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Mucuna and Avocado-Seed Residues as Sustainable Fertilizers and Biostimulants for Cherry Tomatoes

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Abstract: The global demand for sustainable agricultural practices is increasing, necessitating the preference for fertilizers and organic stimulants with minimal chemical transformation. This study investigates the potential use of *Mucuna* (*Mucuna pruriens* sp.) and avocado (*Persea americana* Mills) seed residues in the cultivation of cherry-tomato crops (*Lycopersicon esculentum* Mill.) var. *cerasiforme*. After extracting L-dopa, the Mucuna ground residual seeds were incorporated into the soil substrate as an edaphic fertilizer. In contrast, the hydrolyzed avocado seed was mixed with water or the nutrient Long Ashton and applied as a foliar biostimulant to cherry plants grown in a greenhouse. We report the nutrients and amino acid content in hydrolysates of the avocado and Mucuna's residue seeds and experiment with their effect in plants employing a completely blocked random design of eight treatments with four replicates. Data inspection involved analysis of variance, and mean differences were determined using Fisher's least significant difference test. Significant differences ($p < 0.05$) were observed among the treatments regarding the number of flowers (70%), fruits (23%), and dry weight fruits (25%) in favor of those using these seed residues. A second experiment revealed that treatments containing both seed residues slightly increased the °Brix in fruits. This study supports with evidence that residual seeds benefit tomatoes and probably other important plants, contributing to the path to sustainable agriculture.

Keywords: agroindustry residues; organic nutrition; *Solanum lycopersicum*; sustainable agriculture; yield increment

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1. Introduction

Agroindustry residues, also known as agroindustrial byproducts, are the waste materials that have lost their usefulness or economic value generated in human activities, such as industry, commerce, forest exploitation, livestock, and agriculture [1]. Using agroindustry residues to provide crop nutrients is an essential sustainable practice that needs to be widely adopted. It involves utilizing residual or waste materials from various agricultural and food processing industries as a source of organic matter and nutrients for crop production. This practice helps reduce waste, recycle nutrients, and minimize the need for synthetic fertilizers. Examples of sustainable practices involving agroindustry residues are as follows [2]. (a) Crop residues such as straw, husks, and stalks can be incorporated into the soil as organic matter and nutrient sources. These residues decompose over time, releasing nutrients and improving soil fertility. They also contribute to soil structure and moisture retention; this practice is commonly used in conservation agriculture systems [3,4]. (b) Agroindustry residues, such as fruit and vegetable waste, crop residues, and livestock manure, can be composted to produce high-quality organic fertilizer [5]. Composting involves decomposing organic materials through microbial activity, producing a nutrient-rich and stable product [6]. Compost can be applied to crops to improve soil fertility, enhance nutrient availability, and promote plant growth [7]. (c) Biochar is a carbon-rich product obtained from the pyrolysis of agroindustry residues, such as rice husks, corn cobs, and wood waste. It can be used as an amendment to improve soil structure, nutrient retention, and water-holding capacity [8]. Biochar is also a long-term carbon sink, helping mitigate greenhouse-gas emissions [9]. (d) Agroindustry residues, including animal manure, food-processing waste, and energy crops, can be subjected to anaerobic digestion to produce biogas and nutrient-rich digestate [10]. The digestate can be used as a nutrient source for crop production, reducing the reliance on synthetic fertilizers [11]. Anaerobic digestion also helps in the management of organic waste and the generation of renewable energy.

Moreover, there is increasing concern about the impact of chemical fertilization on workers' health. In addition, it reduces soil fertility and pollutes the air and water, thereby bringing environmental hazards [12]. Consequently, there is a growing interest in finding new organic sources of nitrogen and other major plant nutrients that are environmentally friendly compared to chemically synthesized fertilizers [13]. One potential option is to use noncommercial and neglected legumes, which can fix atmospheric nitrogen through symbiosis with nitrogen-fixing bacteria [14]. One legume of interest is *Mucuna pruriens*, which can be found in the wild in the southeastern states of Mexico [15]. *Mucuna* is intentionally planted as a cover crop in Central and North America to enrich the soil with nitrogen before planting maize [16]. The foliage of *Mucuna* contributes biomass to the soil. At the same time, it is reported that the roots can fix from 201 [17] up to 331 kg of nitrogen per hectare [18], providing organic matter for soil regeneration and health [19,20]. Many studies reported the benefits of using *Mucuna* pruriens as a cover crop or intercrop, mainly with maize [17,21].

Nevertheless, the seeds of *Mucuna*, in addition to having a high level of protein (29–38%) [22,23], contain L-Dopa (3–7%) [24], a derivative of the amino acid tyrosine, which can have undesired effects on animals that consume the seed in excess and has allelopathic effects in plants also [25]. Many supplements have been developed from *Mucuna pruriens* for Parkinson's disease [26], particularly from seeds [27]. In a separate study, we explore the extraction of L-Dopa from *Mucuna* seeds [28], leaving behind, unused, around 80% (w/w) seed residues. This seed residue, solvent-free treated and without L-dopa, could serve as a potential fertilizer in the soil, potentially benefiting agricultural crop yields. The seeds of *Mucuna* are also rich in minerals, such as potassium, magnesium, zinc, calcium, and phosphorus [22]. Previous research has used the plants of *Mucuna deeringianum*, a synonym for *Mucuna pruriens*, to produce green manure, fix nitrogen, and improve soils by incorporating the seeds into the cultivation soil [29]. However, there are no records of using residues of *Mucuna* seeds directly as an organic edaphic fertilizer. *Mucuna* pruriens is not cultivated commercially or for autoconsumption but as an intercropped and covert crop plant. Therefore, there are no registers of worldwide seed production. However, there are reports of from 0.5 to 2 tons/ha production in natural regions in Southern Africa [30].

On the other hand, foliar fertilization is increasingly being adopted worldwide as a strategy to improve crop nutrition [31]. It offers the advantage that nutrients applied directly to the leaves can provide quality, specificity, and rapid response that cannot be achieved through soil fertilization [32]. In this regard, using seed nutrients, including their content of biostimulants [33], is an option to reduce the use of chemical fertilizers and help increase crop yields [34]. The natural complex of the seeds gives these benefits in their extracts, which include essential plant nutrients, plant growth regulators, and plant protective compounds [35]. Therefore, avocado-seed extract could be used as a foliar biostimulant due to its wide variety of carbon sources [36], nitrogen, and micronutrients [37]. The avocado seed is encased in a hard shell and comprises 13–18% of the size of the whole fruit. It contains a good range of fatty acids, dietary fiber, carbs, and a small amount of protein. The seed is also considered a rich source of phytochemicals, including substances that plants produce to protect themselves [38].

