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PERSPECTIVE

Spawn production and cultivation technology for *Volvariella volvacea*: a perspective

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Abstract

Volvariella volvacea has long been cultivated by farmers, but there are still some limitations to producing high-yielding *V. volvacea*. Several factors can lead to low yields, including poor substrate utilization and inadequate technology. Therefore, many attempts have been made over the years to improve the biological efficiency of the crop using various approaches. In this review, the existing technologies for yield improvement in *V. volvacea* production are discussed. This paper also elaborates the current practice including spawn improvement method and cultivation strategy. The smart mushroom house technology equipped with Internet of Things is also presented.

1. Introduction

Volvariella volvacea or paddy straw mushroom from the Pluteaceae family, is typically found in tropical countries that offer warm temperatures year-round. It is known for its benefits as a highly nutritious and medicinal edible mushroom (Chakravarty, 2011). It is known that *V. volvacea* was first cultivated in China and thus is often referred to as Chinese mushroom (Ahlawat and Tewari, 2007). Since then, it has been introduced to other countries where it is continuously cultivated and researched. Today, Asian countries are the largest producers of the mushroom industry, led by China (Yoo *et al*., 2016). In India, *V. volvacea* is one of the four mushrooms grown year-round (Gupta *et al*., 2016). Mushroom production has also been steadily increasing in Malaysia since 2007 due to abundant crop residues that can be used for mushroom cultivation (Rosmiza *et al*., 2016). Indonesia, which exports about 5600 tonnes of *V. volvacea* annually, holds 3.09% of the world production of *V. volvacea* (Sumiati and Djuariah, 2007). In Thailand, *V. volvacea* is locally known as hed-fang and is commercially grown and sold to consumers (Srikram and Supapvanich, 2016).

Favourable conditions such as high temperatures and high carbon and nitrogen concentrations (C/N ratio) are required for optimal growth conditions of *V. volvacea* (Zervakis *et al*., 2001; Diamantopoulou *et al*., 2016). Depending on the location and climate, *V. volvacea* is cultivated either outdoors or indoors. The type of substrates used for the cultivation of *V. volvacea* in a given country is mainly influenced by the number of available free resources. For example, farmers in India use paddy straw as a substrate for *V. volvacea* but water hyacinth has been found to be the best substrate for *V. volvacea* in Thailand (Chaisaena *et al*., 2012; Biswas, 2014). Malaysia and Indonesia, on the other hand, are continuously investigating the potential use of substrate from empty fruit bunches (Triyono *et al*., 2019; Bakce *et al*., 2019; Umor *et al*., 2021). Therefore, enrichment of substrates by different types of supplements is one of the most effective methods to improve fungal yield.

Apart from that, irradiation and genetic modification are one of the strategies proposed by researchers to produce high-yielding *V. volvacea* spawn, albeit there are few studies on it. The application of the

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Table 1. Proximate analysis of *Volvariella volvacea* cultivated on different types of substrates.

Parameter (%)	Paddy Straw		Cotton Waste		Banana Leaves	Sugarcane bagasses	Empty Fruit Bunch
	Zikriyani *et al.* (2018)	Haq *et al.* (2011)	Zikriyani *et al.* (2018)	Haq *et al.* (2011)	Zikriyani *et al.* (2018)	Haq *et al.* (2011)	Triyono *et al.* (2019)
Moisture	90.49±1.43	89.80±0.10	91.25±0.85	89.50±0.20	91.40±0.17	86.00	90.10±0.24
Ash Content	1.08±0.03	2.50±0.20	0.92±0.07	10.80	0.76±0.04	1.00±0.20	9.42±0.57
Protein	4.69±1.03	28.57	3.51±0.40	34.17	2.62±0.16	30.51	33.47±3.08
Total Fat	0.00±0.00	NA	0.07±0.12	NA	0.12±0.16	NA	3.71±0.50
Fibre Content	NA	7.88	NA	11.90	NA	7.22	7.74±0.76
Carbohydrate	3.74±0.37	NA	4.26±0.84	NA	5.11±0.21	NA	45.66±3.19

Internet of Things (IoT) and smart mushroom house is also a major advancement in the mushroom cultivation industry. IoT uses advanced technologies and electronic devices to create an environment suitable for *V. volvacea* and makes it easier for the farmer to monitor the process.

