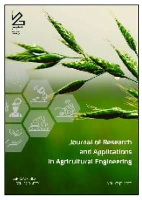
Article citation info:
Taufikurahman T., Rahmi A., Nanan B., Widiyanto S. 2024. Optimizing Sustainable Agriculture: Composting Solutions for Oyster Mushroom Baglog and Livestock Excrement to Enhance Sweet Corn Cultivation. *Journal of Research and Applications in Agricultural Engineering* 69 (1): 11–20. https://doi.org/10.53502/LJSE2836

Łukasiewicz
Poznań Institute of Technology

Journal of Research and Applications in Agricultural Engineering

Journal website: https://tech-rol.eu/



Optimizing Sustainable Agriculture: Composting Solutions for Oyster Mushroom Baglog and Livestock Excrement to Enhance Sweet Corn Cultivation

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Article info
Received: 17 November 2023
Accepted: 16 January 2024
Published: 29 June 2024

Keywords
animal manure
composting
baglog
spent mushroom substrate
sweet corn

Agricultural activities play a vital role in providing essential human sustenance, yet concurrently generate biomass waste, necessitating careful management to prevent environmental pollution. This study emphasizes the significance of proper agricultural waste management to prevent the underutilization of livestock excrement and the indiscriminate burning of crop residues, thereby ensuring food and health security, as well as sustainability in agriculture. The decomposability of agricultural wastes offers an opportunity to harness valuable products that furnish essential nutrients for plants, enhancing soil porosity, aeration, and water availability. Oyster mushroom baglog (OMB) containing wood sawdust, rice husks, and bran presents an environmental challenge when improperly handled in post-cultivation. This mismanagement can lead to pollution and unpleasant odours, and attract pests and diseases. This research explores the potential of composting OMB, incorporating animal manure, to produce composted materials suitable as a growth medium for crops. The study investigates four different compost compositions derived from OMB, evaluating their effectiveness in cultivating sweet corn (*Zea mays sacharata Sturt)* with a focus on determining the composition that yields optimal results for the Bonanza F1 variety. Four distinct treatments were examined: OMB without added animal manure (Ko), OMB with chicken manure (Ka), OMB with cow manure (Ks), and OMB with goat manure (Kk). The treatment involving the addition of chicken manure (Ka) to the OMB demonstrated superior effectiveness in terms of both vegetative growth and sweet corn yield. This study provides valuable insights into sustainable agricultural practices, highlighting the potential of composted materials from oyster mushroom waste to enhance sweet corn cultivation.

DOI: https://doi.org/10.53502/LSJE2836

1. Introduction

The population of Indonesia is predicted to reach 430 million by the year 2050, assuming an annual population growth rate of 1.5%. The rapid increase in population has resulted in the conversion of agricultural land into settlements and infrastructure, leading to competition in land utilization [1]. The national rate of paddy field conversion is estimated to be 96,512 hectares per year, while the growth rate of paddy fields has been less than 1% per year since the 2000s. With this projected rate of land conversion, the current paddy field area of 8.1 million hectares is expected to shrink to around 5.1 million hectares by 2045 [2]. Therefore, alternative materials are needed as ingredients in growing media for cultivating food crops on unproductive land.

Agriculture is one of the sectors producing the largest quantities of biomass. This biomass on one hand can be a burden to the environment, but it can also be an important input for the bioeconomy [3]. Proper agricultural waste management can prevent underutilization of livestock excrement and reckless burning of crop residues to ensure food and health security and sustainability in agriculture [4,5]. Almost all agricultural wastes can be decomposed, and the products of the decomposition process can provide essential nutrients for plants and make soil more porous, which improves soil aeration and soil water availability [6,7].