Additionally, avocado seed has been reported to be rich in polyphenols, with antimicrobial and antioxidant activities. Their hydrolysate provides nutrients for the growth of bacterial cultures, such as *Lactobacillus* sp. and *Escherichia coli* [39–41], as well as different species of fungi [42]. Avocado is a plant native to Central America (Mexico and Guatemala) and the Caribbean (Antilles). Its fruit is valued for its flavor and nutritional properties, leading to increased consumption [43]. Global avocado production expanded at a compound annual growth rate of about 7% during the past decade [44] to just over 8.4 million metric tons in 2022, with Mexico being the largest producer, accounting for approximately 2.8 million tons (30%). It is estimated that the annual output of residual avocado seeds is around one million tons [45] if we consider that the seed represents from 13 to 18% (*w*/*w*) of the whole fruit [37]. While the agrifood industry processes tons of fruit, it also generates tons of discarded seeds as waste, causing potentially severe ecological problems [46].

Therefore, this research aimed to determine the potential beneficial effects of the residual seeds of avocado and *Mucuna Pruriens* on *cherry* plants. The avocado residual seeds can be produced in high quantities as a byproduct of the avocado agroindustry. Alternatively, *Mucuna pruriens* seeds can be the residual seeds after L-dopa extraction, as used in this study. For these purposes, different doses of *Mucuna* residual seed powder were added to the soil substrate, and the avocado seed extract to 1 and 2% on water or Long Ashton was applied as foliar to *cherry*-tomato cultivation under greenhouse conditions. The research is divided into two parts; in the first part, we report the nutrient content of the two seeds. In the second part, we describe the effect of their application on *cherry*-tomato plants. The tomato crop was chosen because it is one of the most produced, consumed, and exported vegetables in México. The market for tomatoes in the United States was USD 2.4 billion in 2020, with 54.6% originating from greenhouses [47]. In Mexico, 82.7% of *saladette* tomatoes and 81.1% of *cherry* tomatoes are produced under protected agriculture.

2. Materials and Methods

2.1. Obtaining Avocado-Seed Hydrolysate (ASH)

We followed the methodology reported by Tzintzun-Camacho et al. (2016) [36]. *Hass* avocado seeds from fruits produced in the Michoacán state (MEX) were cut into small pieces and sun-dried. They were then finely ground and hydrolyzed (20% *w*/*v* in 1% phosphoric acid). Once neutralized to pH 6.5 with 10 M NH_4OH, the hydrolysate was filtered and subject to a second sterilization; the resulting extract was considered 100% avocado-seed hydrolysate (concentrated ASH), from which 1% or 2% (*v*/*v*) was prepared for the described treatments.

2.2. Obtaining the Residues of Mucuna Seed Powder (MSP)

Mucuna pruriens seeds from the ceniza cultivar [48] were finely ground to a particle size of around 1 mm and subject to L-Dopa extraction as described by Hernández-Orihuela et al. [28]. The resulting residue from the seed extraction was dried for exposure to the sun and onward, named *Mucuna* seed powder (MSP). It was mixed and homogenized with the soil substrate in the pots. The soil substrate consists of peat moss®: perlite®: vermiculite® (3:1:1 *w*/*w*/*w*). The supplied doses of MSP to the soil substrate were 2, 4, or 6 g per L of substrate.

2.3. Analyzing the Plant Nutrient Content of Avocado and Mucuna Seed hydrolysates

The sun-dried *Mucuna* seed residual powder was treated precisely equal to the avocado seeds for hydrolysis and nutrient solubilization. The hydrolysate solutions were analyzed for the content of chemical elements relevant to plant nutrition. For this purpose, we use the multiparameter photometer HI 83300 (Hanna® Instruments, Smithfield, RI, USA) and their commercial kits for each chemical element. We also sent the ASH solution, like compost, to the Fertilab laboratories for analysis (Celaya, Guanajuato, Mexico, MEX).

2.4. Extraction of Soluble Amino Acids in the Hydrolysates of Avocado and Mucuna Seeds

For three hours, 1 mL of each hydrolysate was dried under a vacuum at 45 °C. Free amino acids were extracted based on the protocol by Abraham et al. [49] with some minor modifications. Dried samples were extracted with 600 µL of absolute ethanol containing 1% polyvinilpolipirrolidone (PVPP) and stirred for 1 min. After this time, 600 µL of 120 µM α-aminobutyrate was added and incubated at 70 °C for 5 min, followed by a second incubation at 4 °C for 1 h. The samples were centrifuged at 14,000× g for 30 min at 4 °C, and the supernatant was recovered. The recovered supernatant was filtered on a 0.22 µM membrane Millipore (Darmstadt, Germany), and 20 µL was used to quantify amino acids. Before analysis by HPLC, the amino acids were derived with phenyl-isothiocyanate, according to Zheng et al. [50].

2.5. HPLC Conditions for the Quantification of Amino Acids in the Hydrolysates

Derivatized amino acids were analyzed in a reverse-phase HPLC system (Shimadzu DGU, Chiyoda, Tokyo, Japan) equipped with an Agilent Eclipse Plus C18 column (4.6 mm × 150 mm × 5 µm) with a flow rate of 0.9 mL/min. The mobile phases used were A: (0.15 M sodium acetate solution with 7% acetonitrile) and B: (acetonitrile: water in a 4:1 v/v) using the program described by Zheng et al. [50]. An SPD-20A photodiode array detector at 240 nm was used to measure the absorbance of eluted compounds. Pure amino acid standards (Sigma, Burlington, MA, USA) made standard curves. The amino acid content was reported as micrograms per gram of dried weight.

2.6. Experimental Location for Cherry-Tomato Cultivation

The experiment was conducted in an 8 × 8 m greenhouse at Cinvestav, Irapuato Campus facilities in Guanajuato, Mexico (20°43′ N, 101°19′ W) at an elevation of 1780 m. The greenhouse is a dome-shaped structure covered with plastic polystyrene on the top, antiaphid mesh on three sides, and only one side with a transparent polycarbonate wall on the back [51], where it adjoins to another greenhouse, creating a light gradient from the front to the greenhouse's interior. The greenhouse has three corridors in its interior with mud bricks on the floor. The greenhouse was naturally ventilated. Conditions like temperature and relative humidity were not controlled; however, these parameters were monitored at 2 m above the ground with a digital thermometer Loriskors® (Los Angeles, CA, USA) with a temperature precision of ±1 °C and humidity of ±2~3% with a 24 h record of minimum and maximum [51].

2.7. Plant Material

The cherry-tomato seeds used were of the commercial variety "Rojo Vita" (Sakata Seed Corporation, Kakegawa, Japan). These seeds consist of plants with an early cycle and indeterminate growth variety that requires 10 to 14 days to germinate. The fruits have a round shape with a 20 to 30-mm diameter and an intense red color. The fruits mature approximately 90 to 120 days after transplanting.

