Reused substrates in soilless culture greenhouse strawberry production

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Abstract: This study examined the effects of varying reutilization periods of substrate on its physical and chemical properties and the growth and development of strawberries in a greenhouse. The research focused on a specialized substrate formula that had been reused for either two or four years, utilizing the 'Hongyan' and 'Xiangye' strawberry varieties as test subjects. A range of parameters was assessed, including the substrate's physical and chemical properties, photosynthetic performance, fruit quality, and strawberry yield. The results indicated that for the 'Hongyan' strawberry, the bulk density of the substrate that had been reused for four years was higher than that of the substrate reused for two years. However, there were no significant differences observed in total porosity,aeration porosity,water holding porosity, or air-to-water ratio between the two substrate durations. Additionally, parameters such as soluble solids content, Vitamin C content, total acid content, and fruit yield did not show significant differences for 'Hongyan' strawberries. Conversely, for 'Xiangye' strawberries, there were no significant differences in the physical properties of the substrates reused for two years versus those reused for four years. Notably, the yield of 'Xiangye' strawberries grown in the substrate reused for four years experienced a significant reduction of 26.86% compared to that of the substrate reused for two years (p<0.05). These findings suggest that the impact of different reutilization periods varies among strawberry varieties. The specialized substrate can be effectively reused for certain varieties that exhibit strong adaptability and resistance within a specified timeframe, helping to lower costs and facilitate substrate reutilization. This approach holds considerable practical application and potential for advancement in the realm of strawberry substrate cultivation and production.

Keywords: strawberry, reutilization, substrate physical and chemical properties, photosynthetic parameters, quality, yield
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1 Introduction

Strawberry (*Fragaria×ananassa* Duch.), a perennial herbaceous plant belonging to the genus Fragaria in the Rosaceae family[1], is extensively cultivated across China. Its fruit is soft, juicy, and rich in nutrients such as vitamins, amino acids, β-carotene, and strawberry polyphenols[2], offering certain health benefits. Known as the 'Fruit Queen'[3], strawberries are favored by producers due to their short growth cycle and high economic benefits[2]. According to statistics from the Food and Agriculture Organization of the United Nations (FAO), China's strawberry production reached 3.336 million tons in 2019, accounting for over one-third of global production, making China the world's largest strawberry producer[4]. The strawberry industry has thus become one of China's fastest-growing emerging industries[5].

Soilless culture is one of the key modern plant production systems, characterized by a significantly higher utilization of available resources[6]. In soilless cultivation, nutrients essential for plant growth are supplied via nutrient solutions, ensuring uniform, stable, and sufficient nutrient provision. Since it does not rely on soil, this technology can substantially reduce water consumption, as the nutrient solution directly contacts the plant root system, leading to a high nutrient utilization rate[7]. Moreover, soilless cultivation enables precise control over the plant growth environment. By adjusting environmental factors such as temperature, humidity, and light, plant growth can be accelerated, thereby achieving higher yields[8]. This technology plays a crucial role in protecting soil environments and promoting the sustainable development of agriculture. Common substrates used in soilless strawberry cultivation include peat, vermiculite, perlite composite substrate, coir, rock wool, etc. Among these, peat is a non-renewable resource, and excessive exploitation can damage ecosystems. Additionally, the cost of peat-based substrates is relatively high, and their production involves significant energy consumption[9]. Furthermore, the decomposition and fragmentation of composite substrates can alter their physical and chemical properties, severely reducing water permeability and air permeability, which negatively impacts

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strawberry yield and quality. Compared with traditional soil cultivation, the initial investment for vegetable substrate cultivation is higher[10]. From both economic and environmental perspectives, the reuse of cultivation substrates over multiple years represents an inevitable trend in the future development of soilless cultivation. This approach reduces reliance on non-renewable materials, lowers planting costs, minimizes environmental pollution, enhances resource utilization, and supports the green and sustainable development of the modern agricultural industry.

