**Original Research Article**

**Effects of various Plant Growth Hormones on yield and production efficacy of *Agaricus bisporus* (Lange) Imbach**

**Abstract**

Button mushroom (*Agaricus bisporus*) cultivation is a critical component of sustainable agriculture, addressing global food security challenges through efficient resource utilization. This study evaluated the impact of plant growth hormones—gibberellic acid (GA₃), cytokinin (CK), and naphthaleneacetic acid (NAA)—on yield, growth kinetics, and nutritional quality in *A. bisporus*. Compost substrates (4 kg) were amended with hormone concentrations ranging from 2–10 ppm. Results demonstrated that GA₃ at 10 ppm (T₃) exhibited superior performance, achieving the shortest spawn run (12.33 days), earliest pinhead initiation (18.77 days), and fastest first harvest (26.00 days). Morphologically, T₃ produced optimal characteristics with maximum stalk length (3.53 cm), stalk width (2.87 cm), and cap diameter (5.62 cm). T₃ delivered the highest total yield (1345.97 g) and biological efficiency (33.62%), with peak nitrogen (5.32 mg/100 g) and phosphorus (21.09 mg/100 g) content. CK at 10 ppm (T₉) ranked second in overall performance, while NAA at 10 ppm (T₆) maximized magnesium (49.65 mg/100 g) and copper (3.98 mg) concentrations. These findings establish GA₃ supplementation as the most effective strategy for accelerating production cycles and maximizing yield in *A. bisporus*, demonstrating the potential of targeted phytohormone applications for sustainable mushroom cultivation.

**Keywords:** Agaricus bisporus, gibberellic acid, plant growth hormones, biological efficiency, yield optimization, mushroom cultivation

**Introduction:**

Agaricus bisporus thrives on composted substrates derived from diverse organic materials. The composting process, which involves the bioconversion of lignocellulosic agricultural and industrial waste, plays a pivotal role in mushroom cultivation. This sustainable approach not only utilizes abundant renewable resources but also contributes to food security by transforming waste into nutritious, protein-rich food, particularly beneficial for developing nations (Delphina & Royse, 2008).

With the global population expanding rapidly, where a significant proportion of the population lives below the poverty line, suffers from protein malnutrition, necessitating affordable and accessible supplementation While arable land remains finite, food security, protein deficiency remains a critical nutritional concern has become a pressing challenge. In response, researchers are exploring innovative agricultural methods to enhance nutrient-dense food production. Mushroom cultivation emerges as a viable solution, particularly for landless farmers, as it can be practiced in confined spaces, urban settings, or underutilized land. This approach not only generates income and employment opportunities, especially for youth, but also contributes to sustainable food systems (Kumar *et. al.,* 2023).

Plant growth regulators significantly influence mushroom cultivation by affecting mycelial growth, fruiting body formation, and overall yield enhancement. Khandakar (2004) reported that various hormone supplementation effectively increased stipe elongation and cap expansion in mushrooms, demonstrating the hormone's positive impact on morphological development. Alam *et al*. (2007) found that optimal doses of growth regulators increased mushroom biomass in *Pleurotus sajor-caju*, while excessive concentrations proved detrimental to cultivation outcomes. Research by Uddin *et al*. (2012) demonstrated that balanced application of 10 ppm IAA+ 5 ppm NAA as found to be the best for mycelial colony proliferation of Button mushroom suggesting that strategic hormone applications represent a promising approach for optimizing mushroom production.

Keeping the objective of enhancing mushroom production in mind, research study was designed to investigate the "**Effects of various Plant Growth Hormones on yield and production efficacy of *Agaricus bisporus* (Lange) Imbach."**

**2. Materials & Methods**

* 1. **Experimental site**

The present investigation was conducted at the Mushroom Research and Development Centre, Department of Plant Pathology, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur from year 2023 to 2025.

**2.2 Substrate preparation and chemical sterilization**

Mushroom growers can choose from various substrate formulations depending on local material availability and cost considerations. A key feature of these mixtures is maintaining 1.5-1.75% nitrogen content, which initiates proper composting while minimizing dry matter loss. A standard procedure includes 300 kg wheat straw as the base, supplemented with 15 kg wheat bran, 125 kg chicken manure and nitrogen sources (4 kg urea and 9 kg CAN). The mixture is further enhanced with 3 kg each of SSP and MOP for mineral balance, plus 20 kg gypsum to improve substrate structure. This carefully balanced composition creates optimal conditions for mushroom growth while allowing for regional adaptations based on resource availability.