2.8. Germination and Crop Management

The tomato seeds were germinated on 13 August 2020 in 200-cell polystyrene trays filled with a soil substrate consisting of a solarized mix of leaf soil, loam soil, peat moss (Sunshine Mix No. 3®), vermiculite, and perlite in a proportion of 1:2:3:1:1, respectively, to a depth of 3 mm. During germination, each cell was watered with approximately 5 mL of distilled water every third day for the first ten days or until the apparition of the first true leaves. Subsequently, the watering regime remained unchanged, with 20 mL Long Ashton (LA) nutrient solution until transplanting [52,53]. The amount of water for irrigation after transplanting was increased depending on plant growth and the conditions inside the greenhouse. The seedlings were individually transplanted into plastic pots on 10 September. The pots had a volume of 3.0 L, containing 2.5 L of the inert substrate mixture. The plants were spaced at a density of six plants per square meter. After transplanting, the plants were fertilized with a universal Steiner nutrient solution [54,55] twice a week and irrigated with distilled water five times a week, using a volume of 200 mL each time. These volumes gradually increased to 300 mL until the appearance of the first flowers. The amount further increased to 400 mL per plant as the fruits developed, reaching 2 L per week. The average temperature inside the greenhouse was 28–35 °C, with a relative humidity of 40–50%. At the beginning of fruit production, thinning was performed on the first two bunches of each plant [56]. In the experiments, we had an event of blackflies (Diptera, Sciaridae) that we controlled with 2 mL/L Confidor (imidacloprid); the application was early in the morning, around 7:00.

2.9. Experimental Treatments on Cherry Tomatoes

The experiments consist of testing the effects of nutrients on substrate and foliar. Therefore, we have three controls and five treatments (Table 1). Controls consist of applying Steiner solution [55] to the substrate plus different foliar solutions: water (C1), Bayfolan® Forte (Bayer CropSciences, Krefeld, Germany) (C2), and Long Ashton (C3) [57]. Treatments T1–T3 involve applying Steiner solution to soil containing different amounts of MSP (2, 4, or 6 g/L substrate), and a foliar application of 100% LA solution containing ASH (1 and 2%). The treatment T4 differs because ASH was diluted as foliar in water 2% (*v*/*v*) instead of Long Ashton. In the T5 treatment, only water was applied to the substrate with 4 g/L MSP and 2% ASH as foliar, without the Steiner or Long Ashton solutions. When needed, the pH of the foliar solution was adjusted to 5.8 with 1 M NaOH.

Table 1. Substrate and foliar treatment's description.

Treatment Name	Treatment Code	Substrate Fertilization	MSP (g/L)	Foliar Fertilization
C1	S + W	Steiner	0	Water
C2	S + BF	Steiner	0	Bayfolan® Forte
C3	S + LA	Steiner	0	Long Ashton
T1	S–2 g/L + LA–1% ASH	Steiner	0	1% ASH in LA
T2	S–4 g/L + LA–1% ASH	Steiner	4	1% ASH in LA
T3	S–6 g/L + LA–1% ASH	Steiner	6	1% ASH in LA
T4	S–4 g/L + 2% ASH	Steiner	4	2% ASH in water
T5	W–4 g/L + 2% ASH	none	4	2% ASH in water

Abbreviations: MSP, *Mucuna* seed powder; S, Steiner solution; W, water; BF, Bayfolan Forte; LA, Long Ashton; ASH, avocado-seed hydrolysate.

The foliar application was done by mixing the 1 L foliar solution with 1 mL of Inex A® (Cosmocel, NL, Mexico, MEX). Approximately 5 mL of foliar solution was sprayed onto the foliage of the plants every seven days, starting three weeks after transplanting, using a manual sprayer. The spraying volume was increased according to the plant growth. Spraying was performed in the evening, around 18:00 h. Bayfolan® Forte was used as the commercial reference treatment and applied at the recommended dose by the supplier (4 L/ha) for tomato cultivation.

2.10. Evaluated Agronomic Variables

During the growth period after transplanting, we measured the plant height, number of flowers, number of fruits, fresh weight, and dry weight of the fruits. To track the plant height, we measured it weekly. We recorded the number of flowers produced throughout the growth period, conducting six records from October 2020 to January 2021. We harvested ripe fruits per plant on each collection date. Likewise, we recorded the fruits of four collection dates between January and February. These measures allowed us to calculate the average number of mature fruits produced per plant during these four collection dates. To know the fresh weight, we weighed all mature fruits from every plant on four dates and then calculated the average fresh weight per plant. The average dry weight was obtained by incubating the fruits in paper bags in a convection oven at 60 °C for four days. The equatorial diameter of the fruit was determined for the harvested fruits at each collection date using a digital vernier caliper (Mitutoyo™, Nagano, Japan).

2.11. Experimental Cultivate to Measure Fruit Quality

In another trial with identical crop-management practices, like treatment T3, we assessed the quality of the fruit by measuring the soluble solids in °C Brix. The °Brix readings were taken using the Sper Scientific 300058 refractometer (Shenzhen, China), which also reports the percentage of fructose and glucose in the sample. For this analysis, fully ripe fruits were collected at 60 and 70 days after transplanting. Measurements were performed using 100 µL of juice from two tomatoes, with three repetitions per treatment for six fruits per plant, and the readings were averaged from four replicates per treatment. The pH of the fruits was measured by macerating 25 g of tomato in 25 mL of distilled water using the HI 2210 pH meter (Hanna Instruments, Smithfield, RI, USA).

2.12. Experimental Design

The plants were randomly placed in the greenhouse bed using a complete block design. The design compared the fertilization factor with different levels, including three controls and five treatments (T1–T5) mentioned in Table 1. These were randomly distributed within four blocks (B1–B4) with four replications (R1–R4) to minimize the variation in natural luminosity inside the greenhouse. A total of 32 experimental units were compared (Table 2).

Table 2. Randomized blocks experimental design.

Blocks	**Treatments**							
B–1	C3R1	T2R1	C2R1	T5R1	T3R1	C1R1	T1R1	T4R1
B–2	T2R2	C1R2	T4R2	T1R2	C2R2	T3R2	T5R2	C3R2
B–3	C1R3	T4R3	T2R3	T5R3	T1R3	C3R3	C2R3	T3R3
B–4	T2R4	T3R4	C1R4	C2R4	T1R4	T4R4	C3R4	T5R4

B–1,4 Blocks. C1–C3, controls. T1–T5 are treatments. R1–R4, repetitions.

2.13. Statistics

We analyzed the data using ANOVA with a significance level of 0.05. To compare the means, we used Fisher's LSD test with GraphPad Prism 8.0.2 software (La Jolla, CA, USA).

3. Results

3.1. Nutrients Present in Avocado and Mucuna Seeds

Crops and agroindustrial residues are rich in nutrients such as carbon, nitrogen, phosphorus, potassium, and microelements necessary for crop growth. These elements help alleviate imbalances of nutrients in the soil and make up for the drawbacks of inorganic fertilizers. It is reported that avocado seeds are a rich source of nutrients and bioactive compounds [58]. They contain fatty acids, triterpenes, phytosterols, and glucosides from abscisic acid. Here, we analyzed the avocado-seed hydrolysate (ASH) used in this study to quantify the soluble nutrient content relevant to plant nutrition. Table 3 shows the number of nutrients from two quantifications of two batches of hydrolysate concentrated. It calculates their content in the diluted solution as applied to the cultivar; the reading variation between batches was around 1%.