Continuous cropping obstacles can result in poor crop growth and negatively impact crop quality and yield[11]. Studies have shown that the accumulation of stubble in the substrate leads to the deterioration of its physical and chemical properties, exacerbating plant pests and diseases. External environmental factors such as crop root absorption, root exudates, water and fertilizer management, temperature, and humidity can influence the pH value, electrical conductivity, and nutrient content of the substrate. These changes reduce substrate quality and hinder crop growth and development. Therefore, selecting an appropriate substrate for cultivation is crucial[12]. To address the issue of substrate continuous cropping obstacles, domestic scholars have conducted experimental research. For instance, Li et al. investigated the effects of different vegetable rotations and tomato continuous cropping on bacterial diversity and community structure in the rhizosphere of the substrate. Their findings indicated that crop rotation improved tomato plant growth and physiological conditions, with celery rotation yielding the best results[13]. Other studies have demonstrated that adding arbuscular mycorrhizal fungi (AMF) effectively enhances crop growth in substrates and facilitates the reuse of waste substrates[14]. This study's team developed a specialized substrate formula composed primarily of volcanic rocks, peat, and red jade soil, which is well-suited for strawberry cultivation[11]. This substrate resists decomposition and fragmentation, enabling repeated use and contributing to labor and cost savings. However, the long-term effects of continuous planting on the physical and chemical properties of the substrate and its impact on strawberry production remain unclear. Consequently, this experiment was conducted to provide technical support and a theoretical basis for the reuse of strawberry cultivation substrates.

2 Materials and methods

2.1 Experimental materials

In this study, two strawberry varieties, 'Hongyan' and 'Xiangye', were selected for testing because of their distinct characteristics and adaptability to diverse growing conditions. A self-developed specialized formula substrate, specifically designed for strawberry cultivation, was utilized. This substrate was engineered to enhance nutrient availability, moisture retention, and aeration, promoting healthy root development and overall plant growth. The initial physical and chemical properties of the substrate are presented in Table 1, while the initial particle size distribution is detailed in Table 2.

Table 1 Initial physical and chemical properties of the substrate

Bulk density/ $g \cdot cm^{-3}$	Electrical conductivity/ $\mu S \cdot cm^{-1}$	pH value	Total porosity/ %	Aeration porosity/ %	Water holding porosity/%
0.64±0.02	363.67±44.66	6.10±0.05	65.00±0.01	16.04±0.04	48.92±0.04

2.2 Experimental design

This experiment was conducted at the National Protected Agriculture R&D Center, Institute of Protected Agriculture, Academy of Agricultural Planning and Engineering, Ministry of Agriculture and Rural Affairs (116.44°E, 39.23°N) from September 2022 to May 2023. Strawberry plants were cultivated using an A-shaped composite planting frame in a greenhouse measuring 40 m in length and 16 m in span. The cultivation frame was 1.2 m wide, with three rows per frame, and the spacing between frames (measured from midline) was 2.2 m. The plant spacing within each row was 20 cm. 'Hongyan' strawberries were planted in substrates that had been reused for two years (HY-2) and four years (HY-4), respectively. Similarly, 'Xiangye' strawberries were planted in substrates that had been reused for two years (XY-2) and four years (XY-4), respectively. There were four experimental treatments, each repeated three times. The substrate formula consisted of volcanic rock (40%), peat soil (30%), red jade soil (15%), perlite (3.75%), vermiculite (3.75%), and adsorbent (7.50%). The adsorbent was either activated carbon or diatomite, used singly or in combination. The particle sizes were as follows: volcanic rock (10-15 mm), peat soil (<5 mm), red jade soil (5-7 mm), perlite (5-7 mm), and vermiculite (2-5 mm). In the experiment, the self-developed substrate was divided into two parts. The first part was mixed with strawberry fertilizer and used as the bottom layer of the planting substrate, while the second part was layered on top of the bottom substrate. The volume ratio of the first part to the second part of the substrate was 7:3[15]. After the substrate assembly was completed, strawberry planting commenced on September 7, 2022. One week after planting, 5 g of slow-release fertilizer with an N:P:K mass ratio of 12:9:11 was applied between every two strawberry plants. Subsequently, fresh water drip irrigation was performed three tosix times daily, lasting 5 min each time, until most of the strawberry plants blossomed. Thereafter, nutrient solution irrigation was automatically administered via a fertigation machine. At the end of the cultivation period, the substrate was covered with plastic film during the high temperature season in July and underwent solar disinfection through exposure to sunlight. The cultivation and management methods remained consistent across all four treatments throughout the growth period.

Table 2 Initial particle size distribution of the substrate

Particle size range/mm	Mass ratio/%	Volume ratio/%
>10.000	10.1	5.7
5.000-10.000	28.3	25.8
3.000-5.000	21.5	17.6
2.000-3.000	10.5	14.5
1.000-2.000	12.8	19.1
0.500-1.000	5.8	13.4
0.075-0.500	9.5	19.6
<0.075	1.6	2.6

2.3 Indices measurement and methods

2.3.1 Climate data testing in the greenhouse

The indoor air temperature and relative humidity were recorded using the Ridder-Hortimax system (Ridder Group, Maasdijk, The Netherlands). Climate data were configured for continuous collection from 00:00 to 24:00 daily, with a collection interval of 10 min.

