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ORIGINAL PAPER

# Vermicompost and Carbonized Rice Husk Influence the Production of Yellow Passion Fruit Cultivars Seedlings

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## Abstract

**Purpose** The use of agro-industrial subproducts is a sustainable alternative in the formulation of substrates for plants. In this study we aimed to evaluate the effect of substrates formulated from vermicompost and carbonized rice husk on production of yellow passion fruit cultivars seedlings.

**Methods** Four cultivars: BRS Gigante Amarelo, FB 300, IAC 275, and Rubi do Cerrado were sown in tubes filled with six substrates from combinations of vermicompost (V) and carbonized rice husk (CRH): 100% V, 90% V + 10% CRH, 80% V + 20% CRH, 70% V + 30% CRH, 60% V + 40% CRH, and 50% V + 50% CRH.

**Results** We observed that substrates with higher proportions of vermicompost presented better chemical attributes and moisture content. Seedlings from cv. BRS Gigante Amarelo and FB 300 showed higher relative water content produced in substrates with a proportion > 70% of vermicompost. The highest growth and biomass production characteristics were observed in all cultivar's seedlings in 100% V and 90% V + 10% CRH.

**Conclusion** Substrates containing 100% and 90% vermicompost contributed to obtaining passion fruit seedlings with higher growth and photoassimilates accumulation. The addition > 30% CRH in the substrate formulation impaired the production of passion fruit cultivars seedlings.

**Keywords** Biochar · Physiological Indices · Ruminal Content · Sugarcane Bagasse · Sustainable Substrates

## 1 Introduction

Yellow passion fruit (*Passiflora edulis*, Passifloraceae) is one of the plants of greatest interest in World. The species is exploited especially in regions with a tropical and subtropical climate (Vieira et al. 2022), with Brazil being the largest producer in the world, standing out for reaching an average of 697,859 tons in 45,602 hectares in the year 2022 (IBGE 2022; EMBRAPA s/d), making it a great cultivation option, choosing cultivars with good stability or adaptability to producing regions. Choosing substrates that can contribute to the morphophysiology of seedlings is an important decision-making, especially for the nurseryman or rural producer.

The substrate must have good chemical, physical and microbiological attributes (Ripp et al. 2020; Fiorin et al. 2022) according to the needs of the species and cultivar, improving the nutrition, physiology, and plant growth. However, the cost of commercial substrates is high, especially for situations of medium to low purchasing power, and therefore the formulation of alternative and sustainable substrates and or enriched with minerals has increased in nursery farming (Aires et al. 2020).

Among the material options for formulating sustainable substrates for plants, the use of agro-industrial subproducts are excellent raw materials and meet the objectives of the sustainable development goals (SDG), decreasing productions costs and possible environmental impacts with the disposal of these materials. In the Brazil, the sugar-energy sector using sugar cane as raw

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material, animal slaughter plants and the rice processing industry generate high amounts of subproducts (residues), such as sugarcane bagasse, ruminal content and rice husk, respectively.

Vermicomposting is a technique that consists of combining of materials, producing humus or vermicompost (Dohaish 2020; Wong et al. 2020), a product with high value that can play significant role as an organic fertilizer or a suitable medium for plants (Ebrahimi et al. 2021; Serri et al. 2021). Vermicompost is a material with good porosity and water retention (Ečimović et al. 2022) and rich in nutrients and organic matter (Astolfi et al. 2020; Wong et al. 2020; Kumar et al. 2023), which favors the mineral and physiological metabolism of plants.

For rice husk, carbonization is promising, as it is a simple process, in which the material, generally highly lignified (Satbaev et al. 2021; Nzereogu et al. 2023), is subjected to the controlled burning process, not letting it turn into ash, but rather into homogenized carbonized material (Medeiros 1998; Fermino et al. 2018), characterizing the production of Biochar. In the carbonized state, it favors the availability of nutrients for plants (Hashim et al. 1996; Barros et al. 2017; Teixeira et al. 2019), in addition to being an excellent source of silicon (Teixeira et al. 2019; Li et al. 2023a) and promoting an effect conditioner to the substrate (Liberalesso et al. 2021; Costa et al. 2023; ; Li et al. 2023b).

However, there is a lack of additional information on the morphophysiological responses of different passion fruit cultivars to substrates from agro-industrial residues. We hypothesized: (i) the use of sugarcane bagasse and ruminal content in the production of vermicompost contributes to the production of passion fruit seedlings, (ii) the addition of carbonized rice husk favors the chemical characteristics of the substrates and plant growth, and that (iii) responses to sustainable substrates vary of cultivar. Thus, we aimed to evaluate the effect of substrates formulated from vermicompost and carbonized rice husk on production of yellow passion fruit cultivars seedlings.

## 2 Materials and Methods

### 2.1 Vermicompost Production and Rice Husk Carbonization

The experiment was conducted under an agricultural nursery structure with a 150 µm transparent plastic cover and 50% shading screen, with benches suspended 1.00 m, in the Embrapa Agropecuária Oeste (22º 14', 54º 49', 452 m), located in the municipality of Dourados, in the southern region of the State of Mato Grosso do Sul, Brazil.