Table 3. Nutrient elements contents on the ASH.

Element Compound	Content in 1% ASH mg/L or ppm	Element/ Compound	Content in 1% ASH mg/L or ppm
K_2O	68.00	Mo^{6+}	1.58
K	56.00	Mg^{2+}	1.40
Ca^{2+}	7.20	$PO4^{3-}$	0.76
Cl^-	5.00	P_2O_5	0.57
$SO4^{2-}$	3.83	P	0.25
NH_4^+	3.60	Cu	0.12
NH_3	3.40	Fe(II)+(III)	0.06
$NaMoO_4$	3.40	Fe(II)	0.06
NH_3-N	2.80	Fe(III)	0.00
NO_3-N	2.73	Zn	0.01
MoO_4^{2-}	2.65		

In another way, *Mucuna* seeds are nutritionally comparable to other legumes like soybean because of their similar protein, fiber, and carbohydrate contents. *Mucuna pruriens* seed is a good source of crude protein [59,60]. In our study, although only the avocado-seed hydrolysate was applied directly as a foliar solution at different dilutions, we decided to analyze the nutrient content of *Mucuna* seed residue powder, treated precisely equal to the hydrolysis of the avocado seed. This analysis was done only for comparative nutrient content since the MSP was applied without hydrolysate to the substrate in the pots. Table 4 shows the nutrients analyzed in the *Mucuna* seed and their concentrations. The results showed that the *Mucuna* seeds contain more $SO4^{2-}$, NH_4, Fe, Mo, and Mg^{2+} than the avocado seeds. The avocado seed, on the other hand, has a more significant amount of Ca, K, and nitrates than the *Mucuna* seeds. Due to these differences in the amount of nutrients, a combination of the application of both seeds may be beneficial for the cultivation of plants.

Table 4. Nutrient Content of Hydrolyzed *Mucuna* Seed Residue Powder.

Element/Compound	Content in 1% MSP (mg/L or ppm)	Element/Compound	Content in 1% MSP (mg/L or ppm)
K	54.00	Ca^{2+}	1.50
K_2O	45.00	NO^{3-}	0.89
SO_4^{2-}	12.30	Cl^-	0.68
NH_4^+	8.30	P	0.66
NH_3	7.80	Cu	0.08
Zn	7.50	$CaMnO_4$	0.07
NH_3-N	6.70	MnO_4^-	0.05
Fe total	5.12	Mn	0.03
Mo	5.02	$NaNO_2$	0.02
Mg^{2+}	2.25	NO_2^-	0.01
PO_4^{3-}	2.03	Fe(II)	0.01
P_2O_5	1.52	NO_2-N	0.01

3.2. Analysis of the ASH like a Compost Product

Analyzing the nutrient components of liquid compost before applying it to vegetable foliage ensures nutrient balance, prevents deficiencies and excesses, reduces environmental impact, and promotes cost efficiency. It also enables us to make informed decisions regarding compost application rates and adjustments, leading to healthier plants, higher yields, and sustainable agricultural practices. Seed hydrolysates were derived from the breakdown of powder seeds through acid hydrolysis, which involves chemical treatment to release and convert the compounds in the seeds. While seed hydrolysates can benefit plant growth due to the release of nutrients and bioactive compounds, the exact composition and nutrient content can vary depending on the specific seed and the hydrolysis process [61]. Table 5 shows the results of the compost analysis made to the ASH concentrated solution by a certified laboratory. It is observed that the pH and conductivity are adequate for cultivating plants. Their content of macronutrients is low compared to the cultivate requirement, so it was tested in combination with the Long Ashton solution for foliage treatment. The micronutrient content is attractive for complementing a formula for foliage nutriment.

Table 5. Results of compost analysis to the ASH solutions.

Determination	Method	Units	Result
pH	NMX-FF-109-SCFI-2008		6.2
Electric conductivity	NMX-FF-109-SCFI-2008	dSm	40
Total N	Dumas	%	0.02
P	Microwave digestion/ICP	%	0.01
K	Microwave digestion/ICP	%	1.25
Ca	Microwave digestion/ICP	%	0.02
Mg	Microwave digestion/ICP	%	0.01
Na	Microwave digestion/ICP	%	0.2
S	Microwave digestion/turbidometry	%	0.58
Fe	Microwave digestion/ICP	ppm	1.3
Cu	Microwave digestion/ICP	ppm	0.42
Mn	Microwave digestion/ICP	ppm	2.87
Zn	Microwave digestion/ICP	ppm	0.79
B	Microwave digestion/ICP	ppm	0.86
Humidity	Gravimetric method	%	89.7
Organic matter	Calcination	%	6.89
Ashes	Calcination	%	3.45
Organic carbon	Calcination	%	3.98
C/N	Dry base		225

While there is limited specific research on compost nutrient analysis of seed hydrolysates, they are known to contain various beneficial compounds, including amino acids, peptides, enzymes, and growth regulators. Avocado-seed hydrolysates have gained attention due to their potential agricultural applications. These hydrolysates are reported to contain compounds with antioxidant, antimicrobial, and plant-growth-promoting properties. However, the specific nutrient content of avocado-seed hydrolysates can vary depending on the extraction and hydrolysis process used. It is worth noting that while seed hydrolysates may contain beneficial compounds, they are typically used with other fertilizers or compost materials to provide a balanced nutrient supply to plants. Understanding the nutrient content of the hydrolysate and other compost materials used in conjunction is essential to achieving optimal nutrient balance for plant growth.

In addition to their compost analysis, we also decided to test the content of possibly hazardous metals in the ASH solution. Table 6 shows that ASH is safe for plant cultivation.

Table 6. Analysis of heavy metals present in the ASH concentrated solutions.

Determination	Method	Method Limit of Quantification	Content (ppm)
Ni	EPA 6010C 2007	0.25	<0.25
Co	EPA 6010C 2007	0.25	<0.25
As	EPA 6010C 2007	0.05	<0.05
Ba	EPA 6010C 2007	0.5	<0.5
Cr	EPA 6010C 2007	0.3	<0.3
Cd	EPA 6010C 2007	0.01	<0.005
Al	EPA 6010C 2007	0.1	<0.10
Pb	ICP-AES	0.5	<0.5
Hg	ICP-AES	0.1	0.1
Si	ICP-AES	0.5	9.97
Be	ICP-AES	0.5	<0.5

3.3. Analysis of Amino Acids Content in the Avocado and Mucuna Seeds Hydrolysates

Avocado seeds and other plant-derived protein hydrolysates have gained attention as a potential source of bioactive compounds, including amino acids [62]. The hydrolysis of avocado seeds can release various compounds, including proteins, peptides, and amino acids. Table 7 shows the results of soluble amino acids in the ASH and MSP hydrolysates. We can observe that, on average, the ASH is more balanced in amino acid content since it only lacks tryptophan. In contrast, the MSP lacks methionine and valine. However, their content is higher than ASH in almost all the other amino acids. For that reason, a mixture of both hydrolysates could be more equilibrated on amino acid content.