2.3.2 Determination of the physical and chemical properties of the substrate

Bulk density, total porosity, aeration porosity, water holding porosity, and air-to-water ratio were tested according to the standard NY/T 2118-2012. The pH value was measured using a pHs-3cpH meter (INESA Scientific Instrument Co., Ltd., Shanghai, China), while electrical conductivity was measured using a DDS-307 conductivity meter (INESA Scientific Instrument Co., Ltd., Shanghai, China). Organic matter, nitrate nitrogen, available phosphorus, and available potassium were analyzed using a soil fertilizer nutrient rapid measuring instrument (Hebei Tasong Electronic Technology Co., Ltd., Shijiazhuang, China).

2.3.3 Determination of growth and photosynthetic indices

The plant height was measured using a ruler to determine the distance from the central leaf to the third outward leaf. The basal stem diameter was measured using a Vernier caliper. The maximum leaf length and width were also measured using a ruler, and the maximum leaf area was calculated using the formula: maximum leaf area=maximum leaf length×maximum leaf width×0.73[16].

The SPAD value of the leaves was measured using a Konica Minolta SPAD-502 chlorophyll meter (Konica Minolta Co., Ltd., Tokyo, Japan).

The net photosynthetic rate (Pn), stomatal conductance (Gs), intercellular CO_2 concentration (Ci), and transpiration rate (Tr) were measured using the LI-6400 photosynthesis system (LI-COR, Inc., Lincoln, NE, USA). Five representative strawberry plants were randomly selected for each treatment.

2.3.4 Determination of quality and yield

During the high-production period, 10 marketable strawberry fruits were randomly selected from each plot. The fruits were crushed and homogenized using a tissue grinder (AUX Co., Ltd., Guangdong, China) to determine the fruit quality indices.

Soluble solids were measured using a digital refractometer (ATAGO Co., Ltd., Tokyo, Japan); Vitamin C (VC) was determined using the 2,6-dichloroindophenol titration method; soluble sugar was analyzed using the 3,5-dinitrosalicylic acid colorimetry method; total acid content was measured using potentiometric titration with a pH meter (INESA Scientific Instrument Co., Ltd., Shanghai, China). The sugar-acid ratio was calculated as the ratio of soluble sugar content to total acid content.

At the ripening stage of strawberries, three replicates were conducted for each treatment. Ten strawberry plants were randomly selected from each replicate to continuously record the yield of marketable fruit. The planting density was nine plants/m^2.

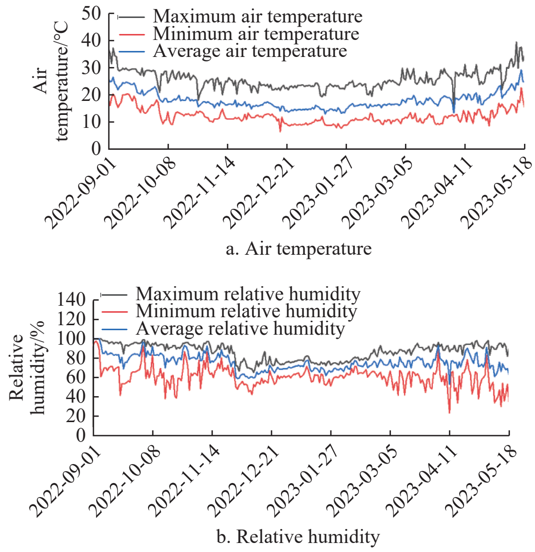
2.4 Data processing

Microsoft Excel 2010 and Graph Pad Prism 6 software were used for data processing and graphing; SPSS 17.0 software was used to analyze the data by one-way ANOVA, and Duncan's test was applied for multiple comparisons of the significance of the differences (p<0.05 indicates a significant difference between treatments).

3 Results and analysis

3.1 Changes in indoor air temperature and relative humidity

This experiment investigated the changes in indoor air temperature and relative humidity from September 1, 2022 to May 18, 2023. As shown in Figure 1a, the indoor air temperature exhibited a downward trend from September to December 2022. From January to February 2023, the indoor air temperature remained relatively stable, with the highest temperature reaching approximately 25°C, the average temperature ranging between 15°C and 20°C, and the lowest temperature dropping to approximately 12°C. In March, the fluctuations in air temperature increased and showed an upward trend. The temperature continued to rise in May, with the maximum temperature reaching 39°C. As depicted in Figure 1b, the indoor relative humidity fluctuated significantly from September to December 2022. From January to February in 2023, the relative humidity remained relatively stable, with the maximum relative humidity reaching approximately 75%, the average relative humidity around 70%, and the minimum relative humidity at approximately 60%. From March to May, the fluctuations in relative humidity increased, with the maximum relative humidity reaching 100% and the minimum relative humidity dropping to 23%.



