



RESEARCH ARTICLE

Effect of different spent mushroom substrates on growth and yield of green gram (*Vigna radiata* L.) under pot conditions

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Abstract

A pot experiment was conducted to assess the effect of *Hypsizygus ulmarius* (Hu) spent mushroom substrates derived from different agro-residues on the growth, yield, nutrient uptake and soil fertility of green gram (*Vigna radiata* L.). The treatments comprised recommended dose of fertiliser (RDF) combined with spent paddy straw (HuSPS), pigeon pea husk (HuSPH) and mulberry waste (HuSMW), either alone or in combination with farmyard manure (FYM), along with a control. Among the treatments, RDF + 50 % HuSPH + 50 % FYM (T₅) recorded significantly better plant growth with maximum plant height at 30 days after sowing (DAS) (28.33 cm), 60 DAS (39.93 cm) and harvest (40.03 cm), followed by RDF + 50 % HuSMW + 50 % FYM (T₇). The number of branches and total dry matter accumulation were also significantly enhanced under integrated treatments, with T₅ showing the highest values at all growth stages. Effective root nodulation was maximum in T₅ (8.67 nodules plant⁻¹), followed by T₇ (8.33 nodules plant⁻¹). Yield attributes such as seeds per pod, test weight and seed yield per plant were significantly superior in T₅ (9.67, 4.02 g and 4.48 g, respectively), closely followed by T₇ and T₃. Soil-available nutrients (nitrogen (N), phosphorus as fertiliser nutrient content (P₂O₅) and potassium as fertiliser nutrient content (K₂O)) and total nutrient uptake (N, phosphorus (P) and potassium (K)) were also markedly improved under integrated nutrient management treatments, particularly T₅ and T₇. The study indicates that the incorporation of *H. ulmarius* spent mushroom substrate, especially pigeonpea husk-based substrate combined with FYM and RDF, enhances the growth, yield performance, nutrient uptake and soil fertility of green gram under pot conditions.

Keywords: farmyard manure; green gram; *Hypsizygus ulmarius*; nutrient uptake; spent mushroom substrate; soil fertility

Introduction

The agricultural residues generated from pigeonpea, particularly the husks remaining after seed extraction and the residual mulberry shoots left after leaf harvesting contribute substantially to the volume of agro-waste. These lignocellulosic biomasses represent a valuable and underutilised resource with significant potential as substrates for mushroom cultivation. Utilising such residues not only facilitates effective waste valorisation but also supports the development of sustainable circular agricultural systems. The integration of these by-products into mushroom production aligns with the principles of the circular economy, enhancing resource efficiency and promoting environmentally responsible agricultural practices.

The residual substrate remaining after mushroom harvest, known as spent mushroom substrate (SMS) is a valuable by-product of mushroom cultivation. It consists of partially degraded agricultural wastes. After a few cultivation cycles, it is biochemically modified by fungal enzymes into a simpler form and enriched with protein. Fresh and aged mushroom spent substrate have been applied to the propagation of fruits, vegetables, flower and foliage

crops (1). It is a rich source of carbon (C), nitrogen (N) and other elements. Nitrogen content varies from 0.4–13.7 per cent and also contains cations like potassium ion (K⁺), sodium ion (Na⁺), calcium ion (Ca²⁺) and magnesium ion (Mg²⁺) and anions like chlorine ion (Cl⁻), nitrate ion (NO₃⁻) and sulphate ion (SO₄²⁻) all of which are essential for optimal plant growth and development (2). The combined application of SMS and farmyard manure (FYM) offers a sustainable strategy to enhance soil fertility and crop productivity. The SMS improves soil structure and organic matter content, while farmyard manure boosts nutrient availability. Their synergistic effect supports better root development, nodulation and yield in agricultural crops.

Green gram (*Vigna radiata* L.) is a tropical pulse known as moong, mung bean, golden gram, etc. It is an excellent source of high-quality protein, containing about 25 per cent protein, which is almost 2.5–3.0 times more than that of cereals. Its fat content is less than 1 per cent and it is high fibre, starch (62 %), vitamins B₃, B₅ and B₉, Ca (132 mg) and Mg (189 mg). Pods can be used as vegetables and can also be used as dry-roasted grains, cooked and sprouted grains or after dehulling, as mung dhal. It is highly digestible pulse crop than any other pulses. The husk and haulms are used as good

fodder for cattle and even the leftover seed coat that is, the testa is used for feeding milch cattle to increase milk production (3). Green gram belongs to the family Leguminosae or Fabaceae, originated in India and largely grown under semi-arid and subtropical environments of India, Myanmar, Pakistan, Thailand, Sri Lanka, Indonesia and China. In India, it is grown in an area of 5.13 M ha with the production of 3.08 MT and productivity of 601 kg ha⁻¹. In Karnataka, it is cultivated in an area of 4.53 lakh ha with 1.81 lakh tonnes of production and productivity of 402 kg ha⁻¹ (4). More than 90 per cent of the area is concentrated in northern districts of Karnataka viz., Belagavi, Bidar, Dharwad and Haveri and some parts of Southern Karnataka. In the context of sustainable agriculture, SMS, a nutrient-enriched by-product, of mushroom cultivation has emerged as a promising organic amendment for enhancing soil fertility and crop productivity. The application of SMS as a manure in green gram cultivation offers a dual advantage: it promotes waste recycling within a circular bioeconomy framework while potentially improving plant growth, yield and soil health due to its organic matter content and residual nutrients. Incorporating SMS into green gram crops thus aligns with eco-friendly and resource-efficient agricultural practices.

Materials and Methods

The study entitled 'Effect of different spent mushroom substrates on growth and yield of green gram (*Vigna radiata* L.) under pot conditions' was conducted at the College of Sericulture, Chintamani. The main aim of the pot experiment was to study the effect of different spent mushroom substrates.