Table 7. Amino acid composition of ASH and MSP hydrolysates.

Amino Acid	ASH, µg/L (SD)	MSP, µg/mL (SD)
Aspartic acid	57.258 (±3.024)	233.119 (±16.991)
Glutamic acid	7.024 (±0.554)	50.389 (±4.353)
Asparagine	8.952 (±1.126)	11.516 (±0.552)
Serine/glutamine	10.758 (±1.541)	4.192 (±0.154)
Glycine	15.871 (±0.570)	12.571 (±1.041)
Alanine/histidine	5.914 (±0.595)	12.593 (±0.642)
Arginine	2.896 (±0.349)	14.431 (±1.304)
Threonine	1.899 (±0.179)	6.989 (±0.449)
Proline	3.870 (±0.248)	50.190 (±1.738)
Tyrosine	4.454 (±0.408)	10.952 (±0.238)
Valine	0.406 (±0.074)	0
Methionine	1.700 (±0.345)	0
Isoleucine	1.136 (±0.205)	5.374 (±0.537)
Leucine	1.171 (±0.184)	16.421 (±1.192)
Phenylalanine	1.871 (±0.379)	6.594 (±0.638)
Tryptophan	0	11.254 (±0.574)
Lysine	6.125 (±0.083)	3.769 (±0.208)

Abbreviations: ASH, Avocado-Seed Hydrolysate; MSP, *Mucuna* Seed Powder; SD, standard deviation.

Amino acids can function as biostimulants for plants and play an essential role in plant productivity, especially under abiotic and biotic stress conditions. Some amino acids are efficient metal-ion chelators, which can help with metal-ion nutrient uptake and help protect plants from toxic levels of metal ions. Additionally, the presence of amino acids in foliage nutrients or stimulants can save the energy expended by the plant to produce organic matter and have to synthesize fewer nitrates and ammonia for amino acids. The importance of amino acids is that they are the building blocks of proteins, which play a crucial role in plant growth and development, as they are involved in cell division, enzyme production, photosynthesis, and overall plant structure. Enzymes, a class of proteins, are crucial in nutrient uptake, hormone regulation, defense mechanisms, and other biochemical reactions. Certain amino acids, such as proline, glycine, and glutamic acid, act as osmoprotectants and play a role in osmotic regulation and stress tolerance. Amino acids are involved in synthesizing and regulating plant hormones like auxins, cytokinins, and gibberellins, which are essential for plant growth, flowering, fruiting, and other developmental processes. Further, amino acids can enhance nutrient uptake and utilization in plants since they can chelate or complex with specific nutrients, making them more available for absorption by plant roots. Finally, amino acids, particularly certain essential ones, have been reported to promote plant growth development and enhance overall plant vigor.

3.4. Experimental Testing of the Contribution of ASH and MSP in Improving the Agronomic Parameters of the Cherry-Tomato Cultivar

3.4.1. Plant Height

When evaluating plant nutrition, differences in plant height can provide valuable insights into plants' overall health and vigor. Plant height is an essential morphological characteristic that reflects the growth and development of plants, and various factors, including nutrient availability, influence it. According to the analysis of results, a tendency was observed to increase the plant height with the applications of Long Ashton and ASH. However, these data were not statistically significant regarding the other treatments (Figures S2 and S3). The plants treated with water as foliar growth was less.

3.4.2. Flower Production

Differences in flower production can provide insights into the plant's reproductive health and the effects of nutrient availability. Adequate nutrition is crucial for cherry tomato plants to produce an optimal quantity of flowers, eventually leading to fruit formation. In our treatments, the analysis of variance showed significant differences ($p \leq 0.05$) in flower production. S–6 g/L + LA–1% ASH (T3) presented the highest number of flowers (29.95) compared to 20.50 of the C1 (S + W) and 17.58 of the C2 with Bayfolan as foliar (S + BF), (Figure 1). It is worth mentioning that treatment T5, with both residues without chemical supplements, performs better than the controls.

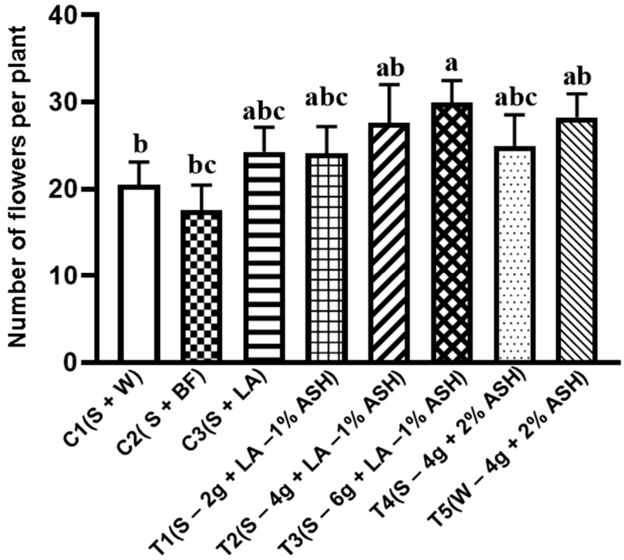

Figure 1. Effect of the treatments on the number of flowers in cherry-tomato plants 150 days after transplanting. Different letters mean significant differences (DMS $p \leq 0.05$); the bar above each column indicates the standard error. Different superscript letters indicate statistically significant differences between group means under each condition.

The more outstanding production of flowers in the treatments with ASH + 6 g of MSP may be because of ASH's K and Zn content. In addition to its biostimulant properties to mobilize and make efficient the use of nutrients in the plant and the absorption of these by the roots. The higher K, Fe, and NH_4^+ content in the MSP can complement the levels of these nutrients in the irrigated Steiner solution in the substrate and the Long Ashton used as a foliar. It has been shown that high levels of K and N influence a more significant number of flowers and earlier flowering [63]. When counting flowers, it is necessary to consider that certain flowers eventually develop into fruits. Therefore, tracking flower and fruit parameters consistently over time is crucial.

3.4.3. The Number of Fruits

When evaluating plant nutrition, differences in fruit production can provide valuable insights into the effects of nutrient availability on the plant's reproductive success. Adequate nutrition is essential for cherry-tomato plants to produce an optimal quantity of fruits. In this regard, significant differences ($p \leq 0.05$) were found between the treatments on the average number of fruits produced per plant on the four collection dates. The highest average numbers of fruits collected per plant per collection date were produced by the T3 treatments, with MSP in the substrate and ASH as foliar (Figure 2), compared to the controls with water (C1) and Bayfolan® Forte (C2) as the foliar, which were those with the poor performance.

