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# A Circular Agricultural Model: Potassium Humate Enhances Fruiting Bodies Yield of Oyster Mushroom, and its Spent Substrate Serves as a Peat Moss Substitute for Cucumber Nursery

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**Abstract**: Mushroom cultivation is an effective biotechnological method for converting agricultural waste into valuable food. We carried out two systematic experiments: (Exp. A) to examine the impact of potassium humate supplementation on oyster mushroom characteristics and (Exp. B) to investigate the effects of spent mushroom substrate (SMS) mixed with peat moss (PM) in the nursery of cucumber seedlings and its synergistic effect on the growth parameters. Our study revealed that supplementing the substrate with 1.5 g $kg^{-1}$ of potassium humate significantly enhanced key mushroom traits. Furthermore, a mixture of 1 part SMS to 2 parts PM (S4) optimally promoted cucumber seedling growth, improving morphological, physiological, and fruit quality parameters across two cultivation seasons. These results could demonstrate the advantages of potassium humate as a critical complement in the growth medium of oyster mushroom and highlight the viability of recycling mushroom production waste into a sustainable nursery substrate. This research contributes to strategies for circular agricultural practices by showcasing the transformation of waste streams into valuable resources for crop production.

**Keywords**: Agricultural waste, Oyster mushroom, Cucumber growth, Potassium humate, Spent mushroom substrate (SMS).

## 1. Introduction

Approximately 1.3 billion tons of agricultural waste, comprising both biotic and abiotic materials, is generated annually. This number is expected to rise due to increasing global demand for agricultural products **(Gustavsson *et al.*, 2011)**; therefore, the transformation of this waste into value-added products is a critical objective. Valorizing agricultural waste into beneficial by-products has garnered significant interest, driven by consumer demand for natural additives and stricter environmental regulations **(Szabo and Vodnar, 2019)**. Cultivation of oyster mushroom is one of the most effective and feasible biological techniques and environmentally friendly approaches for using the bioconversion of agro-lignocellulosic wastes **(Kalmıs Azbar and Kalyoncu, 2008; Rubio-Wilhelmi *et al.*, 2011)**. This process not only recycles waste and converts it into human food but also helps control carbon emissions by providing an alternative to burning agricultural wastes **(Umor *et al.*, 2021 and Amran *et al.* 2021)**. In addition, numerous studies have recently investigated whether the mushroom waste substrate can be used as a nursery growing medium **(Poudel *et al. (*2023)**. Climate is a major factor influencing oyster mushroom productivity, as it directly impacts mycelia evolution and fruiting bodies formation. Optimal conditions include a stable temperature range of 20°C to 30°C and high relative humidity, typically between 80% and 90%, accompanied by adequate air circulation **Mohamed *et al.* (2016)**.

Typically, the chemical and physical characteristics of a single substrate are not sufficient as a growing medium for ideal seedling growth. Consequently, blending different substrates has proven to be more beneficial for vegetable seed germination **Poudel *et al.* (2023)**. For the ideal candidate, growing media have to be available and reasonably priced **DEMİR (2017)**. Seedling growing media should have large particles with adequate pore space between the particles **Bilderback *et al.* (2005)**. For decades, peat moss (PM) has been the most widely used growing medium for transplant production in trays for a long time **Hernández *et al.* (2021)**. However, there is an increasing apprehension regarding the sustainability of PM-based media, since PM is a non-renewable resource whose extraction leads to significant carbon emissions **(Turetsky *et al.*, 2015)**. Furthermore, PM prices have increased in recent years due to shortages caused by supply chain issues and the strict regulation or ban of the commercial PM harvest in some of the countries producing PM, like Canada, Ireland, and Egypt **(Poudel *et al.*, 2023 and Medina *et al.*, 2009)**. In this context, there is a big need to discover further alternatives to PM-based substrates to reduce PM use, at least in part **Di Gioia *et al.* (2017)**. Various studies reported that mushroom spent substrate (SMS), which has suitable particles, can be used as an alternative to PM **(Benito *et al.*, 2005 and Siminis and Manios 1990)**.

There is no doubt that the hybrid seeds of vegetables are too expensive and highly sensitive to growth under controlled or semi-controlled climatic conditions, due to the economic advantages of common vegetables such as tomato, cucumber, pepper, and eggplant that are produced by seedlings; furthermore, the production of seedlings has been stretched to include more vegetables such as cabbage, okra, carrot, lettuce, melon, and many others. To address this, the producers of the seedlings need to take more care with these seeds by preparing high-quality growth media in the nursery. Producing high-quality seedlings is considered the most critical factor in getting a strong plant that can deal with adverse environmental conditions. Hence, this study was designed to (i) determine the optimal dosage of potassium humate for enhancing the growth and biological efficiency of oyster mushroom; and (ii) evaluate the efficacy of SMS-based growth medium on cucumber seedling vigor, yield, and fruit quality.

## 2. Materials and Methods

### 2.1. Experiment (A): Oyster Mushroom (*p. sajor caju*) Production

#### 2.1.1. Collection of Materials:

The current study was carried out at the Central Laboratory of Organic Agriculture (CLOA), Agricultural Research Center (ARC), Giza, Egypt.