Utilisation of spent mushroom substrate for crop growth under pot experiment

A pot experiment was conducted to evaluate the effect of different spent mushroom substrates on the growth and yield of green gram at the College of Sericulture, Chintamani. Uniform pots, each with a surface area of 572.26 cm² were filled with 10 kg of a soil and sand

mixture in a 2:1 ratio (6.66 kg soil and 3.33 kg sand by weight). The pots were subsequently amended with various SMS derived from *Hypsizygus ulmarius*. The control treatment consisted of the standardised soil and sand mixture along with the recommended dose package of practices, but without the addition of spent mushroom substrate. The spent mushroom substrates were applied to the green gram crop based on their N equivalence to FYM to evaluate their effects on crop growth and yield performance. The details of the treatments and the quantities of the different SMS of *H. ulmarius*, applied to the pots are provided in Tables 1 and 2.

Application rates of fertilisers, farmyard manure and *Hypsizygus ulmarius* spent mushroom substrate for pot experiment

In this study, the nitrogen content of FYM was replaced by various spent mushroom substrates derived from *Hypsizygus ulmarius* cultivated on pigeonpea husk, mulberry waste and paddy straw. In the treatments, the amount of N in the different *Hypsizygus ulmarius* spent mushroom substrates was adjusted based on its N equivalence to that of FYM. The quantities of fertilisers, FYM and the different *Hypsizygus ulmarius* SMS used in the pot experiments are provided in Table 3.

Growth parameters

To assess the influence of different treatments on the growth of green gram, periodic observations were recorded at 30 and 60 days after sowing (DAS) and at the harvest stage, as detailed below.

Plant height (cm)

The plant heights of five randomly selected tagged plants were measured from ground level to the growing tip of the fully opened leaf at 30, 60 DAS and at harvest. The average plant height of five plants was computed and expressed in centimetres (cm).

Number of branches plant⁻¹

The number of branches plant⁻¹ arising on the main stem in five randomly selected tagged plants was recorded at 30, 60 DAS and at harvest. The average was taken as the number of branches plant⁻¹.

Table 1. Experimental details of *Hypsizygus ulmarius*

Crop	green gram
Variety	KKM - 3
Number of treatments	07
Number of replications	03
Statistical design	Completely randomized block design
Size of pot	572.26 cm ²
Recommended dose of fertiliser	10:20:20 per acre
FYM	3 tonnes per acre
Biofertilisers	Nitrogen fixer and phosphorous solubilisers used for seed treatment as per package of practices (200g per acre)

FYM: farm yard manure.

Table 2. Treatment details for pot experiment using *Hypsizygus ulmarius* spent mushroom substrate

T ₁	RDF
T ₂	RDF + 100 % <i>Hypsizygus ulmarius</i> spent paddy straw
T ₃	RDF + 50 % <i>Hypsizygus ulmarius</i> spent paddy straw + 50 % FYM
T ₄	RDF + 100 % <i>Hypsizygus ulmarius</i> spent pigeonpea husk
T ₅	RDF + 50 % <i>Hypsizygus ulmarius</i> spent pigeonpea husk + 50 % FYM
T ₆	RDF + 100 % <i>Hypsizygus ulmarius</i> spent mulberry waste
T ₇	RDF + 50 % <i>Hypsizygus ulmarius</i> spent mulberry waste + 50 % FYM

PoP: package of practices; RDF: recommended dose of fertiliser; FYM: farm yard manure.

Table 3. The different *Hypsizygus ulmarius* spent mushroom substrates used in the pot experiments

Treatments	g pot ⁻¹				
	FYM	Urea	SSP	MoP	HuSMS
T ₁	42.90	0.31	1.78	0.47	-
T ₂	-	0.31	1.78	0.47	11.69
T ₃	21.45	0.31	1.78	0.47	5.84
T ₄	-	0.31	1.78	0.47	9.90
T ₅	21.45	0.31	1.78	0.47	4.95
T ₆	-	0.31	1.78	0.47	11.69
T ₇	21.45	0.31	1.78	0.47	5.84

FYM: farm yard manure; SSP: single super phosphate; MoP: muriate of potash; HuSMS: *Hypsizygus ulmarius* spent mushroom substrate.

Total dry matter production plant⁻¹ (g plant⁻¹)

Plant samples for dry matter studies were collected at 30, 60 DAS and at the harvest from the pots. Plants were uprooted at random from each treatment and these samples were oven-dried at 650 °C until a constant weight was recorded. The dry weight of plants was recorded and the total dry matter production per plant was obtained by summing dry weight of the plants and was expressed on a per plant basis (g plant⁻¹).

Number of effective root nodules plant⁻¹

The uprooted plant root system was washed by keeping it in a bucket containing water and then the nodules were separated as active nodules by identifying pink colour after piercing the nodule. The number of nodules was counted and expressed on a per plant basis.

Yield parameters

To evaluate the effect of different treatments on the yield of green gram, observations on yield and yield-contributing parameters were recorded at harvest as detailed below.

Number of seeds per pod

The seeds from each pod were separated manually and counted. The average number of seeds from five pods was recorded.

Test weight (g)

One hundred seeds from each pot were randomly counted and the weight was noted as test weight in grams.

Seed yield (g/plant)

After harvesting the plants, the pods were randomly selected to record the seed yield plant⁻¹. Separated seeds from representative pods of the plants were taken and weighed for seed weight, which was multiplied by average number of pods plant⁻¹. It was expressed as g plant⁻¹.

Soil sample collection and analysis

Soil samples were collected from all treatments at harvest from a depth of 0–15 cm and analysed for available N, P and K using the standard procedures described below.