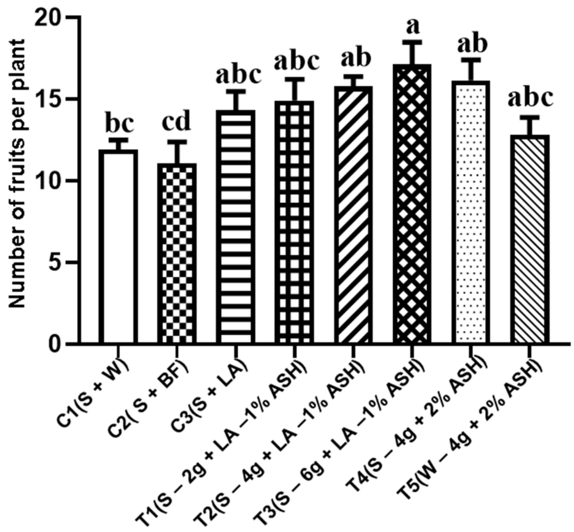

Figure 2. Effect of the treatments on the production of cherry-tomato fruits at 150 days after transplanting. Different letters mean significant differences (DMS $p \leq 0.05$); the bar above each column indicates the standard errors. Different superscript letters indicate statistically significant differences between group means under each condition.

The fruit set may reflect the overall plant performance since, when the plants increase in height, they tend to have a more significant number of leaves, more floral clusters, and more bunches of fruits. Similar to flowers, the number of fruits in tomatoes is increased by the content of N and K [64–66]. KNO foliar spray and urea also increase the production of flowers and the number of fruits in mango [67]. In this investigation, the MSP and ASH treatments provided these nutrients more significantly than the Bayfolan® Forte (C2). Moreover, the biostimulant action of the components of the avocado-seed extract may also favor the absorption and mobilization of nitrogen and nutrients to promote a more significant number of fruits.

3.4.4. Fruit's Fresh Weight

Measuring fruit's fresh weight is essential in evaluating plant nutrients because it helps assess nutrient content, gauge nutrient uptake and translocation, monitor plant health and productivity, estimate yield, and support research and experimentation into plant nutrition. Although gross data show no statistical differences among the treatments (Supplementary Figure S4), comparing the better and the worst treatments reveals differences that could be economically relevant. The average production of fresh-weight fruits per plant in treatment T3 resulted in 1042 g versus 842 g from C3. That is a 23% difference and an 18% respect to the control with Bayfolan® Forte (C2). In practical terms, considering a greenhouse of one hectare with 40,000 plants (four plants per square meter), this difference in fruit weight translates to an overall increase of 2 and 1.64 tons per hectare, respectively.

3.4.5. Fruit's Dry Weight

Measuring the dry weight of fruit complements the information gained from measuring the fresh weight when evaluating plant nutrients. It provides insights into nutrient concentration, water content, storage and shelf life, and nutrient uptake efficiency and facilitates comparative analysis. These data points improve nutrient management, fruit quality, and crop productivity. In this regard, the treatment with 1% ASH plus 4 g MSP presented the highest value of 34.90 g compared to the values of the control C3 (24.92 g) and the

Bayfolan ®Forte C2 (25.1 g) (Figure 3). The fresh weight did not show statistical differences, but the dry weight did. This difference could be because the percentage of dry weight concerning the fresh fruits was 13.4% in T3 versus 11% in the controls. The higher percentage of dry weight in the treatments with residual seeds reflects that these fruits incorporate more solids, contributing to the fruit quality instead of just water as in the controls.

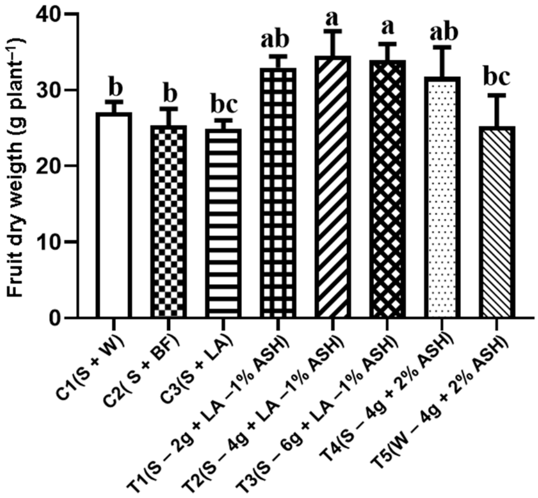

Figure 3. Effect of the experimental treatments on the dry weight of harvested cherry-tomato fruits. The bar above each column indicates the standard error. Different superscript letters indicate statistically significant differences between group means under each condition.

Although in the present study, the potassium concentration in fruits was not determined, Besford and Maw [64] determined that the K content is closely correlated with the dry biomass content of the tomato fruit. The contribution of K present in the MSP and ASH, in addition to the biostimulant property of ASH, can favor the accumulation of K in the fruit. Regarding the weight as a dry matter of the fruit, the characteristics of the number and dry weight of the cherry fruits are fundamental in the yield of the tomato plant. This parameter added to the content of soluble solids and the flavor as the commercial attributes of more significant consideration than the pure agronomic improvement [68].

3.4.6. Fruit's Equatorial Diameter

Estimating the equatorial diameter of fruit is relevant in plant nutrition because it provides information about fruit size, nutrient uptake and translocation, nutrient partitioning, and yield estimation. Our data indicates that this parameter was the most uniform among all the treatments (Supplementary Figure S5). The sizes of fruits were around 21 mm, being slightly greater by around 1 mm in those fruits from the controls C1 and C2.

3.5. Summary of Percent Increment on the Evaluated Parameters

The percentage of increment in growth variables and those associated with fruit yields, such as the height, the number of flowers, the number of fruits, and fruit weight in treatments T1–T3 compared to the control Bayfolán® Forte (C2), are presented in Figure 4. The effect of the 1% ASH plus 6 g MSP treatment reached a maximum increase of 70% in the number of flowers, 23% in the number of fruits, and 25% in the fruits' dry weight. The increment was below 14% in the parameters that were not statistically significant. Interestingly, there is a correlation between the increment of residual *Mucuna* seeds and their positive effect on plant height and the number of flowers and fruits. However, only the number of flowers and fruits was shown to be statistically significant. On the fresh and dry weights of fruits, it seems that treatment T2 is slightly better than T3; that is, 4 g/L MSP to the soil instead of 6 g/L of T3.