#### 2.1.2. Experimental Design and Treatments

This trial was designed in a completely randomized design (CRD) during 2022 and 2023 with three replications. Seven treatments were arranged to evaluate the production of oyster mushroom fruiting bodies *P. sajor-caju* was obtained from the Agricultural Research Center (ARC), Giza, Egypt. Each treatment was presented as nine polyethylene bags /replicate. Before the spawn infection, moistened raw straw substrate was mixed with potassium humate. The treatments were as follows T1

= 1 kg raw wheat straw (RWS), T2 = 1 kg RWS + 1 g potassium humate, T3 = 1 kg RWS + 1.5 g potassium humate, T4 = 1 kg RWS + 2 g potassium humate, T5 = 1 kg RWS + 2.5 g potassium humate, T6 = 1 kg RWS + 3 g potassium humate, and T7 = 1 kg RWS + 3.5 g potassium humate.

### 2.1.3. Preparation of straw and spawn incubation

The RWS was moistened by soaking overnight in water at room temperature, then sterilized in an autoclave and allowed to cool down to room temperature, and wiped off the excess water **Girmay *et al.* (2016)**. Afterward, the mixture substrate was packaged into 20 × 40 cm clear bags containing 1 kg of moistened substrate. The spawn was inoculated at a rate of 5% (based on the wet mass of the substrate) **Mohamed *et al.* (2016)**.

### 2.1.4. Cultivation conditions for spawn and fruiting bodies formation

The substrate inoculated by the spawn was incubated at 24-28ºC through the mycelia running phase in sufficient ventilation and light until fully colonized; after that, the bags were moved into the fruiting chamber. Part of the bags was cut off to create holes that made it easier for the mushroom to grow on pinheads. Mushroom fruiting bodies were harvested a week after pinhead formation. Data recorded as follows: spawn running phase, fruiting bodies yield (across all flushes) (g)/1 kg moistened substrate, spent weight (g), and biological efficiency (BE). According to **(Mohamed *et al.*, 2016)**, BE was calculated as follows: BE = (weight of fresh mushroom fruiting bodies/weight of dry substrate) × 100.

## 2.2. Experiment (B): Spent mushroom substrate (SMS) formulations as a growing medium

### 2.2.1. Growth conditions and treatments

Using leftover SMS from our previous experiment, mixed with various compositions of peat moss, we established a nursery for cucumber seedling production. Cucumber (*Cucumis sativus* L. *cv.* Barracuda) seeds were germinated at 25˚C in darkness, then seeded in trays containing different portions of SMS and peat moss in November 2022 & 2023After three weeks, seedlings with two fully expanded true leaves were transplanted into a greenhouse with 70 × 50 cm between rows and plants. The average temperature and relative humidity during the growth season were 25/17˚C and 75%, respectively. The experiment was conducted in a randomized completely block design (RCBD), with 3 replications; each treatment was presented by 35 plants per replication. These treatments were: S1 = sole peat moss (PM), S2 = sole spent mushroom substrate (SMS), S3 = 1 SMS/1 PM (w/w), S4 = 1 SMS/2 PM (w/w), and S5 = 2 SMS/1 PM (w/w). All cultural activities were implemented as needed, including fertilization, pest control, and irrigation during both seasons. Some of the chemical and physical properties and. the climate data under experiment condition of different treatments is presented in (Table 1). The climatic data under experimental conditions during cucumber (Table 2).

## 3. Data recorded

### 3.1. Morphological characteristics

After 28 days post-transplanting, random seedlings were selected to assess the following morphological characteristics: seedling length (cm), stem diameter (mm), fresh weight of shoot (g), dry weight of shoot (g), fresh weight of root (g), dry weight of root (g), and total yield g / plant. Cucumber fruits were harvested twice a week until the season ended. The fruits were harvested at their commercial maturity stage (15–20 days after flowering) with no signs of deformation. Fruit yield (g) / cucumber plant was calculated by multiplying the number of fruits /plant by the average fruit weight. The absolute shoot and root growth rate (AGR) was determined using the growth rate indicator according to **(Tongos 2016)**; AGR (g) = (W2 - W1 / T2 - T1), where W1 and W2 are shoot or root dry weights that were weighted at two times T1 (15 days) and T2 (28 days).

The seedling vigor index (SVI) was determined using the seedling vigor index (SVI) indicator **Abdelgalil *et al.* (2021)**. The SVI was calculated as SVI = [stem thickness (cm)/seedling length (cm) + root fresh weight (g)/shoot fresh weight (g)] × [shoot fresh weight (g) + root fresh weight (g)].

**Table (1). Physical and chemical properties of the mixture substrate (nursery medium).**

| Treatments | BD (g/cm3) | WHC (%) | EC (mS/cm) | pH | OM (%) | N (%) | K (%) |
|---|---|---|---|---|---|---|---|
| S1 | 1.66 | 15.55 | 1.57 | 3.8 | 39.17 | 1.29 | 0.17 |
| S2 | 0.18 | 7.28 | 22.97 | 7.7 | 34.84 | 0.94 | 1.92 |
| S3 | 0.51 | 24.28 | 12.02 | 5.6 | 48.06 | 0.56 | 0.53 |
| S4 | 1.44 | 47.62 | 13.89 | 6.1 | 63.23 | 0.91 | 1.11 |
| S5 | 0.35 | 33.73 | 15.21 | 5.8 | 57.91 | 0.67 | 0.76 |

BD = bulk density, WHC = water holding capacity, EC = electrical conductivity, OM = organic matter, N = Nitrogen, K = potassium.