The vermicompost was produced in a masonry earthworm farm with a mesh top cover with 50% shading (Suplementary Fig. 1). The Proportion used of ruminal content from beef slaughterhouses and sugarcane bagasse was 1:1 (v $v^{-1}$), both coming from agro-industrials in the region. The mixture was subjected to the action of earthworm *Eudrilus eugeniae* during a period of 90 days, which the earthworms were inoculated in the morning and the moisture was maintained at 60%. The rice husk was subjected to carbonization in a modified simple carbonizer (Suplementary Fig. 2) based on a model adopted at the CNPH (National Center for Research in Vegetables) (Medeiros 1998).

### 2.2 Experimental Design, Substrates, and Cultivars

Experimental design used was completely randomized, with four replicationsof 27 tubes of 290 $cm^3$ each. The tubes were previously filled with six substrates from combinations of vermicompost (V) and carbonized rice husk (CRH): 100% V, 90% V + 10% CRH, 80% V + 20% CRH, 70% V + 30% CRH, 60% V + 40% CRH, and 50% V + 50% CRH. For each $m^3$ of substrate obtained, in all substrates, 1,000 g Yoorin® (18% $P_2O_5$) and 500 g potassium sulfate (50% de $K_2O$) supplementary fertilization were added according propused to Mariani et al. (2014). Subsequently, four passion fruit cultivars were sown: BRS Gigante Amarelo, FB 300, IAC 275, and Rubi do Cerrado, at depth of 2 cm.

The pH, N, P, K, Ca, Mg, and organic carbon (O.C.) values of the substrates from mixtures of V and CRH were determined according to the methodology of Silva (2009) and are presented in Table 1. Moisture contents were 49.70, 45.40, 43.00, 40.20, 39.10 and, 33.30% in substrates 100% V, 90% V + 10% CRH, 80% V + 20% CRH, 70% V + 30% CRH, 60% V + 40% CRH, and 50% V + 50% CRH, respectively.

### 2.3 Cultivation

During experimental period, the seedlings were irrigated once a day by micro sprinkler, adopting a system of rotating tube trays every three days to better standardize water distribution over the seedlings, and plant control was carried out spontaneous by manual starting. After the initial period of emergence, thinning was carried out, leaving only one seedling per tube.

### 2.4 Assessments

At 60 days after sowing, emergence assessment was carried out on 27 tubes and 14 plants per plot for the characteristics evaluated, disregarding the border.

**Table 1** Chemical analysis of substrates based in vermicompost (V) and carbonized rice husk (CRH) for the production of passion fruit cultivars seedlings after supplementary fertilization

| Substrates | pH | N | P | K | Ca | Mg | O.C. |
|---|---|---|---|---|---|---|---|
| | $CaCl_2$ | | $cmol_c\ dm^{-3}$ | | | | |
| 100% V | 6.41 | 1.01 | 0.47 | 0.21 | 1.18 | 0.30 | 13.40 |
| 90% V + 10% CRH | 6.37 | 1.06 | 0.43 | 0.21 | 1.08 | 0.27 | 14.13 |
| 80% V + 20% CRH | 6.45 | 0.93 | 0.41 | 0.23 | 1.04 | 0.28 | 14.70 |
| 70% V + 30% CRH | 6.57 | 0.91 | 0.37 | 0.23 | 0.90 | 0.24 | 17.81 |
| 60% V + 40% CRH | 6.51 | 0.83 | 0.36 | 0.25 | 0.90 | 0.24 | 19.48 |
| 50% V + 50% CRH | 6.49 | 0.82 | 0.30 | 0.29 | 0.80 | 0.20 | 24.39 |

O.C.: organic carbon

#### 2.4.1 Emergence and Relative Water Content

Seedling emergence was evaluated according to Nakagawa (1994) and we calculated the water content in the leaves according to Turner (1981), both results expressed in %.

#### 2.4.2 Plant Growth

Plant height (H) was measured with a ruler graduated in centimeters, taking as a standard the distance from the collar to the apical meristem, the stem diameter (D) was measured with a digital caliper (mm) inserted 1.0 cm above the level of the substrate, and recorded the number of leaves. Using the data from H and D, the HDR was calculated. The seedlings were removed of substrates, washing the roots to remove excess substrate. Leaf area was measured using an area integrator (Model LI 3100 - Area Meter), results expressed in $cm^2$.

#### 2.4.3 Biomass Production

The seedlings were separated into the shoot (stem + leaves) and root, in which the materials were packed in Kraft paper bags and subjected to drying in an oven with forced air ventilation at 60 ºC ± 5 for 72 h, and weighed, results expressed in g $plant^{-1}$.

#### 2.4.4 Physiological and Quality Index

From the leaf area and dry biomass data, the leaf area ratio, specific leaf area and specific leaf mass was calculated according to Hunt (2017), results expressed in $cm^2\ g^{-1}$ and g $cm^2$. Using growth and dry biomass data, the Dickson quality index (DQI) was calculated (Dickson et al. 1960).