One of the materials that can be used to make growing media for cultivating food crops is oyster mushroom baglog (OMB). OMB is the substrate where oyster mushrooms grow, and it becomes non-productive after its cultivation cycle ends. The main ingredients of mushroom substrate are wood sawdust, rice husks, and bran. OMB can only be used once for mushroom cultivation. Improper handling of spent OMB can result in environmental pollution and unpleasant odours, which can attract pests and diseases [8]. OMB contains nutrients such as P 0.7%, K 0.02%, total N 0.6%, and organic C 49%, making it suitable as an alternative growing medium for cultivating food crops [9]. Agricultural waste can be composted, whereby organic matter is broken down into smaller biodegradable components that can be used to improve crop growth and yield [10,11,12]

The nutrient content in OMB is considered low for the purpose of supporting the growth of food crops. To meet the nutrient requirements for plant growth, organic materials such as animal manure (AM) may be added. The use of AM can reduce environmental pollution and production costs. AMW not only supplies macro nutrients such as N (nitrogen), P (phosphorus), and K (potassium), but also contains micronutrients such as Ca (calcium), Mg (magnesium), and Mn (manganese). In Indonesia's rural areas, readily available types of AM that can be used as ingredients in growing media include chicken, goat, and cow manure [13].

AM has a C/N ratio similar to that of soil, ranging from 15 to 25 [14]. Meanwhile, OMB substrate has a high C/N ratio ranging from 50 to 60 [4]. The quality of compost improves when its C/N ratio approaches the C/N ratio of soil, which is around 15–20, and when it contains macro- and micronutrients [15]. A high C/N ratio reduces the activity of microorganisms, and so a mixture of spent OMB and AM requires a composting process to lower the C/N ratio [16]. Such a process is also expected to enrich the nutrient content required for plant growth and productivity, thus reducing the need for fertilizer use in cultivation.

Sweet corn (*Zea mays* saccharata Sturt.) is a commodity that plays a strategic role in food demand and has economic value with growing market demand, not only for direct consumption but also as animal feed and a raw material for certain industries [17]. According to a report from the Ministry of Agriculture's Data and Information Systems Centre, the national corn harvest area in Indonesia for the period January to December 2020 reached 5.16 million ha [18].

Sweet corn is widely accepted by various segments of society because it fulfils nutritional needs for human growth as a source of carbohydrates and protein, and is easy to cultivate. The growth and productivity of sweet corn are influenced by the environment and the availability of sufficient nutrients from growing media.

This study aims to determine how the addition of various AMs, from chicken, cow and goat, to OMB-based compost affects the growth and biomass yield of sweet corn (Bonanza F1 variety).

2. Materials and methods

2.1. Time and location

The research was conducted for six months, from October 2022 to March 2023, at the Educational Garden of Institut Teknologi Bandung (ITB), located at 6°54'22.4"S, 107°50'08.8"E, with an elevation of 865.79 meters above sea level, at Haurngombong Village, Sumedang district, West Java.

2.2. Research design

The study concerned the differences resulting from adding types of AM to the composition of organic compost made from OMB. The studied treatments consisted of OMB without the addition of AM (as a control), OMB with the addition of chicken manure, OMB with the addition of cow manure, and OMB with the addition of goat manure (Table 1). In total there were 4 treatments with 5 replications. Each replication consisted of 3 plant samples, resulting in a total of 60 plants. The planting distance was 30 x 30 cm. The compost treatment variations were applied in accordance with a Completely Randomized Design (CRD) as indicated below.

Table 1. Treatments and compost compositions

<table>
<tr><th>Treatment (media)</th><th colspan="2">Composition of compost</th></tr>
<tr><td>OMB only (as control: MKo)</td><td colspan="2">7 kg of baglog waste</td></tr>
<tr><td>OMB+ chicken manure (MKa)</td><td rowspan="3">5 kg of OMB</td><td>2 kg chicken manure</td></tr>
<tr><td>OMB + goat manure (MKk)</td><td>2 kg goat manure</td></tr>
<tr><td>OMB + cow manure (MKs)</td><td>2 kg cow manure</td></tr>
</table>

2.3 Materials

The materials used in this study included sweet corn seeds (Bonanza F1 variety). This is one of the most popular corn varieties planted in Indonesia. For the composting process, one litre of commercial Effective Microorganism-4 (EM4) was added as a bioactivator, following BAC19 and Hendriani et al. [20] and Suryawan et al. [21].

