directly on the plastic sheet, and the straw-pressed seedling boards measured 58 cm × 28 cm × 1.5 cm. Each treatment consisted of six plates and three replicates. The substrate thickness of the seedling tray was 2.5 cm. Approximately 96.1 ± 2.1 g (75 g of dry rice) of bud seeds were sown in each plate. Before sowing, the rice seeds were soaked in carbendazim for 2 d, germinated for 4 h at 38°C, and then germinated for 24 h at 35°C. After germination, the seeds were dried, weighed, and sown.

Measurement items and methods

Physical and chemical properties of substrate: The pH of the substrate was determined by a METTLER SG8 portable pH meter. Conventional methods were used to determine the water content, bulk density, total porosity, venting pores, water holding pores, and void ratio. Organic matter, total nitrogen, available nitrogen, available phosphorus, and available potassium were determined according to conventional methods (Guo, 2003).

Physiological characteristics of seedlings: Three representative seedlings were selected 4, 8, 12, 16, and 20 d after sowing, and 10 representative seedlings were taken from each plate. Seedling age, plant height, root length, root number, and stem base width (1 cm from the rooting location of seedlings) were determined. Another 100 seedlings were taken from each plate to determine the dry mass of the above-ground parts, root mass, and root–shoot ratio. To obtain above-ground and root masses, the dry and root masses of 100 seedlings were summed. These masses refer to the constant weights of above-ground parts and roots after being placed in an oven at 105°C for 30 min then drying to a constant mass at 80°C. That is, root–shoot ratio = amount of dry matter in the underground parts of the seedlings / amount of dry matter in the above-ground parts of the seedlings. Chlorophyll, malondialdehyde (MDA), SOD, and POD contents were determined at 20 d. Chlorophyll content was determined by spectrophotometry. MDA content and SOD and POD activities were determined according to the method of Li Hesheng (Song, 2014). The nitrogen content of the plants was determined by the Kjeldahl method.

Binding and rooting ability of roots: After 20 d, a representative 20 cm × 20 cm seedling block was cut and fixed at both ends. A spring scale hook was used to pull any part of the seedling block. The maximum value displayed by the spring scale at the point when the block breaks was considered the binding force of the roots. Each treatment was repeated six times. At 20 d, 20 seedlings with uniform growth were selected for each treatment. Roots were cut off and placed in a hydroponic box. After 7 d, new roots (≥5 mm) and root length were counted.

Data processing: Data processing was performed by Excel 2010, and SPSS 12.0.1 (SPSS Inc.) was used for statistical analysis. Duncan’s new multiple range method (LSR) was used to test for significant differences between treatments. The significance level was set as $\alpha = 0.05$.

Results and Analysis

Physical and chemical characteristics of the seedling raising substrate

Physical properties of different types of substrates: The physical properties of the substrate determine its water holding capacity and aeration performance and influence its nutrient conversion ability. The physical properties of the four substrates were significantly different (Table 1). T2 and T3, T1, and CK are substrates with low, medium, and high bulk density, respectively. The bulk densities of the T2 and T3 were 74.11% and 59.82% lower than that of the control, respectively. A suitable substrate bulk density is not only conducive to the growth of the above-ground parts and roots but also provides ease of operation and transportation. The water content of T1 was much higher than those of the CK, T2, and T3, and the latter two showed little difference. The pore distribution of the substrate is essential for water retention and movement as well as water uptake of the rice. The total porosity and water holding porosity of T2 and T3 were significantly higher than those of T1 and CK. Aeration pores of T2 and T3 were significantly larger than those of CK and slightly smaller than those of T1. The void ratios of T2 and T3 were close to that of CK but significantly smaller than that of T1, which indicates that the former have better water holding capacity than the latter. The aeration performance of T2 and T3 was better than that of CK and slightly weaker than that of T1.