### 2.5 Data Analysis

All data were analyzed individually for each cultivar, i.e., did not comparing them statistically. Emergence data were subjected to the Shapiro-Wilk normality test, and all data were subjected to analysis of variance and when significant by F test ($p \leq 0.05$), the means were compared by Scott-Knott test for substrates at $p \leq 0.05$ ± standard deviation, using SISVAR software.

**Table 2** Results of the analysis of variance of the effect of substrates in each cultivar on the characteristics evaluated in yellow passion fruit seedlings

| Characteristics | *p*-value | | | |
|---|---|---|---|---|
| | BRS Gigante Amarelo | FB 300 | IAC 275 | Rubi do Cerrado |
| E | 0.0025 | 0.0355 | 0.0009 | < 0.0001 |
| RWC | < 0.0001 | 0.0012 | 0.0001 | 0.0143 |
| H | < 0.0001 | 0.0002 | < 0.0001 | 0.0002 |
| NL | < 0.0001 | 0.0003 | 0.0006 | 0.0037 |
| D | < 0.0001 | 0.0012 | < 0.0001 | < 0.0001 |
| HDR | 0.7444 | 0.1150 | 0.1864 | 0.0923 |
| LA | < 0.0001 | < 0.0001 | < 0.0001 | 0.0004 |
| SDM | < 0.0001 | 0.0001 | 0.0004 | 0.0314 |
| RDM | < 0.0001 | 0.0050 | 0.0134 | 0.0434 |
| TDM | < 0.0001 | < 0.0001 | 0.0061 | 0.0020 |
| LAR | < 0.0007 | 0.0015 | 0.0333 | 0.0610 |
| SLA | < 0.0004 | 0.0205 | 0.0008 | 0.0002 |
| SLM | < 0.0005 | 0.0009 | 0.0122 | 0.1476 |
| DQI | 0.1010 | 0.1878 | 0.7001 | 0.6312 |

E: emergence, RWC: relative water content, H: height, NL: number of leaves, D: stem diameter, LA: leaf area, SDM: shoot dry mass, RDM: root dry mass, TDM: total dry mass, LAR: leaf area ratio, SLA: specific leaf area, SLM: specific leaf mass, DQI: Dickson quality index

## 3 Results

### 3.1 Description of Variance Analysis

We observed that all morphophysiological characteristics of seedlings, except height: diameter ratio and Dickson quality index in all cultivars and specific leaf mass in cv. Rubi do Cerrado, were influenced by the substrates evaluated (Table 2).

### 3.2 Emergence and Relative Water Content

We observed highest emergence in substrates 90% V + 10% CRH and 60% V + 40% CRH (98 and 95%, respectively) both from cv. BRS Gigante Amarelo (Table 3). In general, emergence values were > 71%, except for cv. Rubi do Cerrado in 90% V + 10% CRH, with 67%.

Regarding the relative water content in the leaves (RWC), the seedlings from cv. BRS Gigante Amarelo and FB 300 showed higher values produced in substrates 100% V, 90% V + 10% CRH, 80% V + 20% CRH, and 70% V + 30% CRH, statistically differing from the other substrates for these two cultivars. For cv. IAC 275 the highest RWC occurred in 90% V + 10% CRH, differing from the other substrates, while seedlings from cv. Rubi do Cerrado was in 100% V and 90% V + 10% CRH. In addition, all cultivars showed lower RWC in 50% V + 50% CRH.

### 3.3 Plant Growth

The highest plant height values were observed in seedlings produced in 100% V and 90% V + 10% CRH, statistically differing from the other substrates, while lowest values occurred in 60% V + 40% CRH and 50% V + 50% CHR (Table 4). The highest values of stem diameter and number of leaves to BRS Gigante Amarelo and Rubi do Cerrado occurred in 100% V and 90% V + 10% CRH, while in FB 300 and IAC 275 produced in substrate containing ≥ 70% V showed higher values (Table 4).

For leaf area (LA), all cultivars presented higher values (> 85 cm²) when produced in 100% V, not statistically different from the seedlings in 90% V + 10% CRH, except for cv. IAC 275 (Table 4). We found that when using 60% V + 40% CRH and 50% V + 50% CRH, seedlings of all cultivars showed lower LA values (< 50 cm²), except those of cv. Rubi do Cerrado in 50% V + 50% CRH.

### 3.4 Biomass Production

The passion fruit seedlings produced in 100% V and 90% V + 10% CRH showed higher shoot dry mass in all cultivars. In general, seedlings from cv. IAC 275 which at 90% V + 10% CRH was lower than the other cultivars in the same substrate (Table 5). For cv. Rubi do Cerrado values did not differ statistically between the first three substrates, i.e., with values ≥ 80% of vermicompost in the substrate composition. In general, lowest values (< 0.35 g plant$^{-1}$) were observed in seedlings produced in 50% V + 50% CRH.