**Table (2). Climate data under experiment conditions during cucumber growth.**

| Season (2022-2023) | | | | | | |
|---|---|---|---|---|---|---|
| Month | Max. Tem. (°C) | Min. Tem. (°C) | Tem. Avg. (°C) | Humidity (%) | Rain (mm) | Solar Radiation (MJ/m^2/day) |
| Nov. | 25.20 | 13.29 | 18.64 | 60.38 | 0.40 | 13.90 |
| Dec. | 23.00 | 11.35 | 16.33 | 63.53 | 15.80 | 11.57 |
| Jan. | 20.48 | 8.27 | 13.32 | 68.54 | 80.50 | 12.98 |
| Feb. | 18.89 | 6.39 | 11.90 | 69.79 | 10.70 | 15.02 |
| Season (2023-2024) | | | | | | |
| Nov. | 27.31 | 15.29 | 20.51 | 61.45 | 11.70 | 13.43 |
| Dec. | 23.10 | 11.59 | 16.60 | 66.89 | 4.80 | 10.93 |
| Jan. | 19.86 | 8.26 | 13.23 | 63.67 | 46.20 | 12.78 |
| Feb. | 20.04 | 7.66 | 13.03 | 71.21 | 35.60 | 15.66 |

Max. = maximum, Tem. = temperate, Min. = minimum, Avg. =Average**.**

### 3.2. Physiological characteristic

#### 3.2.1. Leaf water relative contents (LWRC)

Fresh leaf samples from each treatment were collected then weighed to record their fresh weight, followed by drenching half of their portion in deionized water for 12 hour. To remove extra water, the leaves were wiped, then weighed to record the full leaf turgid weight and exhibited to an oven at 75˚C for 20 hour to record the leaves' dry weight. According to **(Yao *et al.*, (2016)**, the LWRC= [(Leaf fresh weight - Leaf dry weight)/ (Leaf turgid weight - Leaf dry weight)] ×100 is calculated.

#### 3.2.2. Injury index

Briefly, the conductivity approach was utilized to measure the electrolyte leakage from the leaves serving as an injury index. The overall electrolyte quantities produced after boiling were compared to the amounts of electrolytes released from the tissues of each treatment. The injury index was estimated according to **Kubiś *et al.* (2014)**.

### 3.3. Phytochemical parameters

For chlorophyll a and b extraction, 0.2 g of leaf sample was ground using 10 ml of 80% acetone; next, it was filtered through a Whitman No. 1 filter paper. The absorbance was measured by a spectrophotometer at 663 nm and 645 nm. The calculation of chlorophyll A and chlorophyll B was done following the methodology as described by **Kubiś *et al.* (2014).**

### 3.4. Chemical analysis

Random fruit samples were taken from each plot during harvest. The samples were air-dried, before oven-dried at 70ºC until weight was constant. Accurately weighed samples of 0.5 g of the dried ground materials were exposed to wet digestion using a mixture of $H_2SO_4$ and $H_2O_2$ **(Parkinson and Allen, 1975)**. The digested solution was analyzed to determine their nitrogen (N) and potassium (K) contents. Total nitrogen was determined using the micro-Kjeldahl procedure. Total potassium in the digested materials was determined by the flame photometric method **(Motsara, 2015)**. Protein in fruits was calculated according to **(Shafeek *et al.* 2016)**, as follows: Pro. = N content × 6.25. The results of the data were calculated as a percentage.

### 3.5. Quality parameters

In the direction of estimating fruit quality in different treatments, fresh fruits were chopped after washing, and mixed under the lab condition to assess different quality indexes. The TSS% was measured using a refractometer. Sucrose content was determined using a modified phenol sulfuric acid method **(Buysse and Merckx, 1993)**.

## 4. Statistical Analysis

For experiments A and B, statistical analyses were performed using Costat Version 8.1 software. Differences between means were determined using the least significant difference (LSD) test at ($P < 0.05$).

## 4. Results

### 4.1. Experiment (A)

#### 4.1.1. Morphological parameters and biological efficiency

The effects of potassium hamate treatments on the growth parameters of *P. sajor caju* production are presented in (Fig. 1 a, b, c & d). The treatment T3 significantly affected mushroom growth characters in both seasons for all parameters (spawn running phase, total fresh fruiting body yield, spent weight, and biological efficiency) compared with all other treatments.

### 4.2. Experiment (B)

#### 4.2.1. Plant biomass

Significant differences were recorded among the tested treatments of cucumber seedlings in seedling length, stem diameter, shoot fresh weight, shoot dry weight, root fresh weight, and root dry weight. During the first season, the seedlings showed the highest significant number of the above-mentioned parameters by S4 with a recorded value of 14.65 cm, 4.05 mm, 18.95 g, 2.96 g, and 4.69 g, and 1.68 g, respectively. While they documented the values of 14.97 cm, 4.34 mm, 17.69 g, 4.78 g, 3.02 g, and 1.9 g, respectively, in the second season (Tables 3 & 4).