Available nitrogen

Five grams of soil was distilled with 25 mL of 0.32 per cent potassium permanganate (KMnO₄) and 25 mL of 2.5 per cent sodium hydroxide (NaOH). The ammonia released was trapped in 4 per cent boric acid containing a mixed indicator and titrated against standard sulphuric acid (5) and expressed as kg ha⁻¹.

Available phosphorus

Available P was extracted from the soil using Bray's No.1 extractant (0.03 N ammonium fluoride (NH₄F) + 0.025 N hydrochloric acid (HCl)) and concentration in the extract was determined by chlorostannous reduced molybdophosphoric acid blue colour in HCl system using a

spectrophotometer (6) and the results were expressed as kg ha⁻¹.

Available potassium

Available K was extracted from the soils using neutral normal ammonium acetate in a 1:5 soil-to-extract ratio and the concentration of K present in the extract was determined by a flame photometer (6) and results were expressed as kg ha⁻¹.

Chemical analysis of plant samples

The plants sampled for estimating the dry matter production at different intervals were used to determine the major nutrient content. Each sample was washed with distilled water and dried in a hot air oven at 65 °C. The dried samples were powdered to considerable fineness before storing them in polythene bags for further analysis. These samples were used for the estimation of nutrient uptake.

Total nitrogen

The total N content in the seed and plant samples was estimated by Micro-Kjeldahl method (6) expressed as a percentage on a dry weight basis. In this method, a powdered sample of 0.5 g was digested with concentrated sulphuric acid (H₂SO₄) in the presence of a digestion mixture (potassium sulphate: copper (II) sulphate pentahydrate: selenium (K₂SO₄: CuSO₄. 5H₂O: Se) in the proportion of 100:20:1) and distilled under an alkaline medium. The liberated ammonia (NH₃) was trapped in 4 per cent boric acid containing a mixed indicator and titrated against standard H₂SO₄.

Digestion of plant samples with a di-acid mixture

A powdered seed and plant sample of 0.5 g were separately treated with 5 mL of concentrated nitric acid (HNO₃) for 12 h as pre-digestion. Then, the pre-digested samples were treated with a di-acid mixture (HNO₃: perchloric acid (HClO₄) in the proportion of 10:4) and the volume was made up to 100 mL with distilled water and preserved for total nutrient analysis (6).

Total phosphorus: The total P content in the di-acid-digested samples of seed and plant was determined by vanadomolybdate phosphoric yellow colour method in an HNO₃ acid system and the absorbance was estimated using spectrophotometer at a wavelength of 430 nm (6) and expressed as a percentage on a dry weight basis.

Total potassium: The total K content in seed and plant samples was determined by the flame photometry method under suitable measuring conditions (6) and expressed as a percentage on a dry weight basis.

Nutrient uptake

After estimating the nutrient content of seed and straw by adopting standard chemical analytical methods, nutrient uptake (kg ha⁻¹) by the crop was calculated for each treatment separately using the following formula.

Nutrient uptake by seed (kg ha⁻¹) =

$$\frac{\text{Nutrient concentration (\%)} \times \text{Seed yield (kg ha}^{-1}\text{)}}{100}$$

Nutrient uptake by haulm (kg ha⁻¹) =

$$\frac{\text{Nutrient concentration (\%)} \times \text{Haulm yield (kg ha}^{-1}\text{)}}{100}$$

Total nutrient uptake (kg ha⁻¹) = Nutrient uptake by seed + Nutrient uptake by haulm

Results

Effect of different *Hypsizygus ulmarius* spent mushroom substrates on growth parameters of green gram

Plant height (cm)

Data pertaining to effect of *Hypsizygus ulmarius* SMS on plant height of green gram under pot conditions are presented in Table 4. At 30 DAS, the significantly highest plant height was recorded in T₅ (RDF + 50 % *HuSPH* + 50 % FYM) (28.33 cm/plant), followed by T₇ (RDF + 50 % *HuSMW* + 50 % FYM) (27.20 cm/plant) and T₃ (RDF + 50 % *HuSPS* + 50 % FYM) (25.97 cm/plant) and they were on par with each other. The lowest plant height was observed in the control treatment T₁ (18.83 cm/plant) and it was on par with T₂ (RDF + 100 % *HuSPS*) (22.30 cm/plant) and T₆ (RDF + 100 % *HuSMW*) (23.50 cm/plant).

At 60 DAS, the significantly highest plant height was recorded in T₅ (39.93 cm/plant), which was on par with T₇ (39.03 cm/plant) and T₃ (37.03 cm/plant). Treatment T₄ (36.93 cm/plant) recorded significantly higher plant height than T₆ (33.53 cm/plant) and T₂ (32.93 cm/plant). The lowest plant height was observed in the control T₁ (32.00 cm/plant).

At harvest, the maximum plant height was recorded in T₅ (40.03 cm/plant), which was on par with T₇ (39.33 cm/plant). Treatments T₃ (37.37 cm/plant) and T₄ (37.13 cm/plant) recorded significantly higher plant height than T₆ (33.87 cm/plant) and T₂ (33.33 cm/plant). The lowest plant height was observed in the control T₁ (32.40 cm/plant).

Number of branches per plant

Data pertaining to effect of the *Hypsizygus ulmarius* SMS on the number of branches of green gram under pot conditions are presented in Table 5. At 30 DAS, RDF + 50 % *HuSPH* + 50 % FYM (T₅) recorded the significantly highest number of branches (3.33 per plant), which was on par with RDF + 50 % *HuSPS* + 50 % FYM (T₃), RDF + 100 % *HuSPH* (T₄) and RDF + 50 % *HuSMW* + 50 % FYM (T₇). The lowest number of branches was recorded in the control (T₁), with 2.33 per plant.

At 60 DAS, T₅ recorded the significantly highest number of branches (5.33 per plant) followed by T₃, T₄ and T₇ (5.00 per plant) while T₂ and T₆ (4.67 per plant) and the lowest was recorded in T₁ (4.33 per plant).