This paper discusses the advantages and disadvantages of technologies currently used in *V. volvacea* cultivation. In addition, the improvement of spawn and the latest cultivation methods of *V. volvacea* for high yields are highlighted.

1.1 Benefits of Volvariella volvacea

Volvariella volvacea is sought after because of the various benefits that the mushroom provides. As shown in Table 1, *V. volvacea* has relatively high carbohydrate and protein content but low fat and ash content, which is considered highly nutritious for consumption (Singh *et al.*, 2020). It has also been found that *V. volvacea* has many medicinal properties and acts as an antioxidant (Sudha *et al.*, 2008; Ramkumar *et al.*, 2012). Antioxidants reduce the amount of oxygen free radicals that are harmful to the human body (Gülçin, 2012). Another valuable property of *V. volvacea* is that it has great potential as an active ingredient in cancer medicine. This is based on the evidence of the protein content in *V. volvacea* that can induce apoptosis of cancer cells and the antitumor property of the branched β -D-glucans of the fruiting body of *V. volvacea* (Misaki *et al.*, 1986; Wu *et al.*, 2011). A novel lectin successfully purified from *V. volvacea* has been shown to increase the expression of some immunomodulatory proteins essential for lymphocyte proliferation (She *et al.*, 1998; Sze *et al.*, 2004).

2. Growth medium

The type of substrate the farmer uses for mushroom cultivation depends on the availability and accessibility of the feedstock. They are also selected based on the effects of the substrate on the productivity of the mushroom spawn and fruiting body (Philippoussis *et al.*, 2000; Yue and Qing, 2011). In addition, the nutrient content of the fungal fruiting body can also be attributed to the type of substrate used (Haq *et al.*, 2011). Some examples of agricultural wastes used as substrate and their biological efficiency are shown in Table 2.

Table 2. Biological efficiency of *Volvariella volvacea* cultivated on different substrates.

Type of Substrate	Biological Efficiency (%)	References
Paddy straw	12.30	Banik and Nandi (2000)
Banana leaf	15.21	Belewu and Belewu (2005)
Cotton waste	17.69	Zikriyani *et al.* (2018)
Empty fruit bunch pellet	28.00	Umor *et al.* (2021)
Empty fruit bunch (whole stalk)	3.60±1.22	Triyono *et al.* (2019)
Sawdust	18.46	Ajikah *et al.* (2019)
Pea straw	14.16	Maurya *et al.* (2016)
Wheat straw	11.32	
Ear mushroom waste	17.52±0.80	Sao *et al.* (2014)
Lingzhi mushroom waste	21.21±0.74	
Water hyacinth	8.70±0.35	Thiribhuvanamala *et al.* (2012)
Sugarcane trash	13.20±0.26	
Maize Stubbles/ trash	10.00±0.40	

3. Current existing cultivation technology

V. volvacea is quite easy to maintain and requires only a short period of time to grow, usually between 4 and 5 weeks (Ahlawat and Tewari, 2007). Unfortunately, a major disadvantage of the conventional cultivation method is the low yield of *V. volvacea*. To date, numerous studies have been conducted to increase the yield of *V. volvacea*. The strengths, weaknesses, and proposed measures of each strategy are summarized in Table 3. Figure 1 shows an example of outdoor and

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Table 3. Strength, weakness, and measures to overcome of *Volvariella volvacea* cultivation technology.