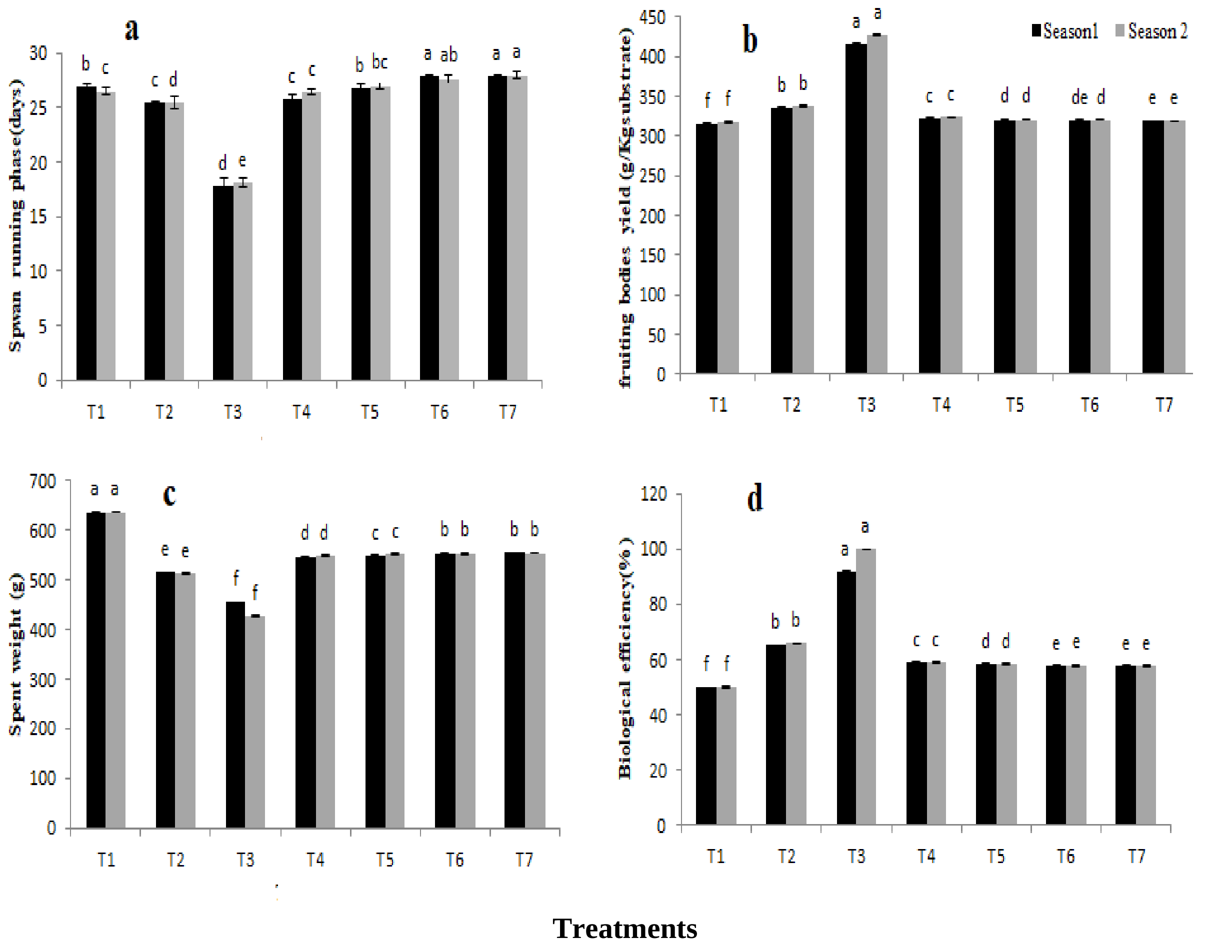



**Figure (1). Effect of potassium humate on the spawn running phase (a), fruiting bodies yield (b), spent weight (c), and biological efficiency (d) of oyster mushroom (*Pleurotus sajor caju*). Vertical bars indicate the SD. Columns that are headed with the same letter are not significantly different (*P* < *0.05*) according to the least significant difference test.**

**Table (3). Effect of spent mushroom substrate (SMS) formulations as a growing media on the morphological characteristics of cucumber seedlings (season 1).**

| Treatments | Seedling length (cm) | Stem diam.(mm) | Fresh wt. of shoot (g) | Dry wt. of shoot (g) | Fresh wt. of root (g) | Dry wt. of root (g) |
|---|---|---|---|---|---|---|
| S1 | 9.78 d | 2.41 d | 11.81 d | 0.61 d | 2.90 d | 0.72 c |
| S2 | 9.33 e | 1.73 e | 8.19 e | 0.75 e | 2.63 e | 0.41 d |
| S3 | 11.39 c | 2.56 c | 15.03 c | 0.94 c | 3.52 c | 0.82 b |
| S4 | 14.65 a | 4.05 a | 18.95 a | 2.96 a | 4.69 a | 1.68 a |
| S5 | 12.28 b | 2.77 b | 15.92 b | 1.54 b | 3.60 b | 0.85 b |

diam. = diameter, wt. = weight. S1 = sole peat moss (PM), S2 = sole spent mushroom substrate (SMS), S3 = 1 SMS/1 PM (w/w), S4 = 1 SMS/2 PM (w/w) and S5 = 2 SMS/1 PM (w / w). Values followed by the same letters within a column are not significantly different (*P* < *0.05*) according to the least significant difference (LSD) test.

**Table (4). Effect of spent mushroom substrate (SMS) formulations as a growing medium on the morphological characteristics of cucumber seedlings (season 2).**

| Treatments | Seedling length (cm) | Stem diam.(mm) | Fresh wt. of shoot (g) | Dry wt. of shoot (g) | Fresh wt. of root (g) | Dry wt. of root (g) |
|---|---|---|---|---|---|---|
| S1 | 10.32 d | 2.30 c | 10.44 d | 0.76 d | 3.09 c | 0.74 d |
| S2 | 9.58 e | 1. 85 d | 7.08 e | 0.60 e | 2.74 d | 0.42 e |
| S3 | 12.14 c | 2.73 b | 14.92 c | 0.96 c | 3.82 b | 0.82 c |
| S4 | 14.976 a | 4.34 a | 17.69 a | 3.02 a | 4.78 a | 1.90 a |
| S5 | 13.02 b | 2.74 b | 15.81 b | 1.65 b | 3.82 b | 0.95 b |

diam. = diameter, wt. = weight. S1 = sole peat moss (PM), S2 = sole spent mushroom substrate (SMS), S3 = 1 SMS/1 PM (w/w), S4 = 1 SMS/2 PM (w/w) and S5 = 2 SMS/1 PM (w / w). Values followed by the same letters within a column are not significantly different (*P < 0.05*) according to the least significant difference (LSD) test.