At harvest, T₅ recorded the significantly highest number of branches (5.33 per plant) followed by T₃, T₄ and T₇ (5.00 per plant) while T₂ and T₆ recorded 4.67 per plant and the lowest was recorded in T₁ (4.33 per plant).

Total dry matter accumulation

The effect of *Hypsizygus ulmarius* SMS on total dry matter of green gram under pot conditions is presented in Table 6. At 30 DAS, RDF + 50 % *HuSPH* + 50 % FYM (T₅) recorded the significantly highest dry matter accumulation (4.16 g per plant) followed by RDF + 50 % *HuSMW* + 50 % FYM (T₇) with 3.52 g per plant. The treatments RDF + 50 % *HuSPS* + 50 % FYM (T₃) and RDF + 100 % *HuSPH* (T₄) recorded 3.13 g and 2.98 g per plant respectively, while RDF + 100 % *HuSMW* (T₆) and RDF + 100 % *HuSPS* (T₂) recorded 2.61 g and 2.48 g per plant respectively. The lowest dry matter accumulation was recorded in the control (T₁), with 1.94 g per plant.

Table 4. Effect of *Hypsizygus ulmarius* spent mushroom substrate on plant height of green gram under pot condition

Treatments	Plant height (cm)		
	30 DAS	60 DAS	At harvest
T ₁ – Control (PoP)	18.83 ^g	32.00 ^e	32.40 ^d
T ₂ – RDF + 100 % <i>HuSPS</i>	22.30 ^f	32.93 ^d	33.33 ^c
T ₃ – RDF + 50 % <i>HuSPS</i> + 50 % FYM	25.97 ^c	37.03 ^c	37.37 ^b
T ₄ – RDF + 100 % <i>HuSPH</i>	24.83 ^d	36.93 ^c	37.13 ^b
T ₅ – RDF + 50 % <i>HuSPH</i> + 50 % FYM	28.33 ^a	39.93 ^a	40.03 ^a
T ₆ – RDF + 100 % <i>HuSMW</i>	23.50 ^e	33.53 ^d	33.87 ^c
T ₇ – RDF + 50 % <i>HuSMW</i> + 50 % FYM	27.20 ^b	39.03 ^b	39.33 ^a
Sem ±	0.30	0.35	0.24
CD at 5 %	0.91	1.05	0.75

RDF: recommended dose of fertilisers; *HuSPS*: *Hypsizygus ulmarius* spent paddy straw; *HuSPH*: *Hypsizygus ulmarius* spent pigeonpea husk; *HuSMW*: *Hypsizygus ulmarius* spent mulberry waste; DAS: days after sowing.

Table 5. Effect of *Hypsizygus ulmarius* spent mushroom substrate on number of branches of green gram under pot condition

Treatments	Number of branches plant ⁻¹		
	30 DAS	60 DAS	At harvest
T ₁ – Control (PoP)	2.33 ^b	4.33 ^b	4.33 ^b
T ₂ – RDF + 100 % <i>HuSPS</i>	2.67 ^{ab}	4.67 ^{ab}	4.67 ^{ab}
T ₃ – RDF + 50 % <i>HuSPS</i> + 50 % FYM	3.00 ^{ab}	5.00 ^{ab}	5.00 ^{ab}
T ₄ – RDF + 100 % <i>HuSPH</i>	3.00 ^{ab}	5.00 ^{ab}	5.00 ^{ab}
T ₅ – RDF + 50 % <i>HuSPH</i> + 50 % FYM	3.33 ^a	5.33 ^a	5.33 ^a
T ₆ – RDF + 100 % <i>HuSMW</i>	2.67 ^{ab}	4.67 ^{ab}	4.67 ^{ab}
T ₇ – RDF + 50 % <i>HuSMW</i> + 50 % FYM	3.00 ^{ab}	5.00 ^{ab}	5.00 ^{ab}
Sem ±	0.25	0.25	0.25
CD at 5 %	0.76	0.76	0.76

RDF: Recommended dose of fertilisers; *HuSPS*: *Hypsizygus ulmarius* spent paddy straw; *HuSPH*: *Hypsizygus ulmarius* spent pigeonpea husk; *HuSMW*: *Hypsizygus ulmarius* spent mulberry waste; DAS: days after sowing.

Table 6. Effect of *Hypsizygus ulmarius* spent mushroom substrate on total dry matter of green gram under pot condition

Treatments	Dry matter accumulation plant ⁻¹ (g)		
	30 DAS	60 DAS	At harvest
T ₁ – Control (PoP)	1.94 ^e	15.39 ^d	16.00 ^c
T ₂ - RDF + 100 % <i>HuSPS</i>	2.48 ^d	16.61 ^{cd}	16.69 ^c
T ₃ - RDF + 50 % <i>HuSPS</i> + 50 % FYM	3.13 ^c	18.28 ^{ab}	18.10 ^{abc}
T ₄ - RDF + 100 % <i>HuSPH</i>	2.98 ^c	17.41 ^{bc}	17.43 ^{abc}
T ₅ - RDF + 50 % <i>HuSPH</i> + 50 % FYM	4.16 ^a	18.78 ^a	19.50 ^a
T ₆ - RDF + 100 % <i>HuSMW</i>	2.61 ^d	16.93 ^c	17.20 ^{bc}
T ₇ - RDF + 50 % <i>HuSMW</i> + 50 % FYM	3.52 ^b	17.57 ^{abc}	19.03 ^{ab}
Sem ±	0.10	0.39	0.65
CD at 5 %	0.31	1.20	1.97

RDF: recommended dose of fertiliser; *HuSPS*: *Hypsizygus ulmarius* spent paddy straw; *HuSPH*: *Hypsizygus ulmarius* spent pigeonpea husk; *HuSMW*: *Hypsizygus ulmarius* spent mulberry waste; DAS: days after sowing.