Cultivation Technology	Strength	Weakness	Measures to Overcome	References
Conventional outdoor cultivation method	Low production cost with good returns	Require large suitable spaces and yield production depends on natural climate	Use high yield *V. volvacea* strain and utilize *V. volvacea* as intercrop	Thiribhuvanamala *et al.* (2021)
Indoor cultivation method using wooden crates and polythene house	Able to maintain stable temperature and relative humidity	Additional cost for mushroom house construction was required and thus increase the initial cost of mushroom cultivation.	Use of quality low-cost material for mushroom house production to reduce cost	Reyes (2000); Rajapakse (2011); Thiribhuvanamala *et al.* (2012)
Supplementation of substrate with organic substance	Organic substance such as red gram powder was proven to increase mushroom yield and biological efficiency	Some organic substance can have an adverse effect on mushroom cultivation including lower yield and biological efficiency and increase vulnerability to contamination.	Pre-analysis of the organic substances should be done to avoid harmful effect	Biswas and Layak (2014)
Supplementation of paddy straw with biogas residual slurry manure	Increase mushroom yield, protein content and essential minerals.	The increase in mineral caused by supplementation is not consistent	Can be utilized as additional option	Banik and Nandi (2000)
Mushroom cultivation using micronutrients combination as booster during pinhead formation on substrate	Increase mushroom yield, biological efficiency and produce sturdier fruiting bodies	The concentrations of each micronutrient must be accurately measured and tested for the positive effect of the booster to take place	Can be utilized as additional option	Thiribhuvanamala *et al.* (2012)
Cultivation using different substrate combination	Combination such as banana pseudo stem and paddy straw increase mushroom yield and biological efficiency compared to one-type substrate method	Some combination could result in even lower yield and biological efficiency compared to one-type substrate method	Meticulous selection of substrate is required	Biswas and Layak (2014)

Figure 1. Cultivation of *Volvariella volvacea* in outdoor cultivation on EFB substrate and indoor cultivation in mushroom house.

indoor cultivation of *V. volvacea.*

3.1 Outdoor cultivation method

Outdoor cultivation is usually done on multiple beds consisting of selected substrate such as empty fruit bunch or paddy straw within a shaded area (Ahlawat and Tewari, 2007; Kamaliah *et al*., 2022). Because this method is influenced by natural microclimate, it has a wide range of sites including the cropping system and agroforestry systems (Thiribuvanamala *et al*., 2021; Kamaliah *et al*., 2022). This method is advantageous since it is less expensive and is easier to set up.

3.2 Indoor cultivation method

Unlike outdoor cultivation, indoor cultivation requires an enclosed space and vertical storage racks. This cultivation strategy attempts to optimize the use of land that has limited space or area (Thiribhuvanamala *et al*., 2012). The initial cost of indoor cultivation is relatively higher than outdoor cultivation due to the cost of materials and labor to build the mushroom house. However, the net profit of indoor cultivation is usually higher because the production of *V. volvacea* is constant (Thuc *et al*., 2020). Since indoor cultivation guarantees the stability of ambient temperature and humidity, the production of *V. volvacea* can be continuous regardless of climate changes such as cloudy weather or rainy season (Karsid *et al*., 2015). Finally, the controlled environment of indoor cultivation also serves as a protection against mold infection, thus reducing contamination (Bisoyi *et al*., 2021).

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4. Postharvest management

Another important part of mushroom cultivation is the management and storage of mushrooms after harvest. Improper preservation of *V. volvacea* may result in deterioration of the quality and physical characteristics of the mushroom. As a result, the value of the mushroom may also decrease due to the reduction in quality (Minh and Hang, 2019).