Chemical properties of different types of substrates: The pH of CK, T1, T2, and T3 ranged from 5.0 to 7.0, which meets the slightly acidic environment necessary for rice growth (Table 2). The content of organic matter is closely related to the level of substrate fertility and can promote the growth of rice seedlings and root development. The organic matter content of the four substrates decreased in the following order: T3> T2 > T1 > CK. The respective organic matter contents of the T3, T2, and T1 were 12.60, 12.45, and 7.72 times greater than that of the control. Nitrogen is an important nutrient elements for rice growth. In this study, the nitrogen contents of the T3, T2, and T1 were significantly higher than that of CK by 477.65%, 239.77%, and 250.38%, respectively. These results reveal that the three substrates could meet the growth demand of rice seedlings without requiring as much additional nitrogen as CK. The contents of available phosphorus and available potassium in T3, T2, and T1 were significantly higher than those of CK. Therefore, the substrates could satisfy the nutrient requirements of seedlings and reduce the management process required during substrate raising.

Growth characteristics of above-ground parts of rice seedlings

Effects of different types of substrates on leaf age of rice seedlings: The physiological characteristics of the above-ground parts of seedlings play an important role in returning green seedlings after machine transplanting and machine transplanting in the field. Dynamic changes in the leaf numbers seedlings of the four breeding media were similar. From the emergence of the seedlings to the age of 12 d, the leaf age of the rice showed a linear growth trend. After 12 d, the leaf age of rice slowly increased and tended to be stable when limited by factors such as plate space and substrate nutrients (Fig. 1a). After 16 d in the straw substrates, the leaf age of seedlings continued to increase markedly. The leaf ages of seedlings in the T2 and T3 were significantly higher than those of CK and T1 ($p<0.05$). This finding may be related to the high content of organic matter and available nutrients in the soilless straw substrate. Although the leaf age of seedlings in the mixed substrate increased greatly at 8–12 d, it increased slowly after 16 d and was not significantly different from that of the control.

Effects of different types of substrates on plant height of rice seedlings: A suitable seedling height for late rice transplantation is 12–20 cm. Rice seedlings shorter or higher than this range can affect the quality of machine transplanting. Similar to the growth trend of rice leaf age, the plant height of seedlings in the four seedling media also initially increased rapidly and then decreased slowly (Fig. 1b). Before 12 d, the plant height of different treatments showed a linear growth trend. The plant height of rice seedlings cultivated in the straw substrates was significantly higher than that of seedlings cultivated in T1 and CK ($p<0.05$). After 12 d, the plant height of the seedlings in the straw substrates showed a steady growth trend. The plant height of the seedlings in T1and CK demonstrated a certain growth rate. After 20 d, the plant heights of the seedlings in the straw and mixed substrates were significantly higher than that of seedlings planted in CK ($p<0.05$).

Effects of different types of substrates on stem base width and amount of dry matter in the above-ground parts of rice seedlings. The amount of dry matter in above-ground parts and the stem base width of rice seedlings can reflect the degree of seedling robustness. Thick seedlings can improve the quality of machine transplanting and reduce the time needed by seedlings to turn green after exposure to a field environment. The amount of dry matter of above-ground rice seedlings in all four treatment groups increased rapidly at early stages and then slowly increased. The overall trend observed was similar to those of leaf age and plant height (Fig. 1c). The amount of dry matter in above-ground seedlings raised in the T2 and T3 before 16 d was significantly higher than those of seedlings planted in the T1 and CK ($p<0.05$). No significant difference was observed in the amount of dry matter of the above-ground seedlings raised in the two straw substrates and T1 after 20 d. Furthermore, no significant difference was observed in the amount of dry matter of above-ground seedlings in T1 and CK before 8 d. However, within 8–20 d, the amount of dry matter of above-ground seedlings in T1 showed a rapid growth trend. By 20 d, growth in T1was significantly higher than that in CK ($p<0.05$). The stem base width of seedlings grown in T2 and T3 was significantly higher than that of seedlings in CK ($p<0.05$) after 20 d, as shown in Fig. 1d. The stem base width of seedlings in T1 was slightly lower than that of seedlings in CK at 12 d. However, the stem base width of T1 increased rapidly after 12 d and was higher than that of CK at 20 d. The leaf age, plant height, amount of dry matter of the above-ground parts, and stem base width of seedlings in T2, T3, and T1 were higher than those of seedlings in CK. Furthermore, the growth characteristics of seedlings raised in the light soilless substrate were better than those of seedlings treated with T1.