At 60 DAS, T₅ recorded the significantly highest dry matter accumulation (18.78 g per plant), which was on par with T₃ (18.28 g per plant) and T₇ (17.57 g per plant). The treatments T₄, T₆ and T₂ recorded 17.41 g, 16.93 g and 16.61 g per plant respectively. The lowest was recorded in T₁ (15.39 g per plant).

Effective root nodules

The effect of *Hypsizygus ulmarius* SMS on effective root nodules of green gram under pot conditions is presented in Table 7. Among the *Hypsizygus ulmarius* SMS treatments, RDF + 50 % *HuSPH* + 50 % FYM (T₅) recorded the significantly highest number of effective nodules (8.67 per plant), followed by RDF + 50 % *HuSMW* + 50 % FYM (T₇) (8.33 per plant) while RDF + 50 % *HuSPS* + 50 % FYM (T₃) and RDF + 100 % *HuSPH* (T₄) recorded 7.67 and 7.00 nodules per plant, respectively. Lower values were recorded by RDF + 100 % *HuSMW* (T₆) (6.33 per plant) and RDF + 100 % *HuSPS* (T₂) (6.00 per plant). The lowest number of effective nodules was observed in the control treatment (T₁) (5.67 per plant).

Table 7. Effect of *Hypsizygus ulmarius* spent mushroom substrates on effective root nodules of green gram under pot condition

Treatments	Effective nodules plant ⁻¹ (no.) <i>Hypsizygus ulmarius</i>
T ₁	5.67 ^e
T ₂	6.00 ^e
T ₃	7.67 ^{bc}
T ₄	7.00 ^{cd}
T ₅	8.67 ^a
T ₆	6.33 ^{de}
T ₇	8.33 ^{ab}
Sem ±	0.28
CD at 5 %	0.85

T₁: Control (PoP); T₂: RDF + 100 % *HuSPS*; T₃: RDF + 50 % *HuSPS* + 50 % FYM; T₄: RDF + 100 % *HuSPH*; T₅: RDF + 50 % *HuSPH* + 50 % FYM; T₆: RDF + 100 % *HuSMW*; T₇: RDF + 50 % *HuSMW* + 50 % FYM.

Effect of *Hypsizygus ulmarius* spent mushroom substrates on yield parameters of green gram under pot culture

The data presented in Table 8 and Fig. 1 indicated that the effect of different *Hypsizygus ulmarius* spent mushroom substrates on yield parameters of green gram. Yield components of green gram were significantly influenced by the application of *Hypsizygus ulmarius* spent mushroom substrate (*HuSMS*).

Seeds pod⁻¹

The highest number of seeds per pod was recorded in T₅ (RDF + 50 % *HuSPH* + 50 % FYM), with 9.67 seeds, which was on par with T₇ (RDF + 50 % *HuSMW* + 50 % FYM), with 9.33 seeds. The control T₁ (PoP) recorded the lowest number of seeds per pod (7.00). Treatments

Table 8. Effect of *Hypsizygus ulmarius* spent mushroom substrate on yield parameters of green gram under pot condition

Treatments	Seeds pod ⁻¹ (g)	Test weight (g)	Seed yield plant ⁻¹ (g)
T ₁	7.00 ^c	2.69 ^d	2.95 ^c
T ₂	7.33 ^c	3.27 ^c	3.62 ^b
T ₃	8.33 ^{bc}	3.84 ^{ab}	4.20 ^a
T ₄	8.00 ^c	3.55 ^{bc}	3.81 ^b
T ₅	9.67 ^a	4.02 ^a	4.48 ^a
T ₆	7.67 ^c	3.40 ^c	3.73 ^b
T ₇	9.33 ^{ab}	4.00 ^a	4.40 ^a
Sem ±	0.41	0.10	0.11
CD at 5 %	1.26	0.32	0.35

T₁: Control (PoP); T₂: RDF + 100 % *HuSPS*; T₃: RDF + 50 % *HuSPS* + 50 % FYM; T₄: RDF + 100 % *HuSPH*; T₅: RDF + 50 % *HuSPH* + 50 % FYM; T₆: RDF + 100 % *HuSMW*; T₇: RDF + 50 % *HuSMW* + 50 % FYM.

receiving 100 % *HuSMS* alone, viz., T₂ (RDF + 100 % *HuSPS*), T₄ (RDF + 100 % *HuSPH*) and T₆ (RDF + 100 % *HuSMW*), produced fewer seeds per pod compared to the integrated treatments.

Test weight

The highest test weight was recorded in T₅ (RDF + 50 % *HuSPH* + 50 % FYM), with 4.02 g which was statistically on par with T₇ (RDF + 50 % *HuSMW* + 50 % FYM), with 4.00 g and T₃ (RDF + 50 % *HuSPS* + 50 % FYM), with 3.84 g. Moderate test weight was observed in T₂ (RDF + 100 % *HuSPS*), 3.27 g, T₄ (RDF + 100 % *HuSPH*), 3.55 g and T₆ (RDF + 100 % *HuSMW*), 3.40 g. The lowest test weight was recorded in the control T₁ (PoP), 2.69 g.

Seed yield plant⁻¹

Seed yield per plant was highest in T₅ (RDF + 50 % *HuSPH* + 50 % FYM), 4.48 g followed closely by T₇ (RDF + 50 % *HuSMW* + 50 % FYM), 4.40 g and T₃ (RDF + 50 % *HuSPS* + 50 % FYM), 4.20 g. Treatments with 100 % *HuSMS* alone (T₂, T₄ and T₆) recorded moderate seed yield ranging from 3.62–3.81 g. The lowest seed yield per plant was recorded in the control T₁ (PoP), 2.95 g.