Chicken, goat, and cow manure and molasses were added for the fermentation process. For the planting media, sands and burnt rice husk were added. The plant was grown in a polybag. NPK fertilizer (350 kg/ha) was applied at the beginning of the experiment. For measuring plant growth, a digital caliper, measuring tape and digital scale were used. A thermometer, lux meter and hygrometer were used for measuring environmental parameters. Equipment used for watering the plants included a 500 mL measuring glass, water jerrycan, water hose, and sprayer.

2.4 Compost production

In the preparation step, 1 ml of EM4 and molasses were dissolved in 1 L of water, and the mixture was left to stand for 24 hours. In the next step, the OMB was finely crushed and mixed with the animal manure specified for the treatment, and spread evenly on a tarpaulin. The EM4 solution was sprayed evenly on the mixture of OMB and animal manure, and it was thoroughly mixed until a moisture content of 30–40% was achieved. The mixed materials were placed in an airtight container and left to ferment for 30 days to ensure a proper fermentation process [20]. On the 14th and 30th days, the moisture and temperature of the compost were checked. Mature OMB compost is characterized by a pleasant aroma. Then, physical characteristics of the compost, including bulk density and pH, were measured. Measurements of organic carbon (C), total nitrogen (N), C/N ratio, total phosphorus (P), and total potassium (K) were also performed.

2.5 Cultivation techniques

Growing media were prepared by mixing burnt rice husk with OMB compost in a 1:1 volume ratio and stirring until well blended. Polybags with a diameter of 22 cm and height of 15 cm were used. 1 kg of sand was placed in the polybag, followed by the addition of the mixture of burnt rice husk and OMB compost, up to a height of 15 cm. The polybags were then arranged in the screen house according to the plot design of the study, with a planting distance of 30 cm x 30 cm. The growing medium was thoroughly watered and left to settle for one week before planting. Sweet corn seeds were planted by making planting holes 3–5 cm deep from the surface of the growing medium and planting three seeds per hole.

At 12 days after sowing (DAS), poorly performing plants were removed, leaving one plant per polybag for maintenance. Watering was performed twice a day from 0 to 14 DAS and once a day from 15 DAS until harvest. Weeding was performed mechanically by removing weeds, hilling took place when the roots become visible at the surface of the growing medium, and basal fertilization using NPK fertilizer was carried out when the plants were 14 days old. Harvesting took place when the sweet corn showed signs such as the corn silk changing colour to reddish-brown, the kernels hardening, and the leaves starting to dry and turn yellow. Parameters measured included cob length, cob diameter, and cob weight without husk for the first and second cob harvest, and shoot-to-root ratio.

2.6 Statistical analysis

Data analysis was performed using IBM SPSS and Microsoft Excel software to determine mean values and standard deviations, perform statistical tests, and plot graphs from the sample data. The data were statistically analysed using one-way ANOVA with a significance level of 5%. If the ANOVA test indicated a significant effect, further analysis was performed using the Duncan Multiple Range Test (DMRT) at a confidence level of 95%.

3. Results and discussion

3.1 Properties of the compost

The bulk density of the compost with added animal manures (MKa, MKs, MKk) was slightly higher than the bulk density of the compost without addition of manures (MKo) (Table 2). All treatments had low bulk density values, ranging from 0.14 to 0.15 g/cm^3. The bulk density value is inversely proportional to the roughness of the growing medium particles: the coarser the particles, the higher the bulk density.

Table 2. Properties of compost produced from fermented mixtures of baglog waste and animal manures

Treatment	MKo	MKa	MKs	MKk
Bulk density (g/cm^3)	0.14	0.17	0.16	0.15
pH	5.70	5.78	5.62	5.70

Note: MKo contained only baglog waste (control), MKa was prepared with added chicken manure, MKs with added cow manure, and MKk with added goat manure.