Growth characteristics of roots of rice seedlings

Effects of different types of substrates on root growth of rice seedlings: Rice roots are not only the main organs for water and nutrient absorption but also important sites for the synthesis of various hormones, organic acids, and amino acids. The morphological and physiological characteristics of roots are closely related to the growth and development of above-ground parts of rice and have a great impact on seedling rooting and the quality of machine transplanting in the field. Root length, root number, and amount of dry matter in the roots of rice seedlings increased rapidly in all treatment groups at the early stages and then slowly increased at later stages (Fig. 2).

The roots of seedlings cultured in T1maintained a relatively fast growth rate that was significantly higher than that of roots in the control treatment ($p<0.05$). The roots of the seedlings cultured in the T2and T3 grew slowly at 0–8 d; in fact, the growth of roots in these treatments was even slower than that in the control treatment. After 8 d, the roots of these seedlings grew faster than those in the control. On the 20th day, root length in the T2 and T3 was significantly higher than that in the control treatment ($p<0.05$) and slightly higher than that in T1. The root number of seedlings treated with T1 increased rapidly within 0–8 d and was significantly higher than that of CK ($p<0.05$). The root numbers of the seedlings in T2 and T3 were lower than that of seedlings in T1 before 4 d. However, no significant difference was observed among the three groups after 12 d. Furthermore, no significant difference was observed in the amount of dry matter in roots among the treatments. The results show that the substrate type has little effect on the amount of dry matter in the root system of seedlings. Binding ability and root robustness are mainly affected by root length and number of roots. While the growth of seedlings in the early stages was strong, it eventually slowed down due to the limitations of growth space and nutrient supply potential. However, the growth characteristics of the roots in T2 and T3 were better than those of roots in the control.

Table 1. Physical properties of substrate raising rice seedlings.

Treatment	Bulk density/ (g.cm-1)	Water content (%)	Total porosity/ %	Aeration porosity %	Water-holding porosity %
Soil (CK)	1.12 ± 0.03 a	4.63 ± 0.12 d	54.67 ± 0.42 d	4.21 ± 0.45 d	50.32 ± 0.17 d
Mixed substrate	0.34 ± 0.02 c	44.47 ± 1.24 a	72.34 ± 0.23 c	6.21 ± 0.29 b	58.36 ± 0.23 c
Crop residue substrate	0.29 ± 0.01 d	9.87 ± 0.19 b	84.45 ± 0.45 a	7.91 ± 0.95 a	74.54 ± 0.51 b
Crop residue substrate board	0.45 ± 0.03 b	7.28 ± 0.09 c	78.21 ± 0.76 b	5.91 ± 0.25 c	79.87 ± 0.66 a

Table 2. Chemical properties of substrate raising rice seedlings.

Treatment	pH value	Organic matter %	Total N/ (g.kg-1)	Available P/ (mg.kg-1)	Available K/ (mg.kg-1)
Soil (CK)	5.82 ± 0.07	6.12 ± 0.13	2.64 ± 0.87	21.02 ± 1.28	134.23 ± 10.21
Mixed substrate	5.98 ± 0.06	47.23 ± 1.23	15.25 ± 1.54	723.09 ± 23.21	1625.39 ± 92.98
Crop residue substrate	6.42 ± 0.03	76.21 ± 2.12	8.97 ± 0.68	783.22 ± 34.67	2219.78 ± 72.78
Crop residue substrate board	6.72 ± 0.02	77.09 ± 1.92	9.25 ± 0.36	786.93 ± 42.45	2109.23 ± 109.21