Note: Date: From September 1, 2022 to May 18, 2023.

Figure 1 Changes in indoor air temperature and relative humidity

3.2 Comparison of the physical and chemical properties of substrate with different reusing years

The three-phase ratio of solid, liquid, and gas in the cultivation substrate can indirectly affect plant root growth and development as well as the absorption and utilization of nutrient elements. These properties can be evaluated using the bulk density, total porosity, aeration porosity, water holding porosity, and air-to-water ratio of the substrate[17]. Generally, the physical and chemical properties of an ideal substrate are as follow: bulk density ranges from 0.1 to 0.8 g/cm^3, total porosity ranges from 54% to 96%, and the air-to-water ratio is between 1:2 and 1:4[18]. As shown in Tables 3 and 4, the bulk density, total porosity, and air-to-water ratio of the substrate used in all four treatments were within the normal range. Specifically, Table 3 indicates that the bulk density of the 'Hongyan' substrate reused for four years increased significantly by 46.14% compared with the substrate reused for two years (p<0.05), while no significant differences were observed in total porosity, aeration porosity, water holding porosity, or air-to-water ratio. Similarly, Table 4 shows that there were no significant differences in bulk density, total porosity, aeration porosity, water holding porosity, or air-to-water ratio between the 'Xiangye' substrates reused for four years and those reused for two years.

Table 3 Comparison of the physical properties of substrates with different reusing years for 'Hongyan' strawberries

Treatment	Bulk density/ g·cm^{-3}	Total porosity/%	Aeration porosity/%	Water holding porosity/%	Air-to-water ratio
HY-2	0.39±0.02^b	59.79±2.41^a	15.16±4.19^a	44.62±4.49^a	0.25±0.07^a
HY-4	0.57±0.03^a	54.20±4.35^a	11.34±3.52^a	42.86±4.75^a	0.21±0.06^a

Note: Different small letters mean significant difference among treatments at 0.05 level (p<0.05). Same as below.

As shown in Table 5, the electrical conductivity, organic matter content, nitrate nitrogen content, and available potassium content of the four-year reuse substrate for ‘Hongyan’ strawberries were significantly lower than those of the two-year reuse substrate, by 12.04%, 21.42%, 37.24%, and 38.99%, respectively (p<0.05). In contrast, the available phosphorus content was significantly higher, by 57.46% (p<0.05). Similarly, Table 6 indicates that the electrical conductivity, organic matter content, nitrate nitrogen content, and available potassium content of the four-year reuse substrate were significantly lower than those of the two-year reuse substrate, by 20.46%, 25.17%, 19.95%, and 38.27%, respectively (p<0.05), while the available phosphorus content was significantly greater, by 19.19% (p<0.05).

Table 4 Comparison of the physical properties of substrates with different reusing years for ‘Xiangye’ strawberries

Treatment	Bulk density/ g·cm^{-3}	Total porosity/%	Aeration porosity/%	Water holding porosity/%	Air-to-water ratio
XY-2	0.41±0.02^{a}	57.07±1.54^{a}	12.17±1.64^{a}	44.90±1.50^{a}	0.21±0.03^{a}
XY-4	0.50±0.06^{a}	54.45±1.89^{a}	11.98±4.18^{a}	42.47±6.06^{a}	0.22±0.09^{a}

Table 5 Comparison of the chemical properties of substrates with different reusing years for ‘Hongyan’ strawberries