Low bulk density is commonly found in soils with high organic matter content. Organic soils generally have bulk density values ranging from 0.1 to 0.9 g/cm^3. With low bulk density, the porosity value becomes high, providing pore space for water and air movement and making it easier for plant roots to penetrate the growing medium in search of nutrients [22]. The pH values of the growing media in each treatment were relatively similar, at around 5.7. Sweet corn plants can grow well at this pH value, as they require an ideal pH range of 5 to 8 for growth. A pH value that is too low can poison plants with aluminium salts, while one that is too high makes it difficult for the nutrients in the growing medium to be absorbed [23].

Chemical analysis of the OMB and animal manures before fermentation showed that the OMB contained lower levels of nitrogen, potassium and phosphorus than the manures, but had a significantly higher C-organic content and C/N ratio (Table 3). Chicken manure had higher nitrogen, potassium and phosphorus contents, but a lower C/N ratio than the other manures. This indicates that chicken manure potentially has better chemical properties than cow and goat manures.

Table 3. Chemical properties of OMB and animal manures before fermentation

Compost ingredients	Nitrogen %	P – total %	K – total %	C – organic %	Water content %	C/N ratio
OMB (Ko)	0.73	0.37	0.09	44.16	19.43	60.49
Chicken manure (Ka)	2.25	3.89	1.42	24.91	17.56	11.07
Cow manure (Ks)	1.50	2.66	0.26	34.12	36.43	22.75
Goat manure (Kk)	0.76	2.21	0.35	20.02	12.04	26.34

In the analysis of the composts after fermentation, the highest contents of N, P, and K were found in the Ka treatment, which had 1.22% N, 2.39% P, and 0.58% K (Table 4). The order of C/N ratios from lowest to highest was Ka (25.34), Ks (33.2), Kk (43.76), Ko (53.71). The composting process was conducted anaerobically to reduce the C/N ratio [24].

Table 4. Chemical properties of the composts (after fermentation)

Compost	Nitrogen %	P – total %	K – total %	C – organic %	Water content %	C/N ratio
OMB (Ko)	0.68	2.25	0.38	36.52	0.38	53.71
Chicken manure (Ka)	1.22	2.39	0.58	30.92	0.58	25.34
Cow manure (Ks)	0.96	2.15	0.24	31.87	0.24	33.2
Goat manure (Kk)	0.68	2.22	0.42	29.76	0.42	43.76

A high C/N ratio can decrease the activity of microorganisms. During fermentation, the reduction of organic carbon occurs, due to a process of assimilation of organic compounds caused by microorganism activity. In the assimilation process, substrate compounds, which serve as an energy source, are transformed into simpler compounds through nutrient breakdown. Microorganisms degrade compost materials such as carbohydrates, proteins, and fats into simpler forms such as glucose, amino acids, and fatty acids. The reduction of organic carbon also occurs due to carbon release. The high C/N ratio indicates that the compost materials have not fully decomposed, meaning that the organic matter in the compost still consists of solid fractions that are difficult to decompose [8].

The Ka treatment had the lowest C/N ratio, probably because the chicken manure decomposed faster than the cow and goat manure. A good decomposition rate provides nutrients, especially N, P, and K. Additionally, chicken manure has higher N, P, and K content than large livestock manure [25]. The Ks treatment had a higher C/N ratio value than Ka because cow manure has a high content of fiber, including cellulose, which results in a high C content [10]. The Kk treatment had a higher C/N ratio than Ka and Ks because, in addition to the high fiber content, the physical state of goat manure in the form of hard pellets can hinder the decomposition process [26]. The Ko treatment had the highest C/N ratio because it did not contain any animal manure. The OMB was primarily composed of sawdust, which has a high C/N ratio [27].