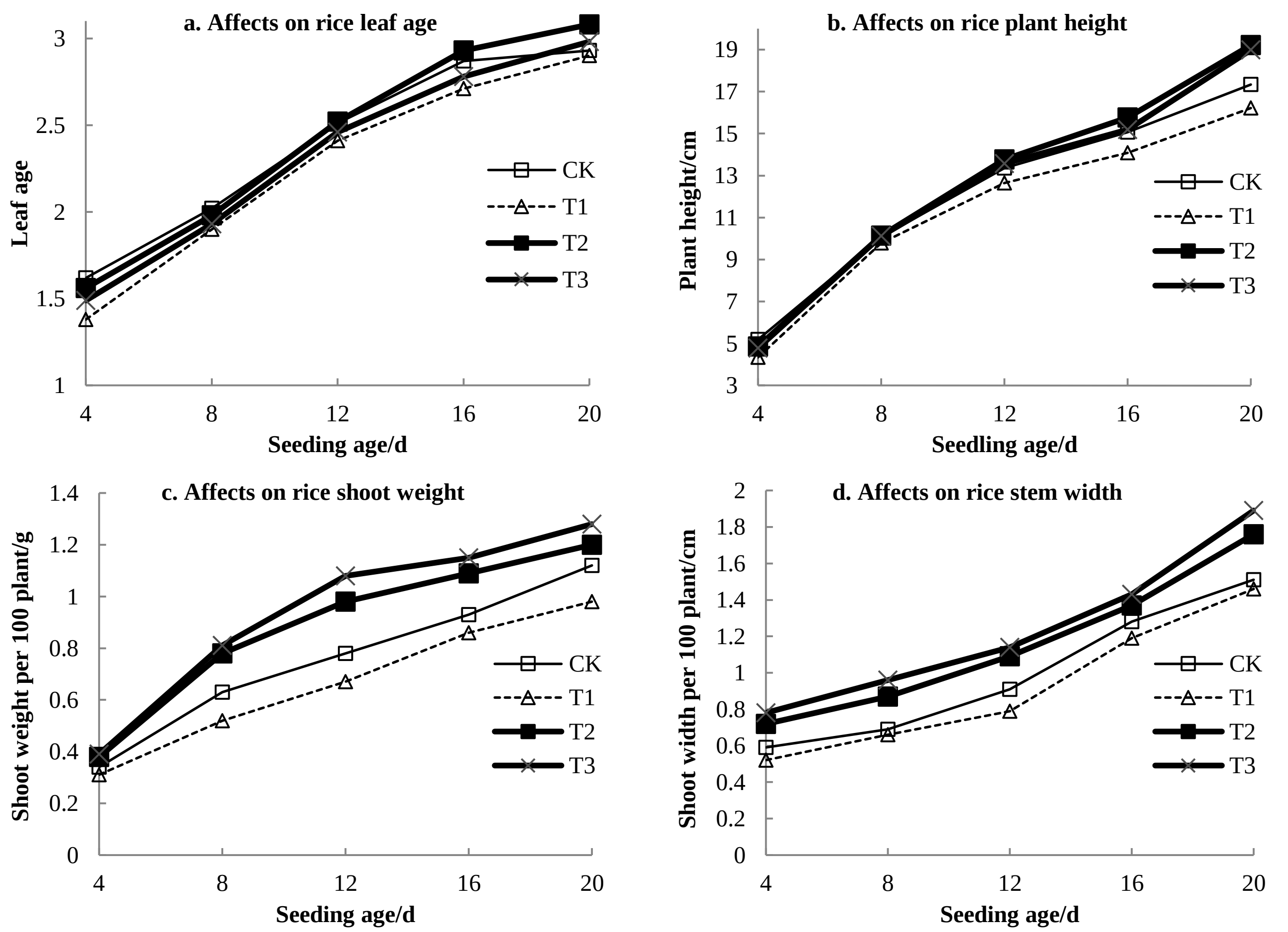

Fig. 1. Effect of different seedling substrates on rice above around growth characteristics.