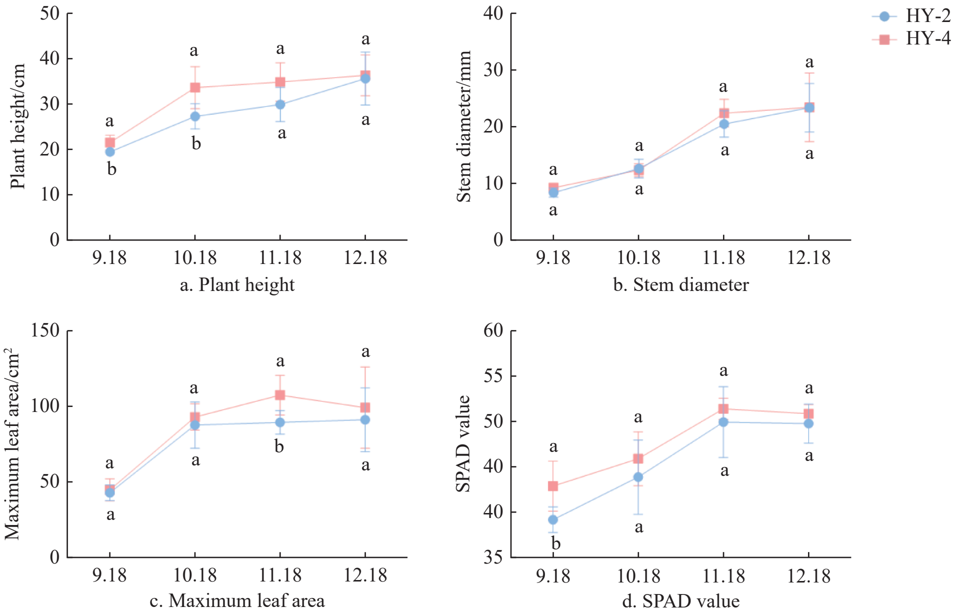
Treatment	Electrical conductivity/μS·cm^{-1}	pH value	Organic matter content/‰	Nitrate nitrogen content/mg·kg^{-1}	Available phosphorus content/mg·kg^{-1}	Available potassium content/mg·kg^{-1}
HY-2	128.70±4.36^{a}	7.98±0.07^{a}	87.80±2.31^{a}	110.53±5.14^{a}	70.01±4.87^{b}	523.63±34.87^{a}
HY-4	113.20±5.84^{b}	7.82±0.19^{a}	69.00±0.64^{b}	69.37±3.35^{b}	110.23±6.25^{a}	319.47±17.46^{b}

Table 6 Comparison of the chemical properties of substrates with different reusing years for ‘Xiangye’ strawberries

Treatment	Electrical conductivity/μS·cm^{-1}	pH value	Organic matter content/‰	Nitrate nitrogen content/mg·kg^{-1}	Available phosphorus content/mg·kg^{-1}	Available potassium content/mg·kg^{-1}
XY-2	144.03±3.87^{a}	7.99±0.16^{a}	90.99±6.06^{a}	93.33±3.79^{a}	90.98±3.18^{b}	589.57±23.31^{a}
XY-4	114.57±1.96^{b}	7.94±0.22^{a}	68.18±13.04^{b}	74.71±1.97^{b}	108.43±2.36^{a}	363.97±13.91^{b}

3.3 Effects of substrates with different reusing years on the growth and physiological indices of strawberries

As shown in Figure 2a, the plant height of ‘Hongyan’ strawberries exhibited a trend of rapid growth in the early stage followed by stable growth. Approximately 10 days and 40 days after planting (September 18, October 18), the plant height of strawberries grown in the four-year reuse substrate was significantly higher than that in the two-year reuse substrate, by 10.45% and 23.13%, respectively (p<0.05). After October 18, no significant difference in plant height was observed between the four-year and two-year reuse substrates. As depicted in Figure 2b, the stem diameter showed an upward trend in the early stage, with accelerated growth from October 18 to November 18 and a slower growth rate from November 18 to December 18. No significant difference in stem diameter was observed between the four-year and two-year reuse substrates. From Figure 2c, it can be seen that the maximum leaf area increased rapidly in the early growth stage and then stabilized. Due to the removal of old leaves during the strawberry growth period, the measured maximum leaf area may have decreased. On November 18, the maximum leaf area of strawberries grown in the four-year reuse substrate was significantly higher than that in the two-year reuse substrate, by 20.07% (p<0.05). As indicated in Figure 2d, the SPAD value of strawberries grown in the four-year reuse substrate was consistently higher than that in the two-year reuse substrate from September 18 to December 18. Specifically, on September 18, the SPAD value of strawberries grown in the four-year reuse substrate was significantly higher, by 9.44%, compared with that in the two-year reuse substrate (p<0.05). As shown in Figure 3, the plant height of ‘Xiangye’ strawberries grown in the four-year reuse substrate was always significantly higher than that in the two-year reuse substrate, by 20.16%, 14.54%, 11.05%, and 10.97%, respectively (p<0.05). No significant differences were observed in stem diameter, maximum leaf area, or SPAD value.



Note: Different small letters mean significant difference among treatments at 0.05 level (p<0.05). Same as below.