The most common method for postharvest treatment is refrigeration (Higgins *et al*., 2017). In addition, the mushroom can also be preserved by freezing, drying, pickling, discrete packaging, application of an edible coating, and carbon dioxide treatment (Wakchaure, 2011; Jamjumroon *et al*., 2012; Sakinah *et al*., 2019; Minh and Hang, 2019). Proper packaging using low density polyethylene (LDPE), controlled atmosphere packaging (CAP) or modified atmosphere packaging (MAP) is essential to maintain the quality of mushrooms (Wakchaure, 2011; Sakinah *et al*., 2019). This is because good packaging protects the harvested mushroom from dirt and foreign matter during transportation between different locations. However, MAP packaging is preferable to standard LDPE packaging because the low oxygen content in the packaging effectively improves the shelf life of *V. volvacea* (Wakchaure, 2011).

Another approach to preserve the quality of *V. volvacea* is to apply an edible coating to the outer part of the mushroom. Several organic materials can be used as coating materials for *V. volvacea*, including chitosan, carboxymethylcellulose, sodium alginate, and modified starch. This strategy is excellent for preserving the quality of *V. volvacea* during storage. It has significant effects on various parameters, especially moisture retention and visual characteristics of *V. volvacea* (Minh and Hang, 2019). Loss of quality in *V. volvacea* can be detected by the browning of the mushroom cap. The browning is related to water loss and polyphenol oxidase (PPO) enzymatic activity.

Treatment with carbon dioxide (CO_2) before or during storage has been identified as a key solution to combat the browning problem and further extend the shelf life of *V. volvacea* after harvest (Jamjumroon *et al*., 2012). Other alternatives such as preservation, drying, pickling, and steep preservation are generally used for long-term storage (Rai and Arumuganathan, 2008). Although these methods do not preserve the original form of the mushroom, *V. volvacea* can be stored longer in these ways compared to fresh mushrooms.

5. Improved method for *Volvariella volvacea* production

A common method for improving the yield of *Volvariella volvacea* is to improve the mushroom spawn. Mushroom spawn is referred to as "seed" in mushroom cultivation. To obtain a high yield of *V. volvacea*, good quality mushroom spawn is required. Therefore, the selection of the *V. volvacea* strain used is critical to ensure that the mushroom spawn is of the highest quality. Fast-growing *V. volvacea* strains have been reported to have better mycelial growth performance compared to normal strains and have higher enzymatic activity, which is essential for fruiting body development (Ahlawat *et al*., 2008). Other strategies that can be used to improve yield include irradiation, genetic and molecular modification, and substrate enrichment. The incorporation of modern technologies such as the Internet of Things is also currently being practiced in mushroom cultivation as a means of data collection.

5.1 Irradiation

Gamma or ultraviolet (UV) irradiation of foods is commonly used to extend the shelf life of mushrooms after harvest and to preserve their quality during storage (Fernandes *et al*., 2012). Similarly, irradiation may have beneficial effects on *V. volvacea*. For example, gamma irradiation can improve the colour and texture of the mushroom in fresh *V. volvacea*, while UV irradiation can increase the content of vitamin D_2 in *V. volvacea* (Nayga -Mercado and Alabastro, 1989; Mau *et al*., 1998). In contrast, to achieve high yield and biological efficiency of *V. volvacea*, the mycelia of *V. volvacea* were treated with gamma and UV irradiation instead of fresh mushroom (Sermkiattipong and Charoen, 2014; Bangyeekhun *et al*., 2020). Interestingly, cultivation of *V. volvacea* on gamma-irradiated substrates can also increase the yield of *V. volvacea* (Darmawi and Suwadji, 1998).

5.2 Genetic and molecular modification

Genetic modification using molecular methods has become increasingly popular recently. Fruiting bodies of *V. volvacea* is sensitive towards temperatures changes, which could be a problem during storage because refrigeration can affect the quality of the mushroom. The development of a new *V. volvacea* strain resistant to low temperatures is one of the solutions to this problem (Zhao *et al*., 2020). Breeding a cold-tolerant strain of *V. volvacea* can be done by chemical mutagenesis or protoplast fusion with other fungal species (Liu *et al*., 2011; He *et al*., 2018). Another strategy is to study the direct effects of specific genes on *V. volvacea* growth. For example, introducing a cellulase gene into the mycelium of *V. volvacea* using the plasmid transformation method can enhance the hydrolysis of cellulosic materials in *V. volvacea* and subsequently increase fungal yield and biological efficiency (Zhao *et al*., 2010). Similarly, exogenous introduction of the trehalose gene during cultivation of *V. volvacea* can also improve fruiting body quality (Zhao *et al*., 2018).