**2.3 Spawning**

# **In the present study, spawn was inoculated at 1% of the compost's fresh weight unless specified otherwise. When trays were employed, they were covered with newspaper sheets sterilized in a 0.5% formaldehyde solution. Moisture was maintained by periodically spraying water onto the sheets. For bag cultures, the open end of the polyethylene bag was folded and covered with sterilized newspaper post-spawning. The bags were incubated at 24 ± 1 °C for 12–15 days, with extended durations required at lower temperatures to complete spawn run.**

**2.4 Experimental Details**

The experimental investigations were implemented utilizing a Completely Randomized Design (CRD) statistical framework. Analysis of variance (ANOVA) was applied where statistical inference was required to evaluate treatment effects. The critical difference was computed at α = 0.05 significance threshold to establish statistical discrimination between treatment means. F-statistics were subjected to hypothesis testing for the assessment of inter-treatment variation significance in the comparative analysis of experimental groups.

**2.5 Details of various treatments**

The details are : T1 = Compost (4kg) **+**GA3 @ 2 PPM, T2 = Compost (4kg) **+**GA3 @ 6 PPM, T3 = Compost (4 kg) **+** GA3 @ 10 PPM, T4 = Compost (4 kg) **+**NAA @ 2 PPM, T5 = Compost (4 kg) **+**NAA @ 6 PPM, T6 = Compost (4 kg) **+**NAA @ 10 PPM, T7 = Compost (4 kg) **+**CK @ 2 PPM, T8= Compost (4 kg) **+**CK @ 6 PPM, T9 = Compost (4 kg) **+**CK @ 10 PPM, T10 = Compost (4kg) **(**Control).

**2.6 Observations recorded**

During the experimental period, observations were systematically recorded for various observations such as radial mycelial growth in centimeters , growth behavior (spawn run period, pinhead formation, and three harvesting phases in days), growth parameters (number, weight, stalk length, cap diameter, and stalk diameter of fruiting bodies), yield potential (per harvest and total), biological efficiency, and fresh/dry weights.

**2.7 Biological efficiency**

The biological efficiency (BE) of the substrate was calculated using the following formula :

Biological Efficiency(BE) = **(Fresh weight of mushrooms/Dry weight of substrate) \* 100**

**2.8 Statistical Analysis**

Each treatment was replicated thrice and values were means ± SE. The data were computed using SPSS software version 21.

**3. Results & Discussion**

The present study was undertaken to assess the influence of various plant growth regulators on the morphological traits, yield attributes, and nutritional composition of *Agaricus bisporus* . The findings of the experimental study are detailed as below:

**3.1 Effect of spent mushroom substrate on duration of growth stage of *Agaricus bisporus***

**3.1.1 Spawn Running and pin head initiation**

The data presented in the Table-1, showed that the spawn running of *Agaricus bisporus* in different days are variable among the treatments representing 12.33-16.00 days. The minimum number of days taken for spawn running was in T3 treatment (Compost @ 4kg + GA3 @ 10 PPM) representing 12.33 days, followed by T9 (Compost @ CK @ 10 PPM) and T6 (Compost @ NAA @ 10 PPM) as 12.67 and 13.00 days, respectively against 16.00 days, in case of control it was observed from the table that all the treatments decrease the number of days of spawn running against control. Researchers like Chaurasia *et al.,* (2020) and **Guler *et al.,* (2009)** have also reported reduced spawn run times with GA3 treatment and found that exogenous GA₃ enhanced mycelial growth and primordia formation in Pleurotus ostreatus.

**3.1.2 Harvesting**

The data presented in the Table-1, showed that the significant variation on number of days require for first harvesting of *Agaricus bisporus* was varied from 26.00 to 31.34 days but the minimum number of days require for first harvesting was found in T3 (Compost (4 kg) **+** GA3 @ 10 PPM) treatment representing 26.00 days, followed by T9 ( Compost (4 kg) **+**CK @ 10 PPM), T6 (Compost (4 kg) **+**NAA @ 10 PPM) and T2 (Compost (4 kg) **+**GA3 @ 6 PPM) treatment representing 26.33, 26.89 and 27.00 days, respectively against 31.34 days, in case of control it was observed from the table that all the treatment significantly decreases the number of days for first harvesting against control.