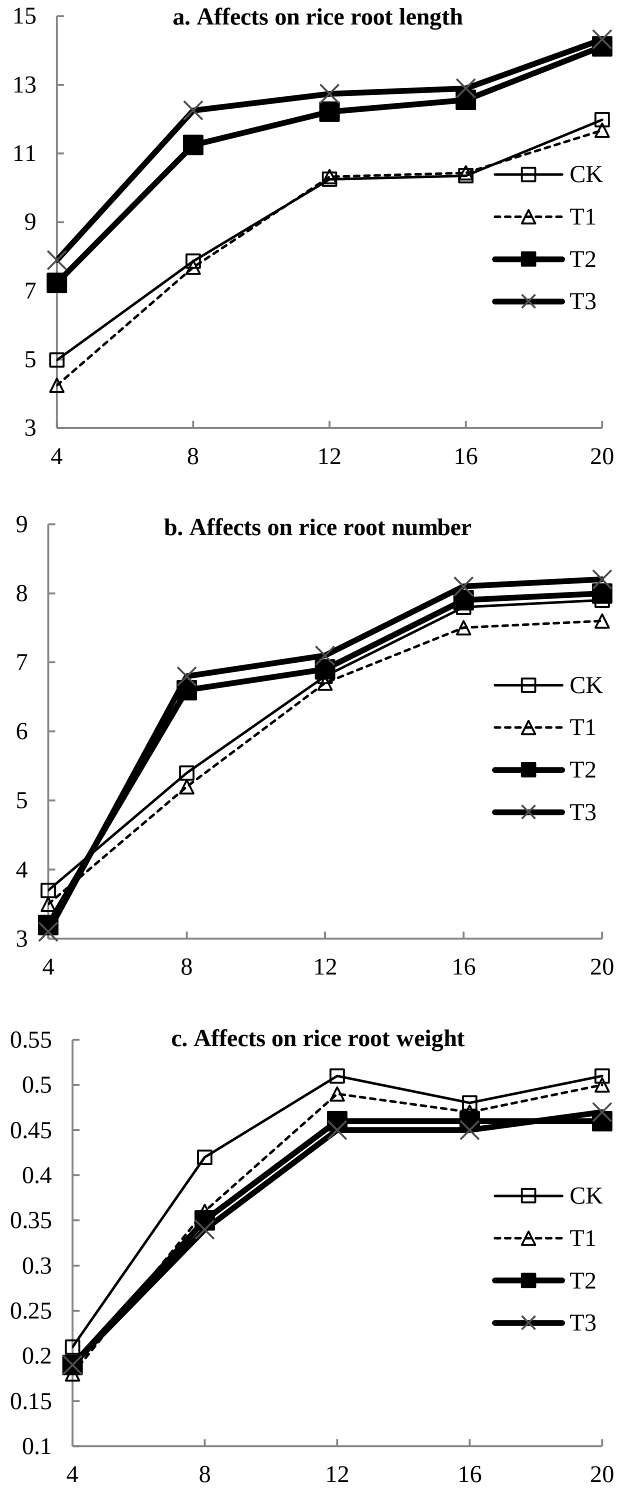

Fig. 2. Effects of different seedling substrates on rice root growth characteristics.

Effects of different types of substrates on physiological indicators of rice seedlings: During long-term evolution, plants can remove active oxygen through a set of anti-oxidation and protection system to protect themselves from injury, maintain balance between the accumulation and elimination of active oxygen, delay plant senescence, and enhance the growth and development of plants. POD and SOD are protective substances that balance the accumulation and elimination of active oxygen in plant protection under adverse conditions, and their activity is closely related to the quality of rice seedlings, and seedlings with strong protective enzyme activity are of good quality. Table 3 shows that the POD and SOD contents of the leaves and roots of seedlings cultured in T2 and T3 are higher than those of seedlings in T1 and CK. In addition, the POD and SOD contents of seedlings planted in T3 were 16.76% and 40.80%, respectively, higher than those of seedlings planted in T1. The MDA contents of T2 and T3 were lower than those of T1 and CK, which indicates that the former substrates can improve the resistance of rice seedlings.