5.3 Enrichment of substrate

The substrate is an important component in the cultivation of *V. volvacea*. As mentioned earlier, there are quite a number of raw materials that can be used as substrates. In addition, most of the studies listed in Table 3 attempted to improve the production capability of these substrates by using boosters. For example, Thiribuvanamala *et al*. (2012) formulated a booster by mixing several micronutrients together and investigated the effect of the booster on paddy straw substrate. Ultimately, the micronutrient-enriched substrate actually resulted in higher yields compared to the non-enriched substrate. Another example is a study by Biswas and Layak (2014), in which all supplements except mustard cake showed higher biological efficiency than non-supplemented paddy straw substrate. An interesting study conducted by Payapanon *et al.* (2011) used two bacterial strains, *Paenibacillus polymyxa* and *Bacillus subtilis*, as supplements. The results of their study proved that the supplemented rice straw compost had a significantly higher yield than the non-supplemented substrate.

5.4 Internet of things (IOT) and smart mushroom house

Unpredictable weather conditions are a major problem in the cultivation of *V. volvacea*, as the fungus requires optimal temperature and humidity to achieve satisfactory results (Rajapakse, 2011). Currently, indoor cultivation with a controlled environment based on fungal house adaptation and remote sensing monitoring system is an effective method to solve this problem (Chen *et al*., 2022). An IoT-based system used in a smart mushroom house includes various technologies to connect physical devices to a wireless network to transmit data to the end user (Hu *et al*., 2021). IoT implementation offers a wide range of benefits for mushroom cultivation, ranging from remote access to data and automatic control to labour and cost reduction. Table 4 shows all the studies on implementation of IoT-based system in an actual mushroom house. On average, remote sensing and automatic control are the most

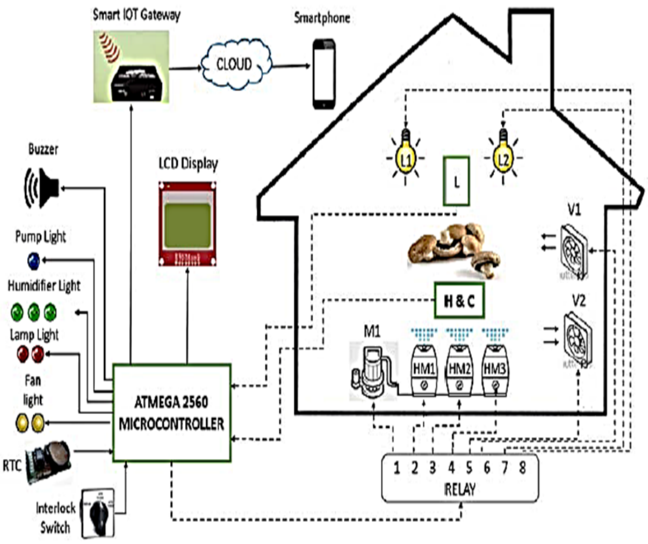

Figure 2. An illustrated diagram of IoT implementation in a mushroom house (Mohammed *et al*., 2018).

Table 4. Implementation of IoT-based system in the mushroom house.