### 4.2.2. Total yield

Regarding total yield (Fig. 2a), absolute shoot growth rate (Fig. 2b), absolute root growth rate (Fig. 2c), and seedling vigor index (Fig. 2d), significant increases were observed when using S4 compared to sole SMS, sole PM, and all other treatments. The recorded values were 4577.55, 2.9, 1.62 g / plant, and 16.72 SVI, respectively, in the first season. At the same time, the seedlings showed the highest significant records of total yield, absolute shoot growth rate, absolute root growth rate, and seedling vigor index under S4, recorded at 4870, 2.96, 1.83 g / plant, and 16.82 SVI, respectively, in the second season.

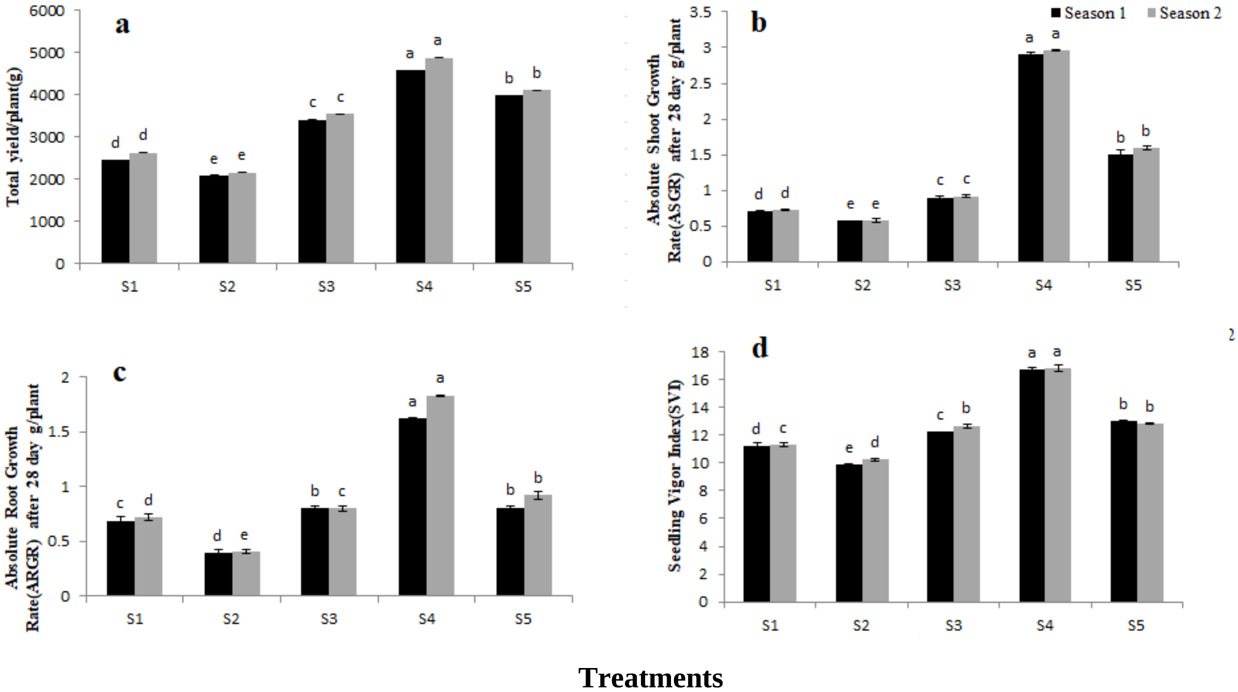


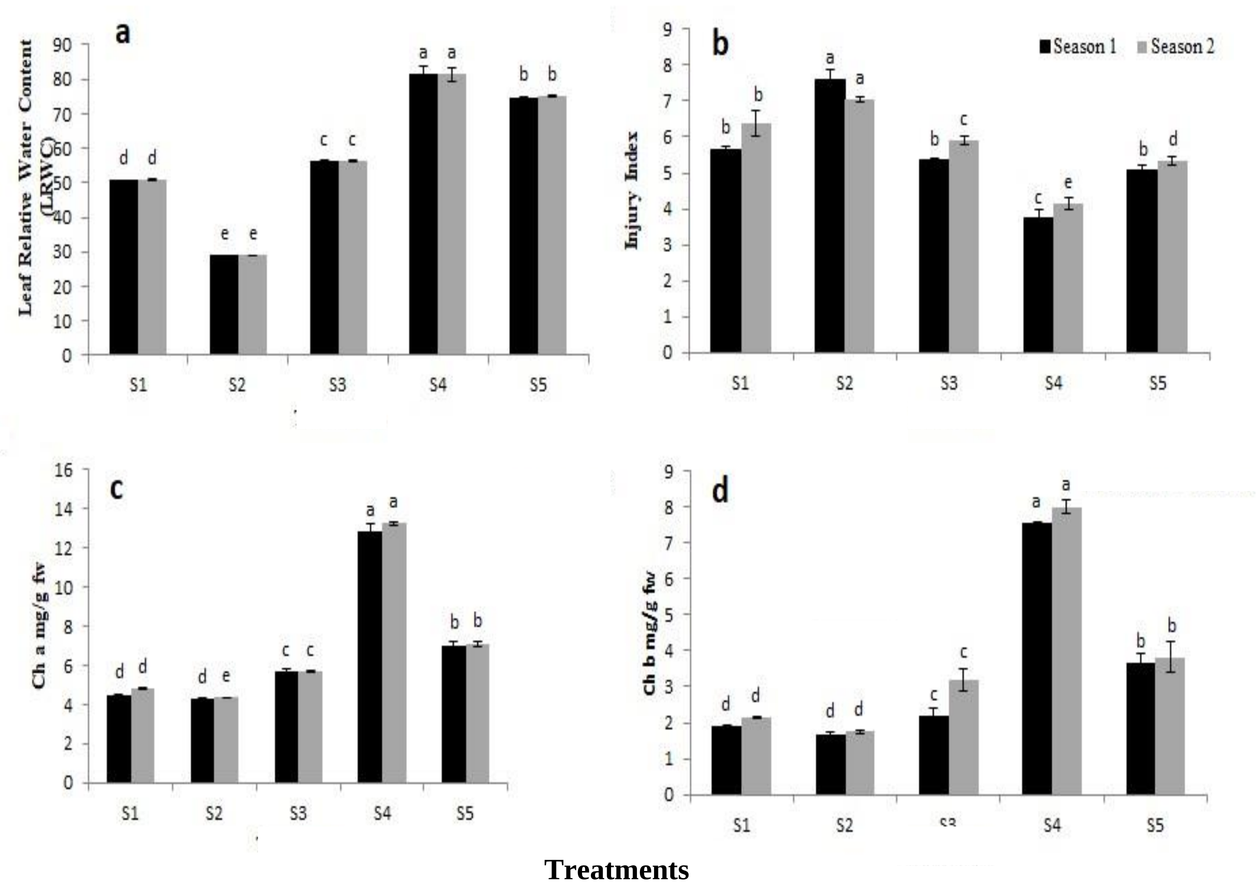

**Figure (2). Effect of spent mushroom substrate (SMS) formulations as a growing media on the total yield (a), absolute shoot growth rate (ASGR) (b), absolute root growth rate (ARGR) (c), and seedling vigor index (d) of cucumber. Vertical bars denote the SD. Columns that are headed with the same letter are not significantly different (*P < 0.05*) according to the least significant difference test.**

### 4.2.3. Leave water relative content (LWRC) and injury index ($L_D$)

The response of leaf water relative content (LWRC) and injury index ($L_D$) to the different treatments is presented in Fig. 3a. Data clearly showed that the different mixtures between PM and SMS increased significantly LWRC and decreased significantly the injury index by S4 in both seasons compared with the sole PM, SMS, and other treatments. The increase in LWRC by S4 compared with S1 and S2 was 37.8 and 64.54 in season 2022, and then recorded 37.65 and 64.41 in season 2023, respectively. The decrease in $L_D$ by S4 compared with S1 and S2 was 44.34 and 42.41 in season 2022. On the other hand, they were recorded as 44.63 and 44.5 in season 2023, respectively (Fig. 3b).