**Table 1. Effect of Spent Mushroom Substrate on duration of growth stage of *Agaricus bisporus.***

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Treatment details** | **Spawn run periods (days)** | **Pinhead initiation periods (days)** | **First harvesting**  **(days)** | **Second harvesting**  **(days)** | **Third harvesting**  **(days)** |
| T1 | 14.44 | 21.77 | 28.12 | 38.14 | 48 |
| T2 | 13.33 | 19.56 | 27 | 36.55 | 46.55 |
| T3 | 12.33 | 18.77 | 26 | 35.2 | 44.8 |
| T4 | 15.77 | 22.45 | 29.25 | 39.25 | 49.2 |
| T5 | 14.2 | 21 | 27.77 | 37.9 | 47.87 |
| T6 | 13 | 19.26 | 26.89 | 36.3 | 46.38 |
| T7 | 15.6 | 22 | 28.33 | 38.56 | 48.67 |
| T8 | 13.5 | 20.36 | 27.67 | 37.6 | 47.1 |
| T9 | 12.67 | 19 | 26.33 | 35.67 | 45.23 |
| T10 | 16 | 22.73 | 31.34 | 39.85 | 49.4 |
| **C.D at 5%** | **1.43** | **2.09** | **2.81** | **3.15** | **2.84** |
| **SE(m)** | **0.48** | **0.70** | **0.95** | **1.06** | **0.96** |
| **SE(d)** | **0.68** | **1.00** | **1.35** | **1.51** | **1.36** |
| **C.V %** | **5.97** | **5.93** | **5.93** | **4.88** | **3.52** |

**3.2 Effect of various combination of SMS on yield parameter of *Agaricus bisporus.***

**3.2.1 Yield in three harvesting**

The data presented in Table-2, showed that significant variation on yield at third harvesting which was ranged from 245.70 to 405.63 g. The treatment T3 (Compost (4 kg) **+** GA3 @ 10 PPM) representing 405.63 g which is highest among all the treatment followed by T9 ( Compost (4 kg) **+**CK @ 10 PPM), T6 (Compost (4 kg) **+**NAA @ 10 PPM) and T2 (Compost (4kg) **+**GA3 @ 6 PPM) about 393.72 g, 392.20 g and 389.28 g respectively, while minimum yield was recorded from control showing 245.70 g. It is cleared that, as compared to control, every treatment enhances yield at third harvesting. Researchers such as Uddin *et al*. (2013) and Kannaujiya *et al*., (2020) had demonstrated that a balanced mix of GA₃ and cytokinins , NAA in improvement of *Hericium erinaceus* yields, suggesting synergistic effects.

**3.2.2 Total Yield**

The total yield significantly varied in all the treatments ranged from 811.22 g to 1345.97 g. As per observations on the total yield of *Agaricus bisporus,* thedata presented in Table-3, showed that the maximum total yield was found in treatment T3 (Compost (4 kg) **+** GA3 @ 10 PPM) as 1345.97 g, followed by T9 ( Compost (4 kg) **+**CK @ 10 PPM), T6 (Compost (4 kg) **+**NAA @ 10 PPM) and T2 (Compost (4kg) **+**GA3 @ 6 PPM) treatment representing 1322.29 g, 1318.08g and 1310.33 g respectively. The lowest yield was recorded from Control that was 811.22 g. It is obvious that every treatment raises the overall yield as compared to control days. A similar finding was published by Godse *et al*., (2021), who found that harvesting using GA3 treated bags needed a minimum of 19 days. Mukhopadhyay *et al*., (2005) also reported enhanced biomass production in mushrooms when grown on hormones supplemented substrates.

**3.2.3 Biological Efficiency (BE %)**

The biological efficiency of the white button mushroom varied significantly among all the treatments. According to the biological efficiency results shown in Table-2, all treatments having higher biological efficiency than the control. The highest biological efficiency was seen in treatment T3 (Compost (4 kg) **+** GA3 @ 10 PPM), which was 33.62%, followed by T9 ( Compost (4 kg) **+**CK @ 10 PPM), T6 (Compost (4 kg) **+**NAA @ 10 PPM) and T2 (Compost (4 kg) **+**GA3 @ 6 PPM), which were 33.05%, 32.95% and 32.75% respectively, while the lowest biological efficiency as 20.27% was observed in Control. Researchers such as Chaurasia *et al*., (2020) had found that growth regulators enhanced biological efficiency of Oyster mushroom.