Effect of *Hypsizygus ulmarius* spent mushroom substrate on available nutrient status (kg ha⁻¹) soil under pot condition

Effect of *Hypsizygus ulmarius*

Available nutrient status of soil as influenced by *Hypsizygus ulmarius* SMS under pot conditions is presented in Table 9. With respect to available N, all treatments were statistically at par, indicating no significant difference.

Nitrogen: The higher N content was recorded in T₂ (RDF + 100 % *HuSPS*), with 235.94 kg ha⁻¹, followed by T₄ (RDF + 100 % *HuSPH*), 234.47 kg ha⁻¹, T₃ (RDF + 50 % *HuSPS* + 50 % FYM), 232.82 kg ha⁻¹ and T₆ (RDF + 100 % *HuSMW*), 232.32 kg ha⁻¹. The lowest nitrogen content was recorded in T₁ (Control (PoP)), with 217.42 kg ha⁻¹.

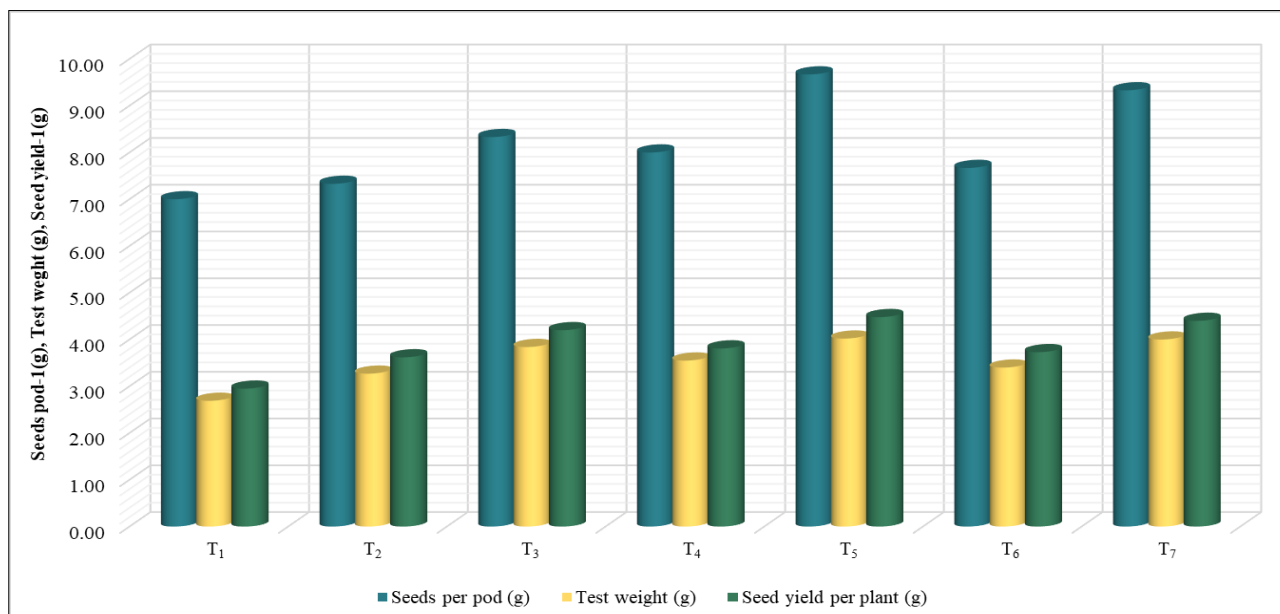


Fig. 1. Effect of *Hypsizygus ulmarius* spent mushroom substrate on yield parameters of green gram under pot condition.

T₁: Control (PoP); T₂: RDF + 100 % *HuSPS*; T₃: RDF + 50 % *HuSPS* + 50 % FYM; T₄: RDF + 100 % *HuSPH*; T₅: RDF + 50 % *HuSPH* + 50 % FYM; T₆: RDF + 100 % *HuSMW*; T₇: RDF + 50 % *HuSMW* + 50 % FYM; *Hu*: *Hypsizygus ulmarius*; SPS: spent paddy straw; SPH: spent pigeonpea husk; SMW: spent mulberry waste; RDF: recommended dose of fertiliser; FYM: Farm yard manure.

Table 9. Effect of *Hypsizygus ulmarius* spent mushroom substrate on available nutrient status (kg ha⁻¹) of soil under pot condition

Treatments	Available N: P ₂ O ₅ : K ₂ O (kg ha ⁻¹)		
	N	P	K
T ₁ – Control (PoP)	217.42 ^a	16.19 ^d	155.14 ^b
T ₂ – RDF + 100 % <i>HuSPS</i>	235.94 ^a	22.12 ^c	180.14 ^a
T ₃ – RDF + 50 % <i>HuSPS</i> + 50 % FYM	232.82 ^a	27.16 ^b	172.2 ^{ab}
T ₄ – RDF + 100 % <i>HuSPH</i>	234.47 ^a	24.17 ^c	173.94 ^a
T ₅ – RDF + 50 % <i>HuSPH</i> + 50 % FYM	223.02 ^a	30.52 ^a	165.12 ^{ab}
T ₆ – RDF + 100 % <i>HuSMW</i>	232.32 ^a	22.37 ^c	175.04 ^a
T ₇ – RDF + 50 % <i>HuSMW</i> + 50 % FYM	226.12 ^a	29.94 ^a	168.04 ^{ab}
Sem ±	6.94	0.74	5.14
CD at 5 %	21.06	2.26	15.61

RDF: recommended dose of fertilisers; *HuSPS*: *Hypsizygus ulmarius* spent paddy straw; *HuSPH*: *Hypsizygus ulmarius* spent pigeonpea husk; *HuSMW*: *Hypsizygus ulmarius* spent mulberry waste.