### 4.2.4. Chlorophyll a and b

The effects of growth media treatments on chlorophyll a and b contents in cucumber leaves are depicted in Fig. 3 c & d. The individual PM and SMS magnificently inhibited the chlorophyll a and b contents after 28 days. In contrast, the use of 1 SMS/2 PM (w/w) magnificently inhibited these factors in both seasons compared to other treatments.




**Treatments**

**Figure (3). Effect of spent mushroom substrate (SMS) formulations as a growing media on the leaf relative water content (a), injury index (b), chlorophyll a (c), and chlorophyll b (b) of cucumber leaves. Vertical bars denote the SD. Columns that are headed with the same letter are not significantly different (*P* < *0.05*) according to the least significant difference test.**

### 4.4.3 Fruit quality parameters

Due to the highest chlorophyll produced on substrate formulation 1 SMS/2 PM (w/w) in both seasons, the cucumber fruits exhibited the highest total nitrogen, total potassium, protein, sucrose content, and TSS% for this formulation compared with sole SMS and PM (Table 5 & 6).

**Table (5). Effect of spent mushroom substrate (SMS) formulations as a growing media on the quality parameters of cucumber fruits (season 1).**

| Treatments | Total N (%) | Total K (%) | Protein (%) | Sucrose content (mg/g) dry wt. | TSS (%) |
|---|---|---|---|---|---|
| S1 | 1.46 d | 1.61 d | 9.16 d | 45.46 d | 3.67 e |
| S2 | 1.24 e | 1.30 e | 7.77 e | 44.88 e | 3.34 d |
| S3 | 3.33 c | 2.00 c | 20.83 c | 48.08 c | 4.72 c |
| S4 | 5.60 a | 3.61 a | 35.00 a | 51.64 a | 7.28 a |
| S5 | 4.55 b | 2.33 b | 27.56 b | 48.59 b | 4.93 b |

N = nitrogen, K = potassium, % = percentage, wt. = weight, TSS = total soluble solids. S1 = sole peat moss (PM), S2 = sole spent mushroom substrate (SMS), S3 = 1 SMS/1 PM (w/w), S4 = 1 SMS/2 PM (w/w), and S5 = 2 SMS/1 PM (w/w). Values followed by the same letters within a column are not significantly different ($P < 0.05$) according to the least significant difference test.