For root dry mass, the response varied with the cultivar. Seedling from cv. BRS Gigante Amarelo showed highest value in 80% V + 20% CRH, FB 300 with a proportion < 70% V, while for cv. IAC 275 was in 100% V. Conversely, cv. Rubi do Cerrado had higher value in 50% V + 50% CRH. We observed that seedlings from cv. FB 300 and IAC 275 showed higher total dry mass in 100% V, while the cv. BRS Gigante Amarelo seedlings showed values did not differ between substrates 100% V, 90% V + 10% CRH, and 80% V + 20% CRH.

### 3.5 Physiological and Quality Index

Seedlings from cv. BRS Gigante Amarelo showed higher leaf area ratio (LAR) in 100% V, while cv. FB 300 values did not vary statistically between substrates 100% V, 90% V + 10% CRH, 80% V + 20% CRH, and 70% V + 30% CRH (Table 6). Conversely, lower LAR was observed in FB 300,

**Table 3** Emergence and relative water content of yellow passion fruit cultivar seedlings produced in substrates based in vermicompost (V) and carbonized rice husk (CRH)

| Substrates | Emergence (%) | | | |
|---|---|---|---|---|
| | BRS Gigante Amarelo | FB 300 | IAC 275 | Rubi do Cerrado |
| 100% V | 84.00 ± 1.41 b | 83.50 ± 3.93 a | 73.83 ± 3.17 b | 91.33 ± 1.64 a |
| 90% V + 10% CRH | 98.12 ± 0.15 a | 82.66 ± 0.35 a | 82.66 ± 2.16 a | 67.66 ± 3.29 b |
| 80% V + 20% CRH | 86.36 ± 1.88 b | 71.33 ± 1.88 b | 85.16 ± 4.58 a | 73.33 ± 2.49 b |
| 70% V + 30% CRH | 86.16 ± 4.77 b | 86.00 ± 2.16 a | 89.00 ± 0.47 a | 77.80 ± 0.43 b |
| 60% V + 40% CRH | 95.00 ± 1.41 a | 81.33 ± 0.94 a | 76.66 ± 2.16 b | 73.33 ± 0.94 b |
| 50% V + 50% CRH | 84.00 ± 2.35 b | 82.66 ± 3.29 a | 81.66 ± 2.94 a | 91.66 ± 3.77 a |
| Substrates | Relative water content (%) | | | |
| | BRS Gigante Amarelo | FB 300 | IAC 275 | Rubi do Cerrado |
| 100% V | 77.26 ± 2.78 a | 71.69 ± 1.70 a | 69.90 ± 1.46 b | 71.63 ± 2.56 a |
| 90% V + 10% CRH | 76.33 ± 2.88 a | 66.49 ± 3.88 a | 80.64 ± 3.72 a | 73.89 ± 4.80 a |
| 80% V + 20% CRH | 75.64 ± 3.32 a | 70.94 ± 4.85 a | 68.13 ± 4.58 b | 60.50 ± 3.37 b |
| 70% V + 30% CRH | 71.00 ± 4.25 a | 62.84 ± 5.79 a | 63.26 ± 2.50 b | 64.21 ± 2.81 b |
| 60% V + 40% CRH | 61.29 ± 4.63 b | 58.63 ± 2.11 a | 65.12 ± 2.14 b | 48.88 ± 4.93 c |
| 50% V + 50% CRH | 22.72 ± 3.50 c | 39.71 ± 5.12 b | 41.61 ± 3.41 c | 44.03 ± 3.84 c |

Means in columns (in each cultivar) with different letters differ statistically using the Scott-Knott test ($p \leq 0.05$) ± standard deviation

**Table 4** Plant height, stem diameter, number of leaves, and leaf area in yellow passion fruit cultivars seedlings produced in substrates based in vermicompost (V) and rice husk carbonized (CRH)