Phosphorus : Significantly, the highest P content was recorded in T₅ (RDF + 50 % *HuSPH* + 50 % FYM), with 30.52 kg ha⁻¹, followed by T₇ (RDF + 50 % *HuSMW* + 50 % FYM), 29.94 kg ha⁻¹. The lowest P content was recorded in T₁ (Control (PoP)), 16.19 kg ha⁻¹.

Potassium : The highest K content was observed in T₂ (RDF + 100 % *HuSPS*), with 180.14 kg ha⁻¹, followed by T₄ (RDF + 100 % *HuSPH*), 173.94 kg ha⁻¹, T₆ (RDF + 100 % *HuSMW*), 175.04 kg ha⁻¹ and T₃ (RDF + 50 % *HuSPS* + 50 % FYM), 172.2 kg ha⁻¹. The lowest was recorded in T₁ (Control (PoP)), 155.14 kg ha⁻¹.

Effect of *Hypsizygus ulmarius* spent mushroom substrate on total plant nutrients uptake by green gram under pot condition

Effect of *Hypsizygus ulmarius*

The total plant nutrient uptake of green gram was significantly influenced by the different treatments under pot conditions, as presented in Table 10.

Nitrogen : The highest N uptake was recorded in T₅ (RDF + 50 % *HuSPH* + 50 % FYM), with 35.00 kg ha⁻¹, followed by T₇ (RDF + 50 % *HuSMW* + 50 % FYM), with 33.66 kg ha⁻¹. Treatments T₃ (RDF + 50 % *HuSPS* + 50 % FYM) and T₄ (RDF + 100 % *HuSPH*), recorded moderate N uptake of 32.00 and 31.00 kg ha⁻¹ respectively. Lower N uptake was

observed in T₆ (RDF + 100 % *HuSMW*), 30.66 kg ha⁻¹, T₂ (RDF + 100 % *HuSPS*), 30.11 kg ha⁻¹ with the lowest recorded in T₁ (Control - PoP), 28.88 kg ha⁻¹.

Phosphorus : The maximum P uptake was observed in T₅, with 12.17 kg ha⁻¹, followed by T₇, with 11.94 kg ha⁻¹. Treatments T₃ and T₄ recorded moderate P uptake of 10.72 and 10.36 kg ha⁻¹ respectively. Lower values were recorded in T₆ 9.78 kg ha⁻¹ and T₂ 8.89 kg ha⁻¹ with the minimum in T₁, 8.72 kg ha⁻¹.

Potassium : Potassium uptake was highest in T₅, with 49.89 kg ha⁻¹, followed by T₇, with 46.22 kg ha⁻¹. Treatments T₃ and T₄ recorded intermediate values of 43.22 and 42.67 kg ha⁻¹, respectively. Lower uptake was observed in T₆ 42.00 kg ha⁻¹ and T₂ 40.67 kg ha⁻¹ with the lowest in T₁, 36.67 kg ha⁻¹.

Discussion

Effect of *Hypsizygus ulmarius* spent mushroom substrate on growth parameters of green gram

The present investigation demonstrated that the integrated application of *HuSMS* with FYM significantly enhanced the growth performance of green gram under pot conditions. Plant height, number of branches, total dry matter production and effective root

Table 10. Effect of *Hypsizygus ulmarius* spent mushroom substrate on total plant nutrients uptake by green gram under pot condition

Treatments	kg ha ⁻¹		
	Nitrogen	Phosphorus	Potassium
T ₁ - Control (PoP)	28.88 ^f	8.72 ^e	36.67 ^f
T ₂ - RDF + 100 % HuSPS	30.11 ^e	8.89 ^e	40.67 ^e
T ₃ - RDF + 50 % HuSPS + 50 % FYM	32.00 ^c	10.72 ^b	43.22 ^c
T ₄ - RDF + 100 % HuSPH	31.00 ^d	10.36 ^c	42.67 ^{cd}
T ₅ - RDF + 50 % HuSPH + 50 % FYM	35.00 ^a	12.17 ^a	49.89 ^a
T ₆ - RDF + 100 % HuSMW	30.66 ^{de}	9.78 ^d	42.00 ^d
T ₇ - RDF + 50 % HuSMW + 50 % FYM	33.66 ^b	11.94 ^a	46.22 ^b
Sem ±	0.18	0.10	0.24
CD at 5 %	0.56	0.31	0.73

RDF: recommended dose of fertilisers; HuSPS: *Hypsizygus ulmarius* spent paddy straw; HuSPH: *Hypsizygus ulmarius* spent pigeonpea husk; HuSMW: *Hypsizygus ulmarius* spent mulberry waste.

nodulation were markedly higher in treatments receiving 50 % SMS combined with 50 % FYM, particularly SMS prepared from pigeonpea husk and mulberry waste. The superior growth observed in these treatments may be attributed to the gradual release of nutrients from SMS, improved soil physical properties and enhanced microbial activity, which collectively promoted better root development and nutrient availability throughout the crop growth period. The incorporation of FYM along with SMS further improved nutrient mineralisation and maintained a balanced nutrient supply, resulting in vigorous vegetative growth.

The increased plant height and branching observed in the present study are in close agreement with the findings previously reported, which indicated that the application of SMS significantly improved crop growth owing to its residual nutrient content and slow-release characteristics (7). Similarly, combining SMS with organic manures enhanced soil fertility, microbial activity and nutrient availability, leading to greater plant height, branching and biomass accumulation (8). The higher dry matter production recorded in the present investigation also indicates improved photosynthetic efficiency and nutrient utilisation under integrated nutrient management.