Overall, all four compost treatments had C/N ratios higher than specified in the Indonesian quality standard (SNI). According to the SNI 19-7030-2004 compost quality standard, a good C/N ratio is within the range 10–20. The high C/N ratio values were due to suboptimal decomposition processes. The raw material for the compost, OMB, had a high C/N ratio, slowing down the fermentation process and requiring more than one month for complete decomposition. C/N ratio values of 10–20 indicate that the nutrient elements bound to the humus have been released through mineralization processes, making them available for plant absorption [28].

3.2 Cob length

The medium used for treatment has a significant effect on the length of sweet corn cobs ($p < 0.05$). The greatest cob length at the first harvest (21.2 cm) was obtained with the MKa treatment, and the smallest (15.6 cm) with MKk. The greatest length at the second harvest (12.4 cm) was again obtained with MKa, and the smallest (0 cm) with MKk (Figure 1).

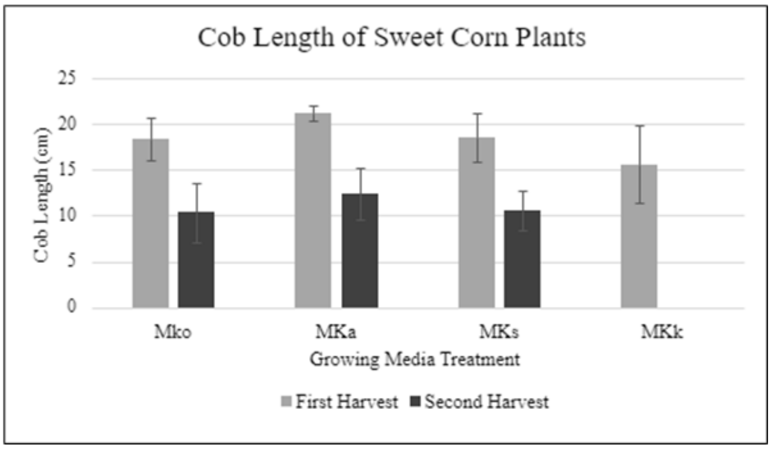

Fig. 1. Cob length of sweet corn plants (n=5)
Error bars represent standard deviation

This is probably because the MKa treatment had higher levels of phosphorus (P) and potassium (K) than the other treatments. Phosphorus plays a role in plant photosynthesis, allowing photosynthetic products from leaves and other photosynthetic cells to be transported to other organs or tissues for growth and storage as food reserves, thereby influencing the length of corn cobs. Additionally, the formation of cobs requires an optimum level of potassium. Potassium plays a part in starch formation and metabolic processes within cells, leading to the accumulation of starch in the cob and increasing the cob length. The MKk treatment did not have a value for cob length at second harvest. This is because the plants subjected to the MKk treatment had only one cob each, while MKo produced some plants with two cobs, and MKa and MKs resulted in two cobs on every plant.

3.3 Cob diameter

The medium used for treatment had no significant effect on the cob diameter at the first harvest ($p > 0.05$), but had a significant effect on the diameter at the second harvest ($p < 0.05$). The MKk treatment did not have a value for cob diameter at second harvest; this is because the MKk treatment produced only one cob per plant, and so there was no second cob harvest. The MKo treatment produced some plants with two cobs, and MKa and MKs resulted in two cobs on every plant.

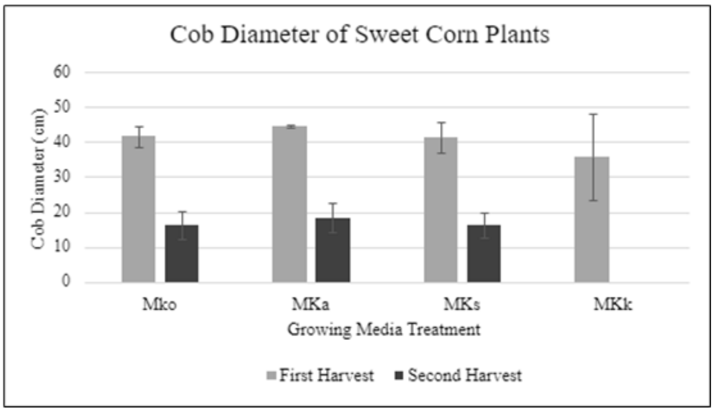

Fig. 2. Cob diameter of sweet corn plants (n=5)
Error bars represent standard deviation