| Substrates | Plant height (cm) | | | |
|---|---|---|---|---|
| | BRS Gigante Amarelo | FB 300 | IAC 275 | Rubi do Cerrado |
| 100% V | 10.52 ± 0.76 a | 9.31 ± 1.16 a | 9.64 ± 0.92 a | 9.09 ± 0.91 a |
| 90% V + 10% CRH | 10.50 ± 0.14 a | 10.07 ± 0.44 a | 9.68 ± 1.12 a | 8.85 ± 0.22 a |
| 80% V + 20% CRH | 8.48 ± 1.19 b | 6.71 ± 0.74 b | 8.88 ± 0.13 a | 7.57 ± 0.51 b |
| 70% V + 30% CRH | 7.24 ± 0.62 c | 7.56 ± 0.62 a | 7.73 ± 0.68 b | 6.64 ± 0.33 c |
| 60% V + 40% CRH | 6.66 ± 0.67 c | 4.95 ± 0.69 c | 5.85 ± 0.70 c | 5.87 ± 0.23 c |
| 50% V + 50% CRH | 5.30 ± 0.17 d | 5.75 ± 0.69 c | 4.56 ± 0.14 c | 5.59 ± 0.47 c |
| Substrates | Stem diameter (mm) | | | |
| | BRS Gigante Amarelo | FB 300 | IAC 275 | Rubi do Cerrado |
| 100% V | 2.38 ± 0.07 a | 2.05 ± 0.29 a | 2.31 ± 0.04 a | 2.30 ± 0.01 a |
| 90% V + 10% CRH | 2.36 ± 0.02 a | 2.18 ± 0.11 a | 2.12 ± 0.14 a | 1.99 ± 0.14 b |
| 80% V + 20% CRH | 1.96 ± 0.01 b | 1.95 ± 0.15 a | 2.05 ± 0.12 a | 1.97 ± 0.11 b |
| 70% V + 30% CRH | 1.72 ± 0.07 c | 1.83 ± 0.09 a | 1.87 ± 0.04 a | 1.81 ± 0.12 b |
| 60% V + 40% CRH | 1.58 ± 0.12 d | 1.51 ± 0.03 b | 1.58 ± 0.02 b | 1.63 ± 0.03 c |
| 50% V + 50% CRH | 1.39 ± 0.06 e | 1.28 ± 0.01 b | 1.21 ± 0.19 c | 1.41 ± 0.05 d |
| Substrates | Number of leaves | | | |
| | BRS Gigante Amarelo | FB 300 | IAC 275 | Rubi do Cerrado |
| 100% V | 7.66 ± 0.44 a | 7.17 ± 0.12 a | 7.52 ± 0.23 a | 7.25 ± 0.08 a |
| 90% V + 10% CRH | 7.23 ± 0.23 a | 7.44 ± 0.43 a | 7.37 ± 0.54 a | 7.16 ± 0.59 a |
| 80% V + 20% CRH | 6.83 ± 0.17 a | 6.94 ± 0.35 a | 6.49 ± 0.25 a | 6.57 ± 0.46 a |
| 70% V + 30% CRH | 5.61 ± 0.38 b | 6.30 ± 0.33 a | 6.75 ± 0.24 a | 6.80 ± 0.54 a |
| 60% V + 40% CRH | 5.35 ± 0.38 b | 5.51 ± 0.81 b | 5.66 ± 0.48 b | 5.94 ± 0.44 b |
| 50% V + 50% CRH | 4.13 ± 0.35 c | 4.63 ± 0.23 b | 4.80 ± 0.54 b | 4.97 ± 0.13 b |
| Substrates | Leaf area ($cm^2$) | | | |
| | BRS Gigante Amarelo | FB 300 | IAC 275 | Rubi do Cerrado |
| 100% V | 91.55 ± 3.68 a | 96.74 ± 3.46 a | 92.91 ± 7.60 a | 85.45 ± 8.00 a |
| 90% V + 10% CRH | 86.19 ± 3.66 a | 82.13 ± 6.21 a | 71.73 ± 6.73 b | 76.49 ± 9.58 a |
| 80% V + 20% CRH | 64.97 ± 7.10 b | 48.45 ± 3.34 b | 34.47 ± 3.14 c | 63.22 ± 5.71 b |
| 70% V + 30% CRH | 44.75 ± 7.23 c | 50.28 ± 4.05 b | 44.82 ± 4.39 c | 42.37 ± 9.86 c |
| 60% V + 40% CRH | 23.02 ± 0.90 d | 18.72 ± 0.16 c | 21.58 ± 3.84 d | 65.51 ± 9.53 c |
| 50% V + 50% CRH | 47.33 ± 7.13 c | 9.31 ± 0.53 c | 13.08 ± 5.42 d | 18.91 ± 8.01 d |

Means in columns (in each cultivar) with different letters differ statistically using the Scott-Knott test ($p \leq 0.05$) ± standard deviation

BRS Gigante Amarelo, and IAC 275 in 60% V + 40% and 80% V + 20% CRH, respectively.

Analyzing the specific leaf area (SLA) cv. BRS Gigante Amarelo showed higher value in 50% V + 50% CRH, while for cv. FB 300 values did not vary statistically between substrates 100% V, 90% V + 10% CRH, 80% V + 20% CRH, and 70% V + 30% CRH (Table 6). The lower SLA was observed in the cultivars IAC 275, Rubi do Cerrado, and BRS Gigante Amarelo in 90% V + 10% CRH, 60% V + 40% CRH, and 50% V + 50% CRH, respectively, differing from the others on these substrates.

For specific leaf mass (SLM), cv. BRS Gigante Amarelo showed higher value in 60% V + 40% CRH, while for cv. FB 300 values did not vary statistically between substrates 100% V, 90% V + 10% CRH, 80% V + 20% CRH, and 70% V + 30% CRH. Overall, the lower SLM were observed in seedlings from cv. BRS Gigante Amarelo and IAC 275 in 50% V + 50% and 90% V + 10% CRH, respectively, differing from the others in these substrates.