Figure 2 Effects of substrates with different reusing years on the growth and physiological indices of ‘Hongyan’ strawberries

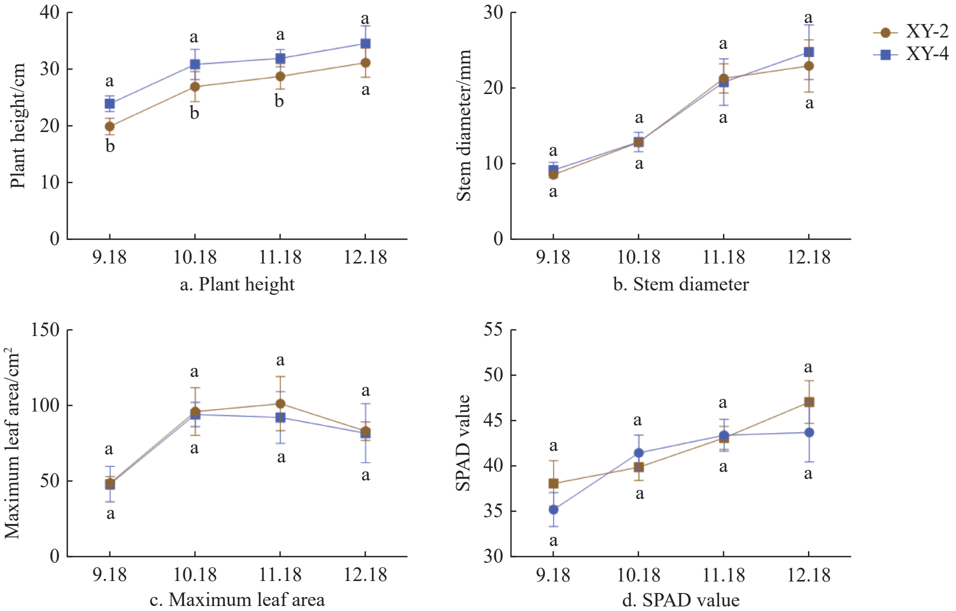


Figure 3 Effects of substrates with different reusing years on the growth and physiological indices of 'Xiangye' strawberries

3.4 Effects of substrates with different reusing years on the photosynthetic parameters of strawberries

Photosynthesis serves as the foundation for the growth and development of green plants[19]. The intercellular CO_2 concentration of the 'Hongyan' strawberries grown in the four-year reuse substrate was significantly higher than that in the two-year reuse substrate, by 2.94% (p<0.05) (Figure 4c). The transpiration rate of 'Xiangye' strawberries grown in the four-year reuse substrate was significantly lower than that in the two-year reuse substrate, by 11.34% (p<0.05) (Figure 5d), while no significant differences were observed in other photosynthetic parameters.

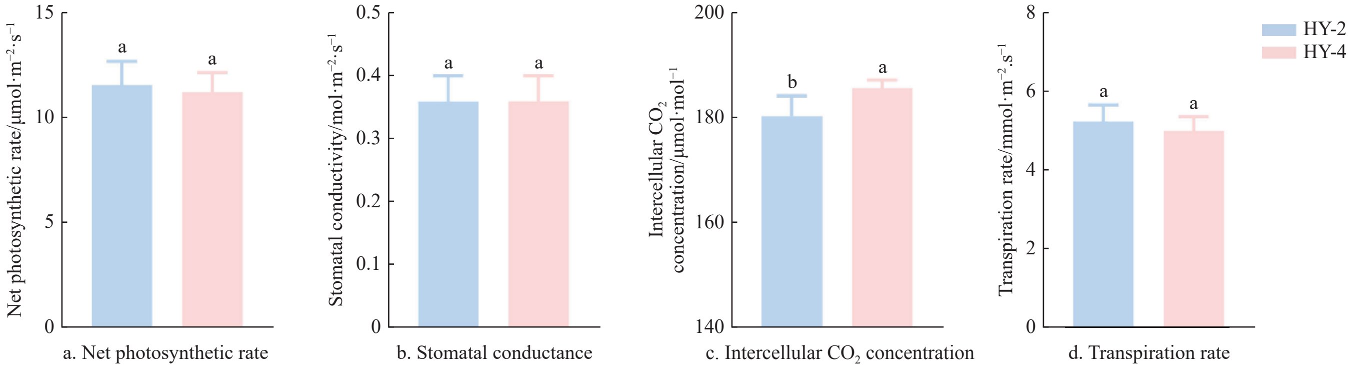


Figure 4 Effects of substrates with different reusing years on the photosynthetic parameters of 'Hongyan' strawberries