The largest cob diameter at the first harvest (44.46 mm) was obtained with the MKa treatment, and the smallest (35.8 mm) with MKk. The largest diameter at the second harvest (18.32 mm) was again obtained with MKa, and the smallest (0 cm) with MKk (Figure 2). MKa contained higher levels of phosphorus (P) and potassium (K) than the other treatments.

Phosphorus helps in distributing photosynthates to the cob or fruit, thereby increasing the cob size. Therefore, differences in phosphorus content in the growing medium can affect the cob diameter of sweet corn [29]. Potassium (K) also plays a role in increasing the cob diameter. Potassium activates numerous enzymes involved in respiration and photosynthesis, thereby increasing the accumulation of photosynthates in the sweet corn cob [24]. The average cob diameters at the first harvest did not indicate significant differences between treatments. This may be due to the relatively similar availability of potassium in the growing media used.

3.4 Cob weight without husk

The medium used for treatment had a significant effect on the weight of cobs without husks. This is probably because the MKk treatment produced only one corn cob per plant, while MKo led to some plants with two cobs, and MKa and MKs produced two cobs per plant.

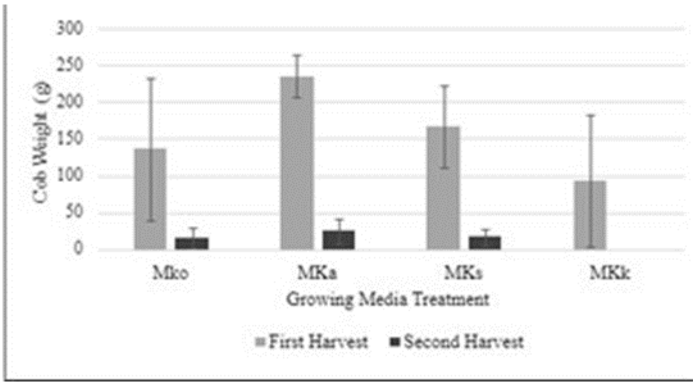

Fig. 3. Cob weight without husk (n=5)
Error bars represent standard deviation

The largest cob weight at the first harvest (235.06 g) was obtained with the MKa treatment, and the smallest (93.94 g) with MKk. At the second cob harvest, the largest cob weight (24.49 g) was again obtained with MKa, and the smallest (0 g) with MKk (Figure 3). MKa contained higher levels of phosphorus (P) and potassium (K) than the other treatments. The MKk treatment did not give any values for cob weight at the second harvest (Figure 3).

Phosphorus plays a significant role in the seed filling process of sweet corn plants. It is continuously absorbed by the plant until the seed approaches maturity. The absorbed nutrients are accumulated in the leaves as proteins, stimulating seed formation. The accumulation of metabolic products during seed formation increases, resulting in maximum weight and size of the seeds [26]. Additionally, potassium (K) enhances the rate of photosynthesis in plants. More than 50% of the total potassium in the leaves is concentrated in the chloroplasts, which increases the rate of photosynthate production [30]. Cob weight is closely related to cob length and diameter. Large length and diameter values result in a higher cob weight.

3.5 Shoot-to-root ratio

The choice of growing medium significantly influences the shoot-to-root ratio of sweet corn. The highest shoot-to-root ratio (13) was obtained with the MKa treatment, and the lowest (7.15) with MKk (Figure 4). The shoot-to-root ratio is influenced by the dry weight of the shoot and roots. When the dry weight of the shoot increases and that of the roots decreases, the shoot-to-root ratio also increases. A high shoot-to-root ratio indicates a faster distribution of photosynthetic products towards the shoot compared with the roots [31].