## 4 Discussion

Sustainable substrates based in vermicompost and carbonized rice husk were promising for production of passion fruit seedlings, confirming our initial hypothesis, in which chemical attributes, except potassium and organic carbon, were better especially with higher proportions of vermicompost. Similarly, yellow passion fruit seedlings were responsive to different substrates based on organic waste (Aires et al. 2020), reinforcing the idea that the use of these materials is a promising and viable proposal. Although all substrates were enriched with Yoorin® and potassium sulfate, it is noted that the proportion of materials is a determining

**Table 5** Shoot dry mass, root dry mass and total dry mass of yellow passion fruit cultivars seedlings produced in substrates based on vermicompost (V) and carbonized rice husk (CRH)

| Substrates | Shoot dry mass (g plant$^{-1}$) | | | |
|---|---|---|---|---|
| | BRS Gigante Amarelo | FB 300 | IAC 275 | Rubi do Cerrado |
| 100% V | 0.79 ± 0.05 a | 0.98 ± 0.03 a | 0.89 ± 0.08 a | 0.77 ± 0.07 a |
| 90% V + 10% CRH | 0.80 ± 0.04 a | 0.94 ± 0.09 a | 0.44 ± 0.02 b | 0.77 ± 0.18 a |
| 80% V + 20% CRH | 0.66 ± 0.01 b | 0.48 ± 0.08 b | 0.71 ± 0.07 a | 0.68 ± 0.09 a |
| 70% V + 30% CRH | 0.57 ± 0.05 b | 0.53 ± 0.08 b | 0.54 ± 0.01 b | 0.56 ± 0.10 b |
| 60% V + 40% CRH | 0.43 ± 0.05 c | 0.53 ± 0.17 b | 0.37 ± 0.03 b | 0.50 ± 0.11 b |
| 50% V + 50% CRH | 0.29 ± 0.02 c | 0.28 ± 0.05 c | 0.30 ± 0.04 b | 0.33 ± 0.06 c |
| Substrates | Root dry mass (g plant$^{-1}$) | | | |
| | BRS Gigante Amarelo | FB 300 | IAC 275 | Rubi do Cerrado |
| 100% V | 0.45 ± 0.05 b | 0.65 ± 0.05 a | 0.74 ± 0.03 a | 0.49 ± 0.01 a |
| 90% V + 10% CRH | 0.49 ± 0.02 b | 0.64 ± 0.14 a | 0.51 ± 0.13 b | 0.50 ± 0.09 a |
| 80% V + 20% CRH | 0.58 ± 0.07 a | 0.37 ± 0.03 b | 0.35 ± 0.06 c | 0.50 ± 0.06 a |
| 70% V + 30% CRH | 0.37 ± 0.03 c | 0.58 ± 0.17 a | 0.46 ± 0.08 b | 0.47 ± 0.09 a |
| 60% V + 40% CRH | 0.31 ± 0.02 c | 0.27 ± 0.03 b | 0.31 ± 0.04 c | 0.47 ± 0.12 a |
| 50% V + 50% CRH | 0.25 ± 0.01 c | 0.31 ± 0.04 b | 0.36 ± 0.12 c | 0.24 ± 0.01 b |
| Substrates | Total dry mass (g plant$^{-1}$) | | | |
| | BRS Gigante Amarelo | FB 300 | IAC 275 | Rubi do Cerrado |
| 100% V | 1.24 ± 0.08 a | 1.63 ± 0.05 a | 1.63 ± 0.09 a | 1.27 ± 0.07 a |
| 90% V + 10% CRH | 1.31 ± 0.05 a | 1.58 ± 0.16 a | 0.96 ± 0.13 b | 1.28 ± 0.10 a |
| 80% V + 20% CRH | 1.24 ± 0.08 a | 0.85 ± 0.07 c | 1.06 ± 0.16 b | 1.18 ± 0.07 a |
| 70% V + 30% CRH | 0.94 ± 0.08 b | 1.12 ± 0.09 b | 1.01 ± 0.07 b | 1.03 ± 0.09 a |
| 60% V + 40% CRH | 0.75 ± 0.04 b | 0.81 ± 0.10 c | 0.68 ± 0.05 c | 0.73 ± 0.04 b |
| 50% V + 50% CRH | 0.55 ± 0.02 c | 0.59 ± 0.01 c | 0.67 ± 0.01 c | 0.60 ± 0.07 b |

Means in columns (in each cultivar) with different letters differ statistically using the Scott-Knott test ($p \leq 0.05$) ± standard deviation

**Table 6** Leaf area ratio (LAR), specific leaf area (SLA) and specific leaf mass (SLM) of yellow passion fruit cultivar seedlings produced in substrates based on vermicompost (V) and carbonized rice husk (CRH)