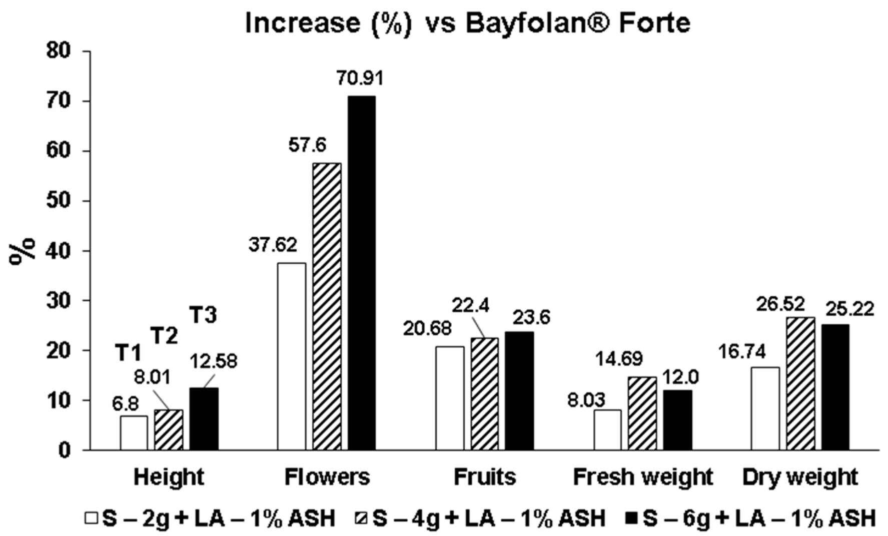

Figure 4. Percentage of increase in the agronomic variables due to the combination of 1% ASH plus 2, 4, or 6 g of MSP (T1–T3) compared to the effect of the foliar Bayfolan® Forte (C2).

The 12.58% increase in the average height of the plant caused by 1% ASH plus 6 g MSP treatment was comparable with that reported for the application of FitoMas-E® biostimulant (0.7 L/ha) in vertisol cultivation of tomatoes, reported by Hijuelos and Martín [69]. They also reported an increment in the number of flowers and fruits per plant. Notably, the T5 treatment in our study, comprising only MSP as a substrate and ASH as a foliar application without the additional chemical supplements of Steiner or Long Ashton, exhibits a performance similar to that of the C1–C3 controls.

3.6. Effects of Nutrients on the Content of Soluble Solids and pH in Fruits

The Brix grades (°Brix) provide insights into the sweetness and flavor of tomatoes and are correlated with specific nutritional components. The measure of °Brix indirectly reflects the nutritional content, determines fruit maturity and ripeness, and influences market value and consumer preference. Furthermore, measuring fructose, glucose, and sucrose in tomato fruits is relevant for evaluating sweetness and flavor, assessing carbohydrate content, understanding nutrient density, determining ripeness and maturity, and monitoring postharvest quality. These sugars are related to the nutrient content in tomatoes as they contribute to the overall nutritional profile and can indicate changes in fruit quality.

Thus, in a second set of plant experiments (C1–3, T1, and T3), we decided to test the concentration of sugars (°Brix) in fruits between two points of collection of fruits (Supplementary Figure S6). The fruits of plants with a higher stage of development had slightly more soluble solids content, but the differences were not statistically significant. The °Brix serves as an indicator of the quality of the vegetables, and their values serve to carry out better management of the crops [70].

The values registered in the °Brix were increased from <6.0 in the controls to between 6.0 and 7.0 with the MSP and ASH treatments. For comparison, the average °Brix of 30 cherry-tomato accesses reported by Ceballos-Aguirre and Vallejo-Cabrera was 4.93 [71].

Fructose and glucose are the main sugars present in ripe tomato fruits, and they increase progressively with the ripening of the fruit, with lower amounts of sucrose [72]. Fructose was the sugar in the highest amount in ripe fruits, almost 30%. It increased above control values in treating ASH in combination with MSP. Similarly, the pH increased with the treatments and with the maturation of the fruit concerning the control treatment. Similar results have been reported elsewhere [73].

Finally, our results compare with the results carried out with the commercial biostimulant FitoMas-E® for soil tomato cultivation [74]. The increasing percentage of flowers and fruits compared to the control with water is like that obtained in this study. In the mentioned study, they report higher values in parameters such as plant height and fresh and dry biomass. However, they grow in soil, while in the present study, it was in a composed inert substrate, which may explain some differences.

4. Discussion

As the world's population grows, finding ways to produce food sustainably is becoming increasingly important. New concepts in sustainable agriculture offer promising solutions that can help protect the environment, adapt to climate changes, and ensure food security for future generations [75,76]. In addition to precision and regenerative agriculture widely reported, this work leads with the concepts of green nitrogen and using agroindustrial residues in plant stimulation and nutrition [77,78]. Green nitrogen is a term used to describe the use of biological nitrogen fixation to replace synthetic nitrogen fertilizers. Our understanding of how nitrogen and carbon in seeds influence plant germination and development is in its beginnings [79,80]. In this study, we work with the process by which nitrogen fixation bacteria in symbiosis with the roots of leguminous plants convert atmospheric nitrogen into forms that plants can use and store part of it in their seeds [81]. Then, we use the seeds resulting from agroindustrial residual processes as a sustainable way to provide crops with nitrogen and other nutrients and stimulants [82]. Notably, crop residues are recognized as more than half of the agricultural fixed biomass that should be used as a provider of essential environmental services [83]. In this study, we complement the content of *Mucuna* and *avocado* residual seeds with a commercial product and a well-known chemical formulation, like Long Ashton, respectively, to improve their performance in cherry-tomato plants. We observed improvements in essential agronomic parameters (number of flowers, number of fruits, and fruits' dry weight); securely, there are soil benefits that we do not quantify because we centered on the plant and their fruits. Still, the MSP probably has low liberation of nutrients to the soil, which should benefit the soil and microbial community in more than a round of plant production, as demonstrated in other plant cultures [84,85].

Although the evaluated variables, such as plant height and fruit diameter, show few differences in crop yield, there was a significant increase in the number of flowers, fruits, and their dry weight when applying MSP and ASH. In both cases, at values above the treatments sprayed with water, the commercial products Bayfolan® Forte and Long Ashton alone. Bayfolan® Forte is declared in its technical information to be a systemic laminar foliar nutrient by Bayer Crop AgroSciences. It was considered a commercial control given that it is a relevant product in the Mexican market of USD 1.5 billion for foliar fertilizers [86]. Despite their market participation, we found only one academic report on their use in microalgae cultivation [87]. The avocado seed is reported to have multiple nutrients [88], and *Mucuna pruriens* is more commonly used as the entire plant for its multiple cultural and agronomic benefits [89,90]. This study shows that avocado and *Mucuna* seeds have significant compounds that can function as plant nutrients, mainly diverse and rich in amino acids. Thus, we found that the dilution of 1% ASH in the Long Ashton nutritive solution plus 4–6 g/L doses of MSP contributes to the plant production of flowers and fruits. This increase is above the values of purely mineral fertilization with the Steiner and Long Ashton solutions. The most adequate treatment is 1% ASH in Long Ashton as the foliar and 6 g/L MSP with Steiner solution to the soil substrate. It is worth highlighting that treatment T5, which consists of 6 g/L MSP to substrate and 2% ASH as foliar, yields comparable results to the controls C2 and C3. This result means we can use the residues alone and omit adding Steiner's nutrient elements to the substrate and Long Ashton as the foliar. These results present a viable alternative for production that eliminates the need for chemical fertilization in favor of using only residual seeds.