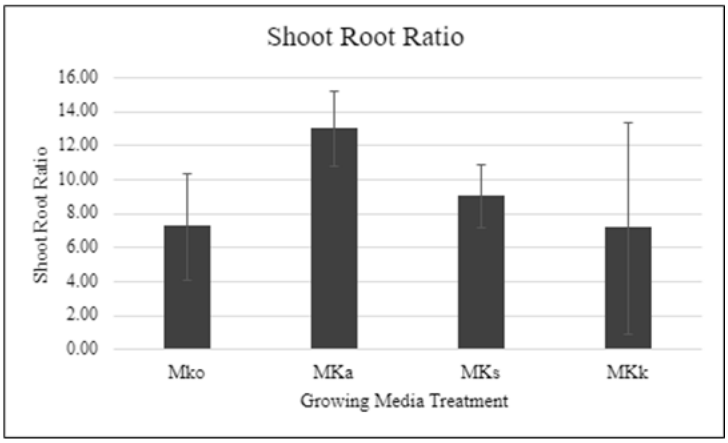

Fig. 4. Shoot-to-root ratio (n=5)
Error bars represent standard deviation

The shoot-to-root ratio is higher in the case of the MKa treatment. This is probably because the medium in the MKa treatment contains higher levels of N, P, and K than in the other treatments. These three elements are essential macronutrients for both vegetative and generative growth stages. N is involved in carbohydrate and protein formation, P plays a role in generative development, and K facilitates carbohydrate translocation from the leaves to other plant organs. Adequate levels of these nutrients can enhance photosynthetic activity, leading to increased production and distribution of photosynthates throughout the plant [32].

3.6 Environmental conditions

The growth and development of plants are influenced by the environmental conditions, which should meet the optimal growth requirements of the cultivated commodity. The average temperature at the research site was 27.8 °C, with a minimum of 22.2 °C and a maximum of 35.5 °C. The average air humidity was 60.68%, with a minimum of 35% and a maximum of 99%. The average light intensity was 2317 lux, with a minimum of 1107 and a maximum of 3263 lux (Table 5).

Table 5. Environmental conditions at the research site

	Temperature (°C)	**Humidity (%)**	**Light intensity (lux)**
Mean	27.80	60.68	2,317
Max	35.5	99	3,263
Min	22.2	35	1,107

The optimal temperature and humidity for the growth of sweet corn are in the ranges 21–35 °C and 60–90% [23]. Temperature and humidity affect the development of sweet corn plants. Higher received light intensity leads to better growth. Sweet corn plants require 8 hours of light exposure for optimal growth [17]. This is because sweet corn is a C4 plant, achieving optimal growth under high light intensity [18]. Sweet corn will grow optimally under a light intensity of 3000–6000 lux [23].

In general, the results indicate that the treatment involving the addition of chicken manure (Ka) to OMB demonstrated superior effectiveness in terms of both vegetative growth and sweet corn yield. This study provides valuable insights into sustainable agricultural practices, highlighting the potential of composted materials from oyster mushroom waste to enhance sweet corn cultivation.

Conclusion

Compost from OMB with the addition of chicken manure (MKa) was found to be the optimal treatment, as it produced the best results in terms of vegetative and yield parameters of the sweet corn variety Bonanza F1. The yield parameters included the cob length at the first harvest (21.2 cm) and at the second harvest (12.4 cm), the cob diameter at the first harvest (44.46 mm) and at the second harvest (18.32 mm), the cob weight without husk at the first harvest (235.06 g) and at the second harvest (24.49 g), and the shoot-to-root ratio (13). Through fermentation techniques, OMB and chicken manure can be used as a good crop growing medium, and this is a very beneficial means of providing organic fertilizer while at the same time reducing the adverse environmental impact of agricultural waste.

Acknowledgement

We are thankfull to ITB for the research grant for conducting the research under the scheme of PPMI 2022.

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