**Table 2 Effect of various combination of Spent Mushroom Substrate on yield parameter of *Agaricus bisporus.***

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Treatment details** | **Yield**  **of first harvesting**  **(g)** | **Yield**  **of second harvesting**  **(g)** | **Yield**  **of third harvesting**  **(g)** | **Total**  **weight**  **(g)** | **Biological**  **efficiency in percent** |
| T1 | 477.04 | 427.49 | 372.22 | 1276.75 | 31.91 |
| T2 | 488.42 | 432.63 | 389.28 | 1310.33 | 32.75 |
| T3 | 495.24 | 445.10 | 405.63 | 1345.97 | 33.62 |
| T4 | 443.37 | 382.20 | 349.44 | 1175.01 | 29.37 |
| T5 | 478.90 | 431.10 | 376.06 | 1286.06 | 32.15 |
| T6 | 491.36 | 434.52 | 392.20 | 1318.08 | 32.95 |
| T7 | 454.36 | 406.55 | 352.17 | 1213.08 | 30.32 |
| T8 | 487.18 | 432.09 | 382.31 | 1301.58 | 32.52 |
| T9 | 492.33 | 436.24 | 393.72 | 1322.29 | 33.05 |
| T10 | 290.54 | 275.61 | 245.70 | 811.22 | 20.27 |
| **C.D at 5%** | **2.25** | **2.29** | **2.70** | **3.18** |  |
| **SE(m)** | **0.76** | **0.77** | **0.91** | **1.07** |  |
| **SE(d)** | **1.08** | **1.10** | **1.29** | **1.52** |  |
| **C.V %** | **0.28** | **0.32** | **0.43** | **0.15** |  |

**3.3. Effect of different combinations of Spent Mushroom Substrate on morphological parameters of *Agaricus bisporus.***

The parameters assessed included the number of fruiting bodies, maximum individual fruiting body weight, stalk length, and cap diameter.

**3.3.1 Number of Fruiting Bodies**

The data shown in Table-3 revealed that all the treatments resulted in an increase in the number of fruiting bodies with the maximum in T3 (Compost (4 kg) **+** GA3 @ 10 PPM) treatment having the highest number of fruiting bodies representing 131 followed by T9 ( Compost (4 kg) **+**CK @ 10 PPM), T6 (Compost (4 kg) **+** NAA @ 10 PPM) and T2 (Compost (4kg) **+**GA3 @ 6 PPM) treatment, which were 129, 128 and 123, respectively, while Control reported its lowest number just 91. Research findings of Sarkar and Chowdhury (2013) and Dey *et al*., (2007) also indicated similar results.

**3.3.2 Stalk Length**

Among all the treatments, the data presented in Table-3, showed that significant variation on width of stalk. The maximum width of stalk was found in T3 (Compost (4 kg) **+** GA3 @ 10 PPM) treatment representing 2.87 cm, followed by T9 ( Compost (4 kg) **+** CK @ 10 PPM), T6 (Compost (4 kg) **+**NAA @ 10 PPM) and T2 (Compost (4kg) **+**GA3 @ 6 PPM) as 2.85 cm, 2.81 cm, and 2.77 cm respectively, while lowest width of stalk recorded from control representing 1.78 cm. It is also cleared that all the treatment decreases the width of stalk against control.

**3.3.3 Cap Diameter**

The result presented in Table-3, showed that the significant variation on cap diameter ranged from 3.87 to 5.62 cm. among all the treatment the maximum cap diameter was found in T3 treatment(Compost (4 kg) **+** GA3 @ 10 PPM) representing 5.62 cm, followed by T9 ( Compost (4 kg) **+**CK @ 10 PPM), T6 (Compost (4 kg) **+**NAA @ 10 PPM) and T2 (Compost (4kg) **+**GA3 @ 6 PPM) treatment which were 5.47 cm, 5.46 cm and 5.33 cm, respectively, while lowest cap diameter showed in control representing 3.87 cm. Here, it is cleared that all the treatment increases the cap diameter over control. Khandakar (2004) reported that various hormone supplementation effectively increased stipe elongation and cap expansion in mushrooms

**Table 3. Effect of different combinations of SMS on morphological parameter of *Agaricus bisporus.***

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Treatment details** | Length of stalk(cm) | Width of stalk (cm) | Cap diameter (cm) | Number of fruiting body | Percent increase in number of fruiting body over control |
| T1 | 2.92 | 2.19 | 4.91 | 107 | 17.58 |
| T2 | 3.41 | 2.77 | 5.33 | 123 | 35.16 |
| T3 | 3.53 | 2.87 | 5.62 | 131 | 43.95 |
| T4 | 2.63 | 1.91 | 4.44 | 98 | 7.69 |
| T5 | 3.18 | 2.43 | 5.04 | 113 | 24.17 |
| T6 | 3.45 | 2.81 | 5.46 | 128 | 40.65 |
| T7 | 2.78 | 2.04 | 4.77 | 101 | 10.98 |
| T8 | 3.29 | 2.65 | 5.21 | 120 | 31.86 |
| T9 | 3.47 | 2.85 | 5.47 | 129 | 41.75 |
| T10 | 1.91 | 1.78 | 3.87 | 91 | ---- |
| **C.D at 5%** | **0.29** | **0.23** | **0.48** | **4.05** |  |
| **SE(m)** | **0.09** | **0.07** | **0.16** | **1.37** |  |
| **SE(d)** | **0.14** | **0.11** | **0.23** | **1.94** |  |
| **C.V %** | **5.64** | **5.68** | **5.68** | **2.08** |  |