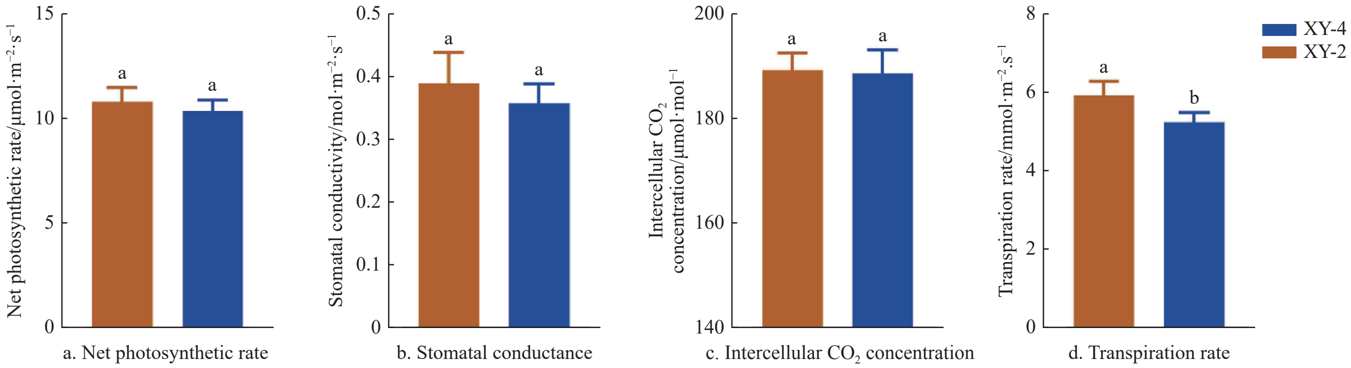


Figure 5 Effects of substrates with different reusing years on the photosynthetic parameters of 'Xiangye' strawberries

3.5 Effect of substrates with different reusing years on the quality and yield of strawberries

As listed in Table 7, the soluble sugar content and sugar-acid ratio of 'Hongyan' strawberries grown in the four-year reuse substrate were significantly lower than those in the two-year reuse substrate, by 22.59% and 21.23%, respectively (p<0.05). No significant differences were observed in soluble solids content, Vitamin C content, total acid content, or yield. As indicated in Table 8, the total acid content and yield of 'Xiangye' strawberries grown in the four-year reuse substrate were significantly lower than those in the two-year reuse substrate, by 11.46% and 26.86% (p<0.05), respectively. No significant differences were observed in soluble solids content, Vitamin C content, soluble sugar content, or sugar-acid ratio between the two treatments for 'Xiangye' strawberries. Overall, long-term reuse of the substrate had no adverse effect on the yield of the 'Hongyan' strawberries but may cause a certain degree of reduction in some quality indicators. For 'Xiangye' strawberries, substrate reuse had no adverse effect on quality but did have a certain impact on yield.

Table 7 Effect of substrates with different reusing years on the quality and yield of 'Hongyan' strawberries

Treatment	Soluble solids content/%	Vitamin C content/mg·100g^{-1}	Soluble sugar content/%	Total acid content/%	Sugar-acid ratio	Yield/kg·m^{-2}
HY-2	11.08±1.20^a	56.00±4.56^a	5.47±0.09^a	0.71±0.06^a	7.77±0.68^a	1662.73±235.62^a
HY-4	10.02±0.69^a	55.38±4.87^a	4.23±0.39^b	0.70±0.07^a	6.12±0.81^b	1443.27±261.34^a

Table 8 Effect of substrates with different reusing years on the quality and yield of 'Xiangye' strawberries

Treatment	Soluble solids content/%	Vitamin C content/mg·100g^{-1}	Soluble sugar content/%	Total acid content/%	Sugar-acid ratio	Yield/kg·m^{-2}
XY-2	12.80±2.34^a	71.38±4.56^a	6.76±0.70^a	0.51±0.04^a	13.15±0.85^a	2012.44±133.42^a
XY-4	12.80±1.41^a	65.85±4.67^a	6.16±0.67^a	0.46±0.02^b	13.58±2.06^a	1471.86±90.18^b

4 Discussion

Currently, a significant amount of strawberry cultivation occurs in greenhouses using cultivation frames. Due to the relatively fixed nature of the cultivation facilities and the closed environment within greenhouse, as the number of planting years for the same crop increases, continuous cropping obstacles are inevitable[20]. Additionally, reusing the same substrate for multiple years can have an adverse effect on crops[21]. Long-term reuse of substrates may lead to the deterioration of their physical and chemical properties, increased pests and disease incidence, impaired plant growth and development, and reduced crop productivity. The ability to recycle substrates effectively has thus become a critical issue in the advancement of soilless culture[13, 22-24].