| Substrates | Leaf area ratio (cm² g$^{-1}$) | | | |
|---|---|---|---|---|
| | BRS Gigante Amarelo | FB 300 | IAC 275 | Rubi do Cerrado |
| 100% V | 73.87 ± 9.23 a | 59.15 ± 3.99 a | 56.62 ± 1.91 b | 74.17 ± 2.53 a |
| 90% V + 10% CRH | 65.84 ± 4.34 a | 51.37 ± 2.25 a | 82.28 ± 6.07 a | 59.59 ± 0.78 a |
| 80% V + 20% CRH | 52.68 ± 9.13 b | 57.98 ± 3.11 a | 35.72 ± 4.85 c | 53.34 ± 1.24 b |
| 70% V + 30% CRH | 47.33 ± 8.55 b | 44.25 ± 5.92 a | 44.85 ± 7.11 c | 40.54 ± 2.75 b |
| 60% V + 40% CRH | 30.70 ± 4.18 b | 25.02 ± 1.69 b | 31.52 ± 4.60 c | 75.87 ± 5.90 a |
| 50% V + 50% CRH | 84.89 ± 10.55 a | 16.06 ± 1.37 b | 20.68 ± 8.18 c | 38.12 ± 4.48 b |
| Substrates | Specific leaf area (cm² g$^{-1}$) | | | |
| | BRS Gigante Amarelo | FB 300 | IAC 275 | Rubi do Cerrado |
| 100% V | 115.47 ± 10.03 b | 98.15 ± 3.62 a | 104.21 ± 6.18 b | 125.66 ± 3.07 a |
| 90% V + 10% CRH | 107.00 ± 8.84 b | 87.54 ± 2.89 a | 163.86 ± 10.72 a | 100.42 ± 3.60 b |
| 80% V + 20% CRH | 98.40 ± 12.06 b | 106.46 ± 3.72 a | 54.09 ± 8.86 c | 93.94 ± 5.73 b |
| 70% V + 30% CRH | 78.24 ± 11.19 c | 97.49 ± 4.32 a | 81.78 ± 5.36 b | 74.61 ± 3.95 b |
| 60% V + 40% CRH | 53.53 ± 8.28 c | 33.27 ± 7.06 b | 58.94 ± 10.56 c | 158.82 ± 8.16 a |
| 50% V + 50% CRH | 157.85 ± 11.08 a | 34.18 ± 2.76 b | 41.46 ± 8.25 c | 44.12 ± 3.17 c |
| Substrates | Specific leaf mass (g cm²) | | | |
| | BRS Gigante Amarelo | FB 300 | IAC 275 | Rubi do Cerrado |
| 100% V | 0.008 ± 0.0007 a | 0.010 ± 0.0003 b | 0.009 ± 0.0005 b | 0.009 ± 0.0018 a |
| 90% V + 10% CRH | 0.009 ± 0.0007 a | 0.0011 ± 0.0022 b | 0.006 ± 0.0009 b | 0.010 ± 0.0009 a |
| 80% V + 20% CRH | 0.010 ± 0.0011 a | 0.010 ± 0.0034 b | 0.026 ± 0.0157 a | 0.010 ± 0.0011 a |
| 70% V + 30% CRH | 0.013 ± 0.0019 a | 0.011 ± 0.0043 b | 0.012 ± 0.0008 b | 0.013 ± 0.0007 a |
| 60% V + 40% CRH | 0.019 ± 0.0033 a | 0.028 ± 0.0094 a | 0.017 ± 0.0041 a | 0.008 ± 0.0024 a |
| 50% V + 50% CRH | 0.006 ± 0.0009 b | 0.031 ± 0.0007 a | 0.026 ± 0.0069 a | 0.014 ± 0.0008 a |

Means in columns (in each cultivar) with different letters differ statistically using the Scott-Knott test ($p \leq 0.05$) ± standard deviation factor in the chemical quality of the substrate. In addition, we emphasize that responses to substrates varied in function of each cultivar as expected, since each material presents its gene expression potential.

Decreased in K and organic carbon in substrates with higher proportions of vermicompost indicates that CRH is an excellent source of these attributes, especially because it is carbonized. Rice husk, being carbonized, is capable of maintaining its organic carbon content stored, in such a way that there is no loss to the atmosphere and that when applied to the soil it is easily available, improving the physical, chemical, and microbiological qualities (Asadi et al. 2021; Karam et al. 2022). Although it has been verified that CRH contributes to increasing the K content in the soil or substrate, there are still no specific explanations for this response in the literature, so we suggest that it is an alternative source of this element.

Our results are promising, as they complement other information regarding the use of these materials in the formulation of substrates for passion fruit cultivars, and these discoveries could contribute to strengthening the fruit crops production chain. The better emergence can also be attributed to the physical conditions of the substrates. The addition of CHR has a conditioning effect on the substrate (Costa et al. 2023), in which it showed high porosity and reduces density, but its addition in greater proportions, especially 40–50%, showed a negative influence. Although the emergence is associated to the reserves stored in the seeds, for good germination and subsequent emergence, the substrate must be sufficiently porous to facilitate good contact with the seed for root protrusion. This information is important because even if it does not influence the quality of seedlings, from a practical point of view, it is possible to know the quantity of seedlings available for commercialization and control costs in the case of the nurseryman, and for the rural producer, if there is a need for sow or formulate substrate in greater quantity to meet the number of plants in the field.

In addition, substrates with higher proportions of vermicompost presented higher moisture, indicating that it increases the soil's water retention capacity under these conditions, which contributes positively to efficient imbibition. Water is a fundamental factor in the germination stage, as it initiates the metabolic activity of the seed, acting to maintain the balance between abscisic acid (ABA) and gibberellin (Smolikova et al. 2021).