Mushroom Species	Technology Used	Parameter and System Tested	Findings	Limitation	References
Pleurotus Ostreatus	Arduino, Thingspeak platform,	Temperature, humidity	Remote sensing, automated system control	Further experiment required	Islahudin *et al*. (2022)
	NodeMCU, Arduino Nano V.3, Blynk application	Temperature, humidity	Remote sensing, dual control system (automated and manual), less labour	Not suitable for small mushroom farm due to additional cost	Bunluewong (2021)
	Node MCU, Arduino, Blynk application	Temperature, humidity, light intensity, carbon dioxide	Remote sensing	Further experiment required	Zainol *et al.* (2021)
Ganoderma Lingzhi	NodeMCU, NETPIE, LINE application, Andromo application	Humidity	Cost-effective, precise parameter measurement, long term data storage	Require stable internet connection	Boonchieng *et al*. (2018)
Lentinula edodes	Wireless sensor network (WSN)	Temperature, humidity, carbon dioxide	Increased mushroom yield, Improved mushroom quality, optimized usage of resources	Require stable internet connection	Kassim *et al*. (2019)
Unspecified	Arduino IDE, ThingSpeak platform	Temperature, humidity, carbon dioxide	Remote sensing, automated system control	Require stable internet connection	Mahmud *et al*. (2018)
	Microcontroller, MQTT node and server, android application, SMS	Temperature, humidity, moisture, carbon dioxide	Remote sensing, automated system control, Increased mushroom yield	Longer time period of testing required	Raja *et al.* (2018)

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applicable aspects of the IoT-based system. Although there is no data for IoT-based technology implemented for *V. volvacea* cultivation, it is expected the use of this method will boost the yield of the mushroom. Figure 2 shows an example of IoT implementation in a mushroom house.

6. Conclusion

Volvariella volvacea, although a popular and highly commercialized mushroom, produces low yields compared to other species. In this paper, different strategies which contribute to the improvement of yield and biological efficiency of *V. volvacea* were compiled including spawn improvement and modern cultivation technologies. Considering temperature stability, low contamination risk and space optimization, indoor cultivation is a more reasonable choice for *V. volvacea* cultivation compared to outdoor cultivation methods. Despite the limited data available for reference, irradiation with gamma rays or ultraviolet rays is another promising method to increase the yield of *V. volvacea*. In addition, genetic and molecular modification techniques are very effective in developing high quality *V. volvacea* strains. The use of micronutrients or organic matter as a booster in the substrate is the most reliable method to increase the yield and biological efficiency of *V. volvacea*. In the near future, the application of a smart mushroom house equipped with IoT technology will benefit the cultivation of *V. volvacea* by allowing better control of parameters. All the strategies discussed are essential to achieving the United Nations vision for indicators 2 and 12 of the Sustainable Development Goal 2030, that is zero hunger and responsible consumption and production.

Conflict of interest

The authors declare that there are no conflicts of interest.

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References

Ahlawat, O.P., Gupta, P., Kamal, S. and Dhar, B.L. (2008). Development of molecular and biochemical markers for selecting a potential high-yielding strain of paddy straw mushroom (*Volvariella volvacea)*. *Journal of Plant Biochemistry and Biotechnology*, 17 (1), 57–63. https://doi.org/10.1007/BF03263260

Ahlawat, O.P. and Tewari, R.P. (2007). Cultivation technology of paddy straw mushroom (*Volvariella volvacea*) (Vol. 36). *India: National Research Centre for Mushroom.*

Ajikah, L.B., Abasi, M.A., Sanni, R.O. and Walter, O.J. (2019). Assessing the growth performance of *Volvariella volvaceae* on local homemade substrate. *International Journal of Recent Innovations in Academic Research*, 3(6), 108-115.

Bakce, D., Syahza, A., Bahri, S., Irianti, M., Riadi, R. and Asmit, B. (2019). Pemanfaatan limbah kelapa sawit untuk budidaya jamur merang dalam upaya perbaikan ekonomi *desa: Pengabdian kepada masyarakat di Desa Kampung Baru, Kabupaten Pelalawan. Unri Conference Series: Community Engagement*, 1, 235–242. https://doi.org/10.31258/unricsce.1.235-242

Bangyeekhun, E., Sawetsuwannakul, K. and Romruen, U. (2020). UV-induced mutagenesis in *Volvariella volvacea* to improve mushroom yield. *Songklanakarin Journal of Science and Technology,* 42(4), 910-916.