The significant increase in effective root nodules may be attributed to improved soil organic carbon, favourable rhizosphere conditions and enhanced microbial populations created by the combined application of SMS and FYM. Such conditions promote the establishment of *Rhizobium* and improve biological nitrogen fixation in legumes. Similar observations were reported, which indicated that the integrated application of SMS and FYM significantly enhanced root nodulation, biomass accumulation and overall crop performance in pulse crops (9).

Effect of *Hypsizygus ulmarius* spent mushroom substrate on yield parameters of green gram

Application of *Hypsizygus ulmarius* spent mushroom substrate significantly improved the yield attributes and seed yield of green gram, particularly when SMS was integrated with FYM. The highest pod yield, seed yield, haulm yield, pod length, number of pods per plant, seeds per pod and test weight were recorded in treatments receiving 50 % SMS and 50 % FYM derived from pigeonpea husk and mulberry waste. The improvement in yield parameters may be attributed to enhanced nutrient availability during reproductive growth, improved moisture retention, better soil aeration and increased microbial activity resulting from organic matter decomposition. These favourable soil conditions enhanced photosynthate production and efficient translocation of assimilates towards reproductive organs, thereby increasing yield.

The present findings corroborate those previously reported, which showed higher growth and yield of green gram following the combined application of spent mushroom substrate and FYM (10). Likewise, the integrated use of SMS and organic manures significantly improved yield attributes in vegetable crops due to sustained nutrient release and improved soil health (11). Similar results were reported in black gram, where the combined application of SMS and FYM resulted in a significant enhancement of grain yield (12). Furthermore, the integration of SMS with FYM improved soil physical and chemical properties, enhanced nutrient uptake and ultimately increased crop productivity in legumes and vegetable crops (13, 14). The present findings therefore reinforce the potential of *Hypsizygus ulmarius* SMS as an effective organic nutrient source under integrated nutrient management practices.

Effect of *Hypsizygus ulmarius* spent mushroom substrate on soil nutrient status and nutrient uptake of green gram

Application of *Hypsizygus ulmarius* spent mushroom substrate markedly improved post-harvest soil fertility by increasing available N, P and K compared with the control. The improvement in soil nutrient status may be attributed to the decomposition of organic residues present in SMS, which gradually released essential nutrients while simultaneously enhancing microbial activity and organic matter content. The increase in available nitrogen could be associated with enhanced mineralisation of organic nitrogen compounds and stimulation of beneficial microorganisms responsible for nutrient cycling.

These findings are consistent with earlier reports, indicating that the application of organic amendments, including spent mushroom substrate, significantly increased soil nitrogen availability through enhanced decomposition and microbial activity (15). The increase in available phosphorus observed in the present study may be due to the production of organic acids during decomposition, which reduced phosphorus fixation and improved its solubility. Similar explanations were provided previously, indicating that organic amendments stimulate phosphate-solubilising microorganisms capable of releasing phosphorus through solubilisation and chelation processes (16, 17). Likewise, higher available K recorded in treatments receiving SMS may be attributed to the release of exchangeable K during the decomposition of lignocellulosic residues. Comparable observations were reported, which demonstrated significant improvement in soil potassium following the incorporation of organic residues and spent mushroom substrate (18, 17).

The enhanced uptake of N, P and K by green gram in the present study further confirms the beneficial role of SMS integrated with FYM. Treatments receiving 50 % SMS combined with 50 % FYM recorded significantly higher nutrient uptake than either the control

or sole SMS application. Improved nutrient uptake may be attributed to enhanced nutrient availability, better root growth, improved soil structure and increased microbial activity in the rhizosphere, which collectively enhanced nutrient absorption efficiency. The gradual mineralisation of nutrients from SMS and FYM ensured a continuous nutrient supply throughout the crop growth period, thereby improving nutrient use efficiency. These observations are in close agreement with reports showing that organic amendments and plant growth-promoting rhizobacteria improve nutrient acquisition and uptake in leguminous crops (19, 20). Similarly, significantly higher NPK uptake in pulse crops following the incorporation of organic residues was reported due to improved soil physical conditions, enhanced microbial activity and sustained nutrient mineralisation (21). Overall, the present findings clearly indicate that integration of *Hypsizygus ulmarius* SMS with FYM not only improves crop growth and yield but also enhances soil fertility and nutrient use efficiency, thereby supporting sustainable pulse production.

Conclusion

The present study demonstrated that the integrated application of *Hypsizygus ulmarius* spent mushroom substrate (HuSMS) with farmyard manure (FYM) and the recommended dose of fertilisers (RDF) significantly improved the growth, yield, nutrient uptake and post-harvest soil fertility of green gram under pot conditions. Among the treatments, T₅ (RDF + 50% HuSPH + 50% FYM) consistently recorded superior performance in terms of plant height, number of branches, dry matter accumulation, effective root nodulation, yield attributes, seed yield and uptake of nitrogen, phosphorus and potassium. The integrated treatments also enhanced post-harvest soil phosphorus and potassium availability, indicating improved soil fertility and nutrient use efficiency. The findings suggest that pigeonpea husk-based *H. ulmarius* spent mushroom substrate can effectively substitute a substantial proportion of conventional farmyard manure when integrated with RDF. Recycling spent mushroom substrate as an organic amendment not only improves green gram productivity but also promotes sustainable nutrient management, soil health and environmentally sound utilisation of mushroom industry residues. However, since the present investigation was conducted under pot conditions, further multi-location field experiments are recommended to validate these findings and assess their long-term effects on soil properties, crop productivity and economic viability under diverse agro-climatic conditions.

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Authors' contributions

PAG undertook conceptualisation, investigation, validation, methodology, nutrient analysis and visualisation, as well as writing – original draft, revision and editing. RNL, NU, RN, VV, PV contributed to supervision and provision of facilities. All authors read and approved the final manuscript.

Compliance with ethical standards

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Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used AI tools (ChatGPT) to rephrase sentences and standardise paragraphs. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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