**Table (6). Effect of spent mushroom substrate (SMS) formulations as a growing media on the quality parameters of cucumber fruits (season 2).**

| Treatments | Total N (%) | Total K (%) | Protein (%) | Sucrose content (mg/g) dry wt. | TSS (%) |
|---|---|---|---|---|---|
| S1 | 1.56 d | 1.60 d | 9.79 d | 45.96 d | 3.64 d |
| S2 | 1.48 d | 1.38 e | 9.30 d | 45.41 e | 3.47 e |
| S3 | 3.52 c | 1.93 c | 22.01 c | 47.71 c | 4.78 c |
| S4 | 5.53 a | 3.60 a | 34.58 a | 51.89 a | 7.18 a |
| S5 | 4.55 b | 2.38 b | 28.47 b | 48.86 b | 5.06 b |

N = nitrogen, K = potassium, % = percentage, wt = weight, TSS = total soluble solids. S1 = sole peat moss (PM), S2 = sole spent mushroom substrate (SMS), S3 = 1 SMS/1 PM (w/w), S4 = 1 SMS/2 PM (w/w), and S5 = 2 SMS/1 PM (w/w). Values followed by the same letters within a column are not significantly different ($P < 0.05$) according to the least significant difference test.

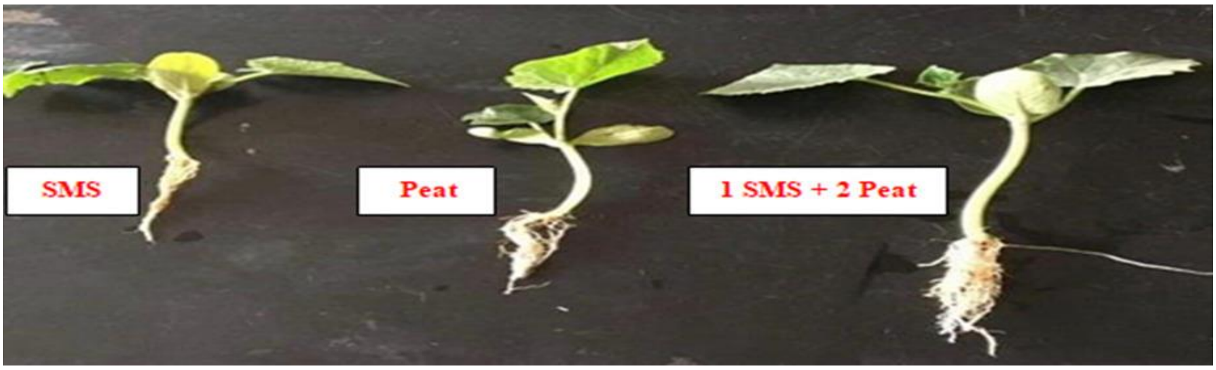



**Figure (4). Cucumber seedlings grown in different substrate formulations of spent mushroom mixed at different portions with peat**.

## 5. Discussion

Humic acid substances (HAS) such as potassium humate, are a category of organic fertilizers used in agriculture to stimulate the growth of higher plants and mushrooms. These natural supplements are derived from the degradation of plant material **(Zahid *et al.*, 2020)**. The mycelium of mushrooms requires essential elements for its life cycle, and supplementing the substrate can increase mushroom production by enhancing the availability of these nutrients **(Rühl and Kües, 2006)**. In this investigation, the application of potassium humate on oyster mushroom *P. Sajor Cajo* had a highly magnificent enhancement on morphological parameters by T3 compared with other treatments. One of the most vital factors in edible mushroom productivity is the spawn running phase. In the present investigation, the running phase period was 17.73 days by T3 in season one and 18.13 days in season two. This finding is consistent with **Buah *et al.* (2010)**, who reported a spawn run of 2-3 weeks on different substrates, and with **Girmay *et al.* (2016)**, who observed mycelium colonization in approximately 16 days. Other studies have recorded longer spawn running phases **(Taskirawati, 2020)**. The significant differences in the time observed by T3 to complete this process might be due to modifications of environmental growth factors, such as moisture, temperature, and $CO_2$ levels potentially enhanced by the potassium humate supplementation.

The addition of potassium humate at 1.5g /1 kg of moistened substrate detected an extra significant effect on yield and spent weight. The yield of *P. Sajor Cajo* had a positive effect with the addition of potassium humate at varied rates compared to the control. Our results are in agreement with **Trevisan *et al.* (2010)**, who showed that HAS improved the morphological and physiological characteristics of various crops. Alternatively, the HAS might induce the uptake of minerals such as N-P-K **(Pehlivan *et al.*, 2008)**. In addition, HAS is also useful to raise the yield of edible mushrooms **(Nardi *et al.*, 2007)**. Furthermore, HAS has demonstrated an important role in the biosynthesis of proteins and the regulation of enzyme activities **(Pehlivan *et al.*, 2008)**. In our study, using T3 had a significant effect in improving the biological efficiency of *P. Sajor Cajo* in comparison with other treatments. **(Bhattacharjya *et al.*, 2014)** reported that the biological efficiency of the mushroom and it was increased when the substrate was supplemented with different rate from HAS. Parallel results were observed by **Kirbag *et al.* (2006)**. A recent study demonstrated that the decrease in spent mushroom substrate corresponds with an increase in biological efficiency. Our findings showed that *P. Sajor Cajo* cultivated on T3 had the least amount of spent mushroom substrate. According to our theory, *P. Sajor Cajo* decomposed and consumed more compounds with T3 than with any other treatments.

In Exp. B, we used SMS, which contains beneficial components for seedling growth, as a portion mixed with peat in the production of cucumber seedlings. **(Negrão *et al.*, 2017)** showed that aged spent mushroom substrate in particular can be utilized as a substitute for PM in the growing media used for eggplant seedlings. Additionally, **(Yang *et al.*, 2012)** discovered that combining SMS with different ingredients may be utilized as a seedling medium for cucumber and tomato plants. According to our findings, the beneficial impacts associated with SMS are the remaining nutrients and residual fungal mycelium **(Umor *et al.*, 2021)**.