In this sense, the results of the present investigation indicate that the MSP residue mixed with the substrate may gradually release nutrients into the soil. In addition, its content of biostimulants towards the tomato plant, in combination with the nutrient and foliar biostimulant provided by ASH, can be used to improve the cultivation of Cherry tomatoes in greenhouses, soil, or hydroponics. This study on environmentally safe organic fertilization can indicate that it is possible to have a competitive product without chemical components, reducing the economic and environmental costs invested in developing synthetic fertilizers.

This study can also be an example of the integral use of residual biomass. This approach may be integral because no solvents were used to treat the avocado and *Mucuna* seed residues; neither chemicals nor wastes were released into the environment. There are only avocado-seed insoluble residues (around 65% w/w) in obtaining ASH [36]; this insoluble residue, after the hydrolysis, can be mixed with the MSP and integrated into the soil substrate. This use of ASH residues is a pending task we will test to have an integral use of the residual seed biomass.

We try to compare our results to those obtained when applying similar organic products of agroindustrial processes. However, there are rare similar products with documented information on their effects on plant performance. However, recent meta-analysis studies conclude that bio-organic fertilization greatly benefits the plants, their product, and the soil. In particular, these bio-organic products improve specific soil properties, such as pH and conductivity, differently from chemical fertilization [91]. In tomato cultivation, organic fertilizer widely improves different parameters of the tomato fruit's quality [92,93]. An example of a product with documented results was FitoMas-E®, produced with wastes from the sugar industry in Cuba. Our results were nearly comparable to those obtained when applying FitoMas-E®. Some observed differences may be because of the different organic sources used to make the products and the different experimental conditions; FitoMas-E® has been almost wholly tested directly in the soil [69] and in vitro [94].

In any case, the wide use of agroindustrial residues is necessary. A study reviewed the utilization of agroindustrial waste for sustainable green production and found that the accumulation of agricultural waste is over two billion tons worldwide [95]. The study suggests that it is imperative to investigate how agroindustrial waste utilization can be advanced to maximize benefits to the sector. In another study, they report a bio-organic fertilizer (BoF) prepared using kitchen waste (79%), chita-dhan (unfilled rice grain) biochar (15%), rock phosphate (5%), and a consortium of 10 plant-growth-promoting bacteria (PGPB) (1%). With this BoF, they can replace 30% nitrogen and triple superphosphate (TSP) fertilizer in rice production and improve soil health [96,97]. In any case, there are many products in the market of organic fertilizers [98], but almost none have academic support regarding their composition or mode of action for the plants. Thus, more products must be experimented with scientifically to advance to a more precise and sustainable agriculture [96]. In addition to having sustainable agriculture, human health should benefit from the wide adoption of organic agriculture [99,100]. In our study, we need to make further tests in other plants of the *Solanaceae* to affine a sure product. However, we are confident in our approach to the work we have done in the last three years in experimenting with the avocado-seed hydrolysate in tomato and chili.

From the social and familiar perspective in low-income countries, a recent study proposed creating affordable, sustainable technologies tailored for rural farmers to adopt to valorize byproducts. This transformation would transition traditional agribusiness into a more sustainable value chain. The study outlined three productive initiatives centered around utilizing byproducts as raw materials to achieve socioeconomic and environmental sustainability. These initiatives encompassed processes such as biodrying to extract moisture from byproducts, the creation of compost, vermicompost, and bokashi, as well as the cultivation and harvesting of edible mushrooms. These proposed activities can significantly enhance rural farmers' sustainability and profitability [101]. By curbing the reliance on mineral fertilizers, rural fuel could be generated while simultaneously generating additional income for families.

5. Conclusions

The research carried out in this work aimed to show the nutritional value of residual seeds. For this purpose, we use the avocado seed as one byproduct of the great avocado agroindustry in México. The other seed was from *Mucuna*, which can result after the L-dopa extraction. The nutrient analysis of *avocado* and *Mucuna* seeds reveals the presence of essential plant nutrition elements and is safe for agriculture. Furthermore, both seeds have a balanced content of amino acids as putative biostimulants. The nutrition experimentation with cherry-tomato plants confirms the beneficial effect of combining the *Mucuna* seed powder residue added to the soil substrate and the foliar biostimulant prepared from a concentrated extract of avocado-seed hydrolysate. Combining 6 g/L MSP in soil with Steiner nutritive solution and 1% ASH in Long Ashton nutritive solution as a foliar significantly increased the three primary parameters for plant productivity: number of flowers, number of fruits, and dry weight. Overall, this work contributes to the potential use of agroindustrial residues as providers or essential nutrients to crops, which can contribute to the path of having sustainable agriculture, resilience to climate changes and resource scarcity, and contribute to covert the global demand for foods with good public perception.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agrochemicals2040029/s1, Figure S1. A photograph of this experiment's Cherry tomato plants when growing in the greenhouse. Figure S2. Plant height. This photograph shows a representative comparison of plant stature among the different treatments. The plants that were treated with T1–T3 showed higher height than the others. Figure S3. Plant height. This graph shows differences in plant height among different treatments, although the differences were not statistically significant ($p < 0.05$). C3, T2, and T3 treatments presented a higher difference compared to C1 treatment. Figure S4. Fruit fresh weight. There were no significant ($p < 0.05$) differences in Cherry tomatoes' fresh weight among the different treatments, although T2 and T3 treatments presented higher values than C1–C3 controls. Figure S5. Fruit diameter (mm). Fruits were not significantly different ($p < 0.05$) in equatorial circumference. Figure S6. Fruit quality of Cherry tomatoes. Measurement of sugar concentration and pH trend of the fruits at 60 and 70 days after transplanting. DAT = days after transplanting. Figure S7. Mature fruits. The picture shows a representative view of ripe fruits harvested four months after transplanting. All fruits had an intense red color. Figure S8. Inside view. Cross sections of tomato fruit tissues present normal characteristics. For instance, on mesocarp thickness, and placenta or seed size. Figure S9. A sample of dried tomatoes after incubation in an oven at 60 °C for 72 h. Table S1. Plant height data (cm). Each value represents the average measure per plant from six measuring dates. Table S2. Number of flowers data. Each value represents the average number of flowers per plant from six count dates. Table S3. Fruit number data. Each value represents the average number of fruits per plant from five harvesting dates. Table S4. Fruit fresh weight data (g). Each value represents the average weight of the sum of fresh weights of five harvesting dates per plant. Table S5. Fruit dry weight data (g). Each value represents the average weight of the sum of dry weights of five harvesting dates per plant. Table S6. Fruit diameter data (mm). Each value represents the average weight of the sum of dry weights of ten harvesting dates per plant. Table S7. ANOVA statistics for plant height. Table S8. ANOVA statistics for flowers production. Table S9. ANOVA statistics for the number of fruits. Table S10. ANOVA statistics for fruit fresh weight. Table S11. ANOVA statistics for fruit dry weight. Table S12. ANOVA statistics for fruit diameter.

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