The binding ability of roots is a key indicator affecting the quality of machine transplanting. Weak binding ability can easily cause breaking of the seedlings, which further affects the seedling raising speed and quality of transplantation. Amongst the treatment groups, the binding ability of roots of seedlings cultured in T3 was the highest, and the binding ability of roots in the straw seedling substrate was significantly higher than those in CK and T1. The binding ability of seedlings raised in T3 was 8.80% higher than that of seedlings in T1. The contents of total nitrogen, soluble sugar, starch, and chlorophyll of seedlings cultured in straw were consistently higher than those of seedlings planted in CK and T1. This finding suggests that seedlings raised in the straw seedling substrate have a stronger growth potential, which is conducive to the growth of seedlings in the field after machine transplantation, and lays a solid foundation for future research on high-yield agriculture.

Discussion

Effects of substrate types on seedling quality and physiology: High yield and high quality has always been the main goal of cultivation, and the primary consideration of seedling substrate selection is also the increase of grain yield and quality (Zhao *et al.,* 2018; Cha-Um *et al.,* 2010; Shao *et al.,* 2019; Ren *et al.,* 2020).The physical and chemical properties of substrates, such as bulk density, water holding capacity, pore condition, pH value and nutrient content, are closely related to the quality of rice seedlings and affect the transplantation quality and rice yield (Li *et al.,* 2016; Lei *et al.,* 2017). In general, a bulk substrate density range of 0.1–0.8 g/cm^3, total porosity of 54%–96%, pH of 5.4–7.0, C/N of less than 30, and the proper nutrient contents are considered necessary for optimal crop growth (Guo *et al.*, 2005). In this experiment, most of the physical and chemical properties of T2, T3, and T1 were found to be within suitable ranges for rice growth. Many research used substrates to raise seedlings and revealed that the nutrient content, water retention, water conservation, and drought resistance of the resulting seedlings were better than those of seedlings raised in soil (Sarangi *et al.*, 2015; Song *et al.*, 2014). In addition, the height, stem base width, amount of dry matter in the above-ground parts, root number, amount of dry matter in roots, and root activity of the test seedlings presented significant advantages over seedlings raised in CK. In the present study, suitable physical properties and high nutrient content were observed in the T2, T3, and T1. The growth characteristics of the above-ground seedlings and roots in these substrates were better than those of seedlings in CK. The available nutrient contents of the T2 and T3 were significantly higher than that of T1. Thus, the stems of seedlings in T2 and T3 were thick and suitable for machine transplanting. Compared with those of CK, the straw and mixed substrates revealed better aeration conditions, a larger water holding capacity, and lower bulk density, all of which are beneficial to the emergence and root extension of rice seeds. Thus, the root system of seedlings raised in these substrates is robust and can show good rooting effects. The binding ability and contents of total nitrogen, soluble sugar, starch, and chlorophyll contents of plants grown in the T3 and T2 were higher than those of CK and T1. This finding suggests that seedlings raised in the straw seedling substrate have strong growth potential, which is conducive to their growth in the field after machine transplantation, and lays a solid foundation for research on high-yield agriculture (Table 4).