The substrate serves as one of the core environments for plant growth, providing essential materials and energy for plant survival. The bulk density, porosity, organic matter content, and nitrate nitrogen content of the substrate play a critical role in maintaining substrate structure and supplying crop nutrients. In this study, the physical and chemical properties of the substrate reused for two and four years for the 'Hongyan' and 'Xiangye' strawberry varieties were measured separately. The results showed that the bulk density of the 'Hongyan' strawberry substrate increased with planting duration but remained within the range suitable for crop growth. Simultaneously, there was no significant difference in the air-to-water ratio or pH value between the substrates reused for two and four years for the two varieties, indicating that the self-developed substrate could effectively improve its physical and chemical properties to some extent and reduce the incidence of continuous cropping obstacles. Additionally, the available potassium content in the substrates of the two strawberry varieties decreased with increasing planting years, which may be attributed to the relatively high demand of strawberries for potassium. This finding aligns with the results reported by Vandecasteele et al.[25]

Plant leaves are critical organs for photosynthesis, and photosynthetic parameters serve as important indicators for evaluating plant photosynthetic capacity. In this experiment, no significant differences were observed in net photosynthetic rate and stomatal conductance between the two strawberry varieties grown in substrates reused for two and four years. This may be attributed to the self-developed cultivation substrate's ability to enhance water retention, thereby effectively maintaining substrate productivity and ensuring that strawberry plant growth and development are not inhibited. The specific physiological mechanisms underlying those observations warrant further investigation.

Quality and yield are critical indicators for evaluating fruit quality and economic benefit. The sugar-acid ratio is a widely recognized parameter used to assess strawberry taste and consumer acceptance[26]. Unlike traditional mixed substrates, the specially formulated substrate contains a certain proportion of volcanic rocks, which enhances porosity and reduces the likelihood of anaerobic stress in strawberry plants. Therefore, with increasing planting years, no significant difference was observed in the sugar-acid ratio of fruits between the four-year reuse substrate and the two-year reuse substrate for specific varieties such as 'Xiangye'. Woznicki et al. evaluated the effects of both virgin substrates and spent materials reused for one to two years on strawberries, concluding that planting new crops in old substrates had only marginal effects on strawberry yield[27]. Vandecasteele et al. found that reusing peat for up to three cycles did not negatively affect strawberry yield[28]. These findings align with the conclusion of this study regarding 'Hongyan' strawberries. However, for 'Xiangye' strawberries, the yield in the four-year reuse substrate was lower than that in the two-year reuse substrate. This may be attributed to the differing characteristics of the variety, which could impact yield with prolonged planting years. Nevertheless, the experiment demonstrated that the four-year reuse substrate still ensured plant quality and yield to some extent.

Based on the above analysis, it can be concluded that for specific varieties, the substrate can be reused for up to four years without significantly affecting crop growth and yield. This finding is consistent with the service life of strawberry cultivation substrates imported from Japan, as reported by Chen et al.[29] Xu et al. mentioned the application of coconut shell fiber as a substrate in soilless cultivation, which exhibits low acidity, high calcium content, and can be reused for up to four seasons[30]. Relevant standards indicate that after four to six reuse cycles, the physical and chemical properties of the substrate deteriorate significantly, making it unsuitable for continued use in strawberry production. This study suggests that whether the substrate remains usable after four years of use requires experimental verification, a conclusion that is similar with this study[31].

5 Conclusions

There are notable differences in the effects of different reutilization periods on strawberry varieties. This study found that for 'Hongyan' strawberries, although some substrate indices changed after continuous use for four years, the bulk density, total porosity, and air-to-water ratio remained within the range suitable for crop growth and did not affect the normal growth or yield of the plants, indicating that the substrate could be effectively reused. Similarly, for 'Xiangye' strawberries, the bulk density, total porosity, and air-to-water ratio of the substrate were also within the appropriate range; however, the yield was significantly reduced, indicating that the reuse effect of the substrate varies depending on the crop variety. For specific varieties, crops can adapt to change within a certain range of changes without negatively impacting their growth, which can effectively reduce production costs, promote sustainable agricultural development, and significantly enhance resource utilization efficiency.

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