Our investigation revealed that the utilization of spent mushroom substrate (SMS) formulations mixed with peat moss (PM) as a growing media had a positive effect on cucumber growth compared with SMS and PM individually. Our results showed that treatment S4 had significantly higher morphological parameter means than other treatments. The increase in S4 may be due to the nutrient balance and a promising potassium humate leftover effect **(Pascual *et al.*, 2018)**. On the other hand, the decrease of morphological parameters by S1 and S2 might be due to the unsuitable EC, which can be used as an indicator of salt level, and the inappropriate pH, which may not be suitable for seedling growth **Fidanza *et al.* (2010)**. Hence, mixing PM with SMS likely diluted soluble salts and adjusted the pH to a level more appropriate for seedling growth. Our results are supported by **(Islam *et al.*, 2014)**, who found that SMS produced the highest plant morphological factors and total yield in broccoli, and by **(Marques *et al.*, 2014)**, who reported that SMS addition resulted in high-quality, marketable lettuce heads and superior plantlets.

According to our findings, S4 may have generated the most optimal potassium K+ level in the growth media. The increased potassium uptake could explain the noticeable increase in the seedling vigor as well as the absolute growth rate of the shoot and root. The adequate $K^+$ absorption regulates several activities, including protein synthesis, cell function, oxidant metabolism, ionic balance regulation, enzyme activity, photosynthetic rate, and many more **(Sofo *et al.*, 2005)**. On the other hand, the downgrade in cucumber parameters by other treatments arose with $K^+$ levels in the growth media. Notably, low K+ causes low antioxidant enzyme activity, which can, not only, result in secondary oxidative stress but also, drastically, diminish the ability to exclude reactive oxygen species **(Sairam and Srivastava, 2001)**. Likewise, enrichment in plant growth and many other physiological factors were shown in higher plants by modifying ions in growth media **(Bohra and Doerfflin, 1993)**.

In relation to chlorophyll a and b, our study reported that S4 had a highly significant value in seasons 1 and 2. The extra progressive increase in chlorophyll by S4 might be due to the ideal dose of $K^+$ for this stage, while the lowering of chlorophyll by S1 and S2 is because $K^+$ deprivation frequently has a detrimental effect on plant metabolism, leading to reductions in chlorophyll synthesis **(Rus *et al.*, 2004)**. Whereas excessive $K^+$ may accelerate the breakdown and delay the synthesis of chlorophyll a and b **(Redman *et al.*, 2011 and Cheng *et al.*, 2015)**. Some $K^+$-dependent enzymes may require additional activating agents when nutrients, particularly $K^+$, are starved **(Fu and Luan, 1998)**, which can cause a physiological issue as well as restrict plant growth **(Banuelos *et al.*, 2002)**. Consequently, more affinity $K^+$ absorption and sufficient internal $K^+$ supply may be the primary drivers of improved plant development **(Kaya *et al.*, 2001).**

Physiological factors, such as leaf relative water content (LRWC) and injury index ($I_D$), are crucial in determining a plant's ability to grow effectively **(Kubiś *et al.*, 2014)**. In this respect, it is possible that the gas exchange capacity improved, nutrient uptake increased, and S4 modified $K^+$ /$Na^+$ ratio. Otherwise, the results of $L_D$ in addition to LRWC reflect on the induction of antioxidant enzyme metabolism **(Abbasi *et al.*, 2014)**. Unsuitable $L_D$ and LRWC could contribute to low cell elongation, an imbalance between micro and macro elements, a lower osmotic regulation potential, and other factors that can decrease plant growth **(Grieve *et al.*, 2001)**.

Fruit quality can indicate the high marketable value of the cucumber. Our study suggests that the chemical and physical properties of seedling growth media were more significantly improved with S4 compared to the other treatments. Consequently, a well-structured growth media can promote plant growth and aid in the augmentation of chemical fruit quality. Our research in both seasons revealed that S4 greatly raised the chemical fruit quality parameters such as TSS, sucrose, N/K, and protein. The dual effects of the SMS as an organic substance and the leftover potassium humate in it could be causing this rise. Our findings are consistent with those of **Kazemi (2013)**, who noted that the application of organic substances such as HAS increased the tomato's TSS% and vitamin C content. Another study found a similar tendency and indicated that HAS increases nutrient uptake in gerbera and cucumber plants **(Nikbakht *et al.*, 2008)**. In addition, humic compounds raise the pumpkin seed's crude protein content **(Jariene *et al.*, 2007)**. Furthermore, potassium is vital for numerous processes, including yield production, ionic balance, enzyme activity, and the metabolism of carbohydrates **(Shafeek *et al.*, 2016)**. Hence, using potassium humate is very essential for plant growth.

## 6. Conclusion

In conclusion, our study demonstrates that mushroom cultivation can serve as a model for zero-waste management in agriculture. The application of potassium humate at 1.5 g per kg $^{-1}$ of moistened substrate significantly enhanced mushroom growth characteristics. Subsequently, the spent mushroom substrate (SMS) shows promising potential for at least partially substituting peat moss (PM). This approach represents an environmentally friendly and low-cost technology for utilizing rural and agro-industrial residues, particularly in developing countries. Our data confirm that the substrate treatment with a 2:1 PM to SMS ratio (S4) produced high-quality seedlings compared to the sole substrates. SMS from oyster mushroom (*P. sajor-caju*) provided the most adequate conditions for the growth and development of cucumber, resulting in vigorous, marketable plants.

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