ABA has an antagonistic function to germination, as it induces the seed to remain dormant (Hu et al. 2021), but gibberellin acts positively by stimulating seed germination (Liu et al. 2022). The greater humidity in the substrate in contact with the seeds, provides both dissolved $O_2$ and nutritious materials present in the seed's endosperm, as well as promoting softening of the seed coat, allowing the emergence of the radicle and also the plumule (Xue et al. 2021; Khaeim et al. 2022).

We also highlight that the emergence potential response varies depending on the cultivar used, that is, its technological, physiological aspect and stored reserves. In this sense, cv. BRS Gigante Amarelo in general, obtained better results in terms of seedling emergence, especially in the substrate with 90% V + 10% CRH. However, cv. Rubi do Cerrado showed lower emergence, which can be disadvantageous, since it will be necessary to higher cost of purchasing seeds and substrates to obtain a greater number of seedlings.

The higher growth values of shoot can be explained by better chemical attributes of the substrates with higher proportions of vermicompost, especially N, Ca, and Mg. This is because N acts as a component of the chlorophyll molecule, which contributes to photosynthetic metabolism, promoting better plant growth and development (Jia et al. 2021; Yin et al. 2023). It is worth noting that N is an essential constituent of amino acids that act as precursors for the synthesis of proteins and enzymes (Zayed et al. 2023), contributing to biomass accumulation in passion fruit seedlings.

Ca is an essential component for the structuring of plant cell membranes and walls, in addition to being associated as an intracellular secondary messenger at physiological levels (Thor et al. 2019; Ghosh et al. 2021). Conversely, Mg is closely related to chlorophyll, participating in photosynthetic activities, as well as in the transport of photoassimilates (Geng et al. 2021; Kumari et al. 2022), what was reflected in the leaf area of passion fruit seedlings. This increase in leaf area contributes positively to maximizing the absorption of light energy, $CO_2$ assimilation, and production of photoassimilates, a fact reinforced in our study.

Vermicompost is a biostabilized product, rich in organic matter and nutrients from the materials used (Shafique et al. 2021). In our study, ruminal content and sugarcane bagasse are materials with low and high C/N ratio, respectively, which contributes to obtaining a substrate with good chemical and physical attributes. The use of vermicompost in the composition of the substrate contributes positively to the physiological and growth characteristics of plants depending on the chemical quality of substrate (Ebrahimi et al. 2021; Jankauskien et al. 2022), similar to our study with yellow passion fruit cultivars.

The increase in shoot and root dry mass in 100% V and 90% V + 10% CRH can be explained by the higher nutrient values in the substrates, especially P. Phosphorus plays several roles in plants, including its participation in the synthesis of energy in photochemical reactions, being a substrate for $CO_2$ assimilation, in addition to constituting nucleotides and phospholipids (Arellano et al. 2021; Toledo et al. 2021).

In addition, P acts as a structural component of membranes (Neocleous and Savvas 2019; Toledo et al. 2021), which resulted in an increase in biomass in passion fruit seedlings. Furthermore, the increase in shoot characteristics on these same substrates resulted in the carbohydrates accumulation. We emphasize that adding 10% CRH at substrate, in addition to improving porosity due to the conditioning effect (Li et al. 2023b), it is a source of silicon (Otero et al. 2023), which can contribute to resistance and physiological performance. Studies with Biochar, represented here by CRH, for passion fruit are recent, and little is known about the direct mechanisms of its participation in plant growth.

In general, regarding cultivars, we observed that seedlings from cv. FB 300, IAC 275, and Gigante Amarelo showed good adaptability to the substrates used, especially with higher proportions of vermicompost, that is, with better chemical attributes in the substrates, while Rubi do Cerrado under these conditions showed a lower percentage of emergence (67%) in 90% V + 10% CRH, reinforcing the better combination. In this sense, the choice of cultivar to be produced varies on the available input, but we emphasize that adding > 30% CRH is harmful to the growth of passion fruit seedlings, i.e., the need for greater adjustments on physiological indices to supply the biomass production. Similarly, Barros et al. (2017) found that added < 25% of Biochar from wood industry waste to the substrate composition negatively influences the growth of yellow passion fruit seedling from cv. BRS Gigante Amarelo.

Although DQI did not influenced by substrates, which indicates broad adaptability to cultivation conditions, we emphasize that seedlings with larger leaf areas, height and biomass increase, and substrates with better chemical attributes are the most determining choice factors in nursery, especially as it presents a greater photoassimilates.

In addition, the use of these materials in the formulation of substrates that, in addition to reducing production costs with commercial substrates, promotes the SDGs. In future perspectives, we suggest new studies aiming to evaluate the nutritional status and photosynthetic metabolism of seedlings of these cultivars and the mechanisms of biomass increase and adjustments through phenotypic plasticity.

## 5 Conclusion

The use of vermicompost and carbonized rice husk is a strategy for formulation of sustainable substrates. Substrates containing 100% and 90% vermicompost contributed to obtaining passion fruit seedlings with better growth and physiological indices. In general, all cultivars are most responsive to substrates with higher proportions of vermicompost. The addition > 30% of carbonized rice husk in the substrate formulation harms the production of seedlings of passion fruit cultivars.

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## Declarations

**Competing Interests** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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