**3.4 Effect of different combinations of SMS on the fresh and dry weight of *Agaricus bisporus.***

**3.4.1 Fresh Weight (g)**

The data presented in the Table-4, showed that significant variation on fresh weight of *Agaricus bisporus* was varied from 811.22 to 1345.97 g but the maximum fresh weight was found in T3 treatment(Compost (4 kg) **+** GA3 @ 10 PPM) representing 1345.97 g followed by T9 ( Compost (4 kg) **+**CK @ 10 PPM), T6 (Compost (4 kg) **+** NAA @ 10 PPM) and T2 (Compost (4 kg) **+** GA3 @ 6 PPM) treatment as 1322.29 g, 1318.08 g and 1310.33 g respectively, while the lowest fresh weight was recorded in untreated bag representing 811.22 g. It is cleared that every treatment reduces the fresh weight compared to control. According to Tolera *et al*., (2017), have also been showed that newly picked mushrooms had a moisture content of 88.75 0.02%. Similarly, Rashid *et al*., (2016) found fresh fruiting bodies of *Pleurotus ostreatus* had a moisture level of 90.10±0.09%.

**3.4.3 Dry Weight**

Dry weight of white button mushrooms significantly varied different treatments. The observations on dry weight, the data presented in Table-4, showed that the dry weight was increased in all the treatments ranged from 88.26 to 151.21 g. The maximum dry weight was found in T3 (Compost (4 kg) **+** GA3 @ 10 PPM) treatment representing 151.21 g, followed by T9 ( Compost (4 kg) **+**CK @ 10 PPM), T6 (Compost (4 kg) **+**NAA @ 10 PPM) and T2 (Compost (4kg) **+**GA3 @ 6 PPM) about 149.58 g, 148.54 g and 148.05 g respectively, while the lowest fresh weight was recorded in control representing 88.26 g. It is cleared that, as compared to controls, every treatment enhances the dry weight against control. The research findings of Pani (2011) and Carrasco *et al*. (2018) also represent that the dry weight of mushrooms significantly varied on different treatments.

**Table 4. Effect of different combination of SMS on the fresh and dry weight of *Agaricus bisporus.***

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Treatment details** | **Total fresh weight of fruiting bodies (g)** | **Total fresh weight percent increased over control** | **Total dry weight of fruiting bodies (g)** | **Total dry weight percent increased over control** |
| T1 | 1276.75 | 57.38 | 143.97 | 63.12 |
| T2 | 1310.33 | 61.52 | 148.05 | 69.48 |
| T3 | 1345.97 | 65.91 | 151.21 | 71.32 |
| T4 | 1175.01 | 44.84 | 132.77 | 50.43 |
| T5 | 1286.06 | 58.53 | 144.64 | 63.87 |
| T6 | 1318.08 | 62.48 | 148.54 | 68.29 |
| T7 | 1213.08 | 49.53 | 136.81 | 55.00 |
| T8 | 1301.58 | 60.44 | 146.63 | 66.13 |
| T9 | 1322.29 | 63.00 | 149.58 | 67.77 |
| T10 | 811.22 | **-------** | 88.26 | ------ |
| **C.D at 5%** | **4.64** |  | **3.98** |  |
| **SE(m)** | **1.57** |  | **1.35** |  |
| **SE(d)** | **2.22** |  | **1.91** |  |
| **C.V %** | **2.22** |  | **1.68** |  |

**Conclusion**

It may be concluded from the above findings that among all the treatments, T3 (Compost (4 kg) **+** GA3 @ 10 PPM) have ability to reduce the number of days of spawn running, pinhead formation and harvesting days and change the morphological parameter like stalk length, cap diameter , pileus diameter, number of fruiting body and yield parameter on *Agaricus bisporus****.*** .Therefore, T3 (Compost (4 kg) **+** GA3 @ 10 PPM) are advised in commercial cultivation of *Agaricus bisporus.*

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