Compatibility of substrate seedling trays with agricultural machinery and agronomy: The adaptability of seedling equipment and transplanting equipment is an important index to measure the seedling substrate (Alizadeh *et al.,* 2011; Meng *et al.*, 2014). The planting of strong seedlings requires a leaf age of 2.5–4.0 and a plant height of 12–20 cm. The stem base is thick and roots are clumped into blocks. Early rice should be resistant to cold, and late rice should have age elasticity. Healthy soil is nutrient rich and can improve seedling quality and increase age elasticity. Planting in this type of soil is the most common method of seedling raising. However, in actual production, healthy soil is often prepared by producers. In this case, the type of bed soil and fertility level are not uniform, and irregular seedling growth and undesired planting effects may be observed. These conditions are not conducive to increasing crop yields. Rice seedling substrates are mostly taken from industrial and agricultural wastes through industrialization, which is beneficial to the standardization of substrates and improves stability. Meng and Zheng hold that a low bulk density of the substrate can reduce the intensity of substrate pipeline seedling raising (Zheng *et al.*, 2006; Meng *et al.*, 2014). In the present experiment, the straw and mixed substrates featured a small bulk density, which can effectively reduce the work intensity during seedling raising and machine transplantation and improve the efficiency of these processes. The results of this study indicate that substrates suitable for transplanting seedlings should contain sufficient nutrients to support the growth of seedlings and promote thick growth of above-ground parts and roots. In addition, it should have excellent permeability to enable roots to form blocks. A strong ability to conserve water and fertilizer is required to reduce the leaching of nutrients and ensure an adequate supply to seedlings. A small bulk density is also required to reduce the work intensity during raising and transplantation. Low water content and good water absorption are necessary to improve the speed of raising and extend the quality and lifetime of the substrate. With the large-scale promotion of machine transplanting, the traditional method of raising seedlings in CK can barely adapt to increasing demands. In the future, more raising substrates will replace CK raising. The straw seedling tray developed by our research team can completely replace traditional plastic seedling trays. Our trays greatly reduce the use of plastic floppy disks and hard disks and introduce a new approach to comprehensively utilize straws. China has abundant straw resources that are easy to obtain. After entering the soil, straw can be completely decomposed into soil nutrients. It is an ideal material for other raising substrates. In this experiment, T3 was mainly processed from crop straws, which are lightweight and have good quality and long lifetimes. The above-ground parts of the seedlings are thick and the roots are clumped into blocks; these characteristics are suitable for the development and application of industrialized seedlings. In this study, only the quality and physiological characteristics of the seedlings were tested. Our next goal is to conduct field experiments to support the conclusions of this paper with more substantial field data.

Table 3. Effect of different seedling substrate on MDA content, POD and SOD activities of seedling leaf and root before transplantation.

Treatment	Leaf			Root		
	Peroxidase POD ($U \cdot g^{-1}$)	Superoxide dismutase SOD ($U \cdot g^{-1}$)	Malonaldehyde MDA ($\mu mol \cdot g^{-1}$)	Peroxidase POD ($U \cdot g^{-1}$)	Superoxide dismutase SOD ($U \cdot g^{-1}$)	Malonaldehyde MDA ($\mu mol \cdot g^{-1}$)
Soil (CK)	92.36b	289.45c	5.34b	49.65b	146.8b	8.4a
Mixed substrate	87.65c	276.59d	5.69a	47.76b	143.2b	7.8a
Crop residue substrate	100.28a	364.32b	4.87c	57.65a	173.4a	5.3c
Crop residue substrate board	102.34a	389.43a	4.23d	58.54a	176.5a	5.7c

Table 4. Effect of different seedling substrate on nitrogen, sugar content in rice seedling before transplantation

Treatment	Nitrogen content ($mg.g^{-1}$)	Soluble sugar content ($mg.g^{-1}$)	Starch content ($mg.g^{-1}$)	Chlorophyll content ($mg.g^{-1}$)	Rooting ability (cm)	Root twining power (kg)
Soil (CK)	15.98b	12.34c	50.43b	4.53b	14.22b	0.1456b
Mixed substrate	14.34c	10.87d	46.89c	4.21c	13.54c	0.1421b
Crop residue substrate	16.38a	16.54a	54.35a	4.68a	15.76a	0.1523a
Crop residue substrate board	16.63a	15.67b	56.34a	4.62a	15.64a	0.1546a

Conclusions

The physicochemical properties of T3 are better than those of T1 and CK; it can meet the nutrient requirements of seedlings during rice raising and reduce their management process. The physiological characteristics of the seedlings planted in T3 are generally better than those raised in CK and T1. T3 is mainly composed of rice and wheat straw, which are easy to obtain. It can be completely decomposed in the rice field. Its light weight, good quality, long lifetime, and obvious advantages in production and application render the proposed T3 substrate highly suitable for the development and utilization of industrialized seedling substrates.

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