Banik, S. and Nandi, R. (2000). Effect of supplementation of paddy straw with biogas residual slurry manure on the yield, protein and mineral contents of *Volvariella volvacea* mushroom. *Journal of Scientific and Industrial Research*, 59(5), 407–412. DOI: 10.1016/ j.indcrop.2003.11.003

Belewu, M.A. and Belewu, K.Y. (2005). Cultivation of mushroom (*Volvariella volvacea*) on banana leaves. *African Journal of Biotechnology*, 4(12), 1401–1403. http://dx.doi.org/10.4314/ajb.v4i12.71441

Bisoyi, S. and Chattarjee, S. (2021). A review on paddy straw mushroom production and incidence of contestant molds. *International Journal of Current Microbiology and Applied Sciences*, 11, 1612-1621.

Biswas, M.K. (2014). Cultivation of paddy straw mushrooms (*Volvariella volvacea*) in the lateritic zone of West Bengal-a healthy food for rural people. *International Journal of Economic Plants,* 1(1), 43-47.

Biswas, M.K. and Layak, M. (2014). Techniques for increasing the biological efficiency of paddy straw mushroom (*Volvariella Volvacea*) in Eastern India. *Food Science and Technology*, 2(4), 52–57. https://doi.org/10.13189/fst.2014.020402

Boonchieng, E., Chieochan, O. and Saokaew, A. (2018). Smart farm: applying the use of NodeMCU, IOT, NETPIE and LINE API for a Lingzhi mushroom farm in Thailand. *IEICE Transactions on Communications*, 101(1), 16-23. https://doi.org/10.1587/transcom.2017ITI0002

Bunluewong, K. (2021). Semi-automated mushroom cultivation house using internet of things. *Engineering Access*, 7(2), 181–188. DOI: 10.14456/mijet.2021.24

Chaisaena, W., Mopoung, R., Sanawong, P. and Ditkrachan, S. (2012). Suitability of water hyacinth, paddy straw and sunflower residues for the production of the edible mushrooms C*oprinopsis cinerea* and *Volvariella volvacea* in Thailand. *Chiang Mai University Journal of Natural Sciences*, 11, 395–402.

Chakravarty, B. (2011). Trends in mushroom cultivation and breeding. *Australian Journal of Agricultural Engineering*, 2(4), 102-109.

Chen, L., Qian, L., Zhang, X., Li, J., Zhang, Z. and Chen, X. (2022). Research progress on indoor environment of mushroom factory. *International Journal of Agricultural and Biological Engineering*, 15(1), 25–32. https://doi.org/10.25165/j.ijabe.20221501.6872

Darmawi and Suwadji, E. (1998). Pengaruh iradiasi dan inkubasi media tandan kosong kelapa sawit terhadap pertumbuhan jamur merang (*Volvariella volvaceae), Penelitian dan Pengembangan Aplikasi Isotop dan Radiasi,* (1), 129–136.

Diamantopoulou, P., Papanikolaou, S., Aggelis, G. and Philippoussis, A. (2016). Adaptation of *Volvariella volvacea* metabolism in high carbon to nitrogen ratio media. *Food Chemistry*, 196, 272–280. https://doi.org/10.1016/j.foodchem. 2015.09.027

Fernandes, Â., Antonio, A.L., Oliveira, M.B.P.P., Martins, A. and Ferreira, I.C.F.R. (2012). Effect of gamma and electron beam irradiation on the physico-chemical and nutritional properties of mushrooms: a review. *Food Chemistry,* 135(2), 641–650. https://doi.org/10.1016/j.foodchem.2012.04.136

Gülçin, I. (2012). Antioxidant activity of food constituents: an overview. *Archives of Toxicology*, 86 (3), 345–391. https://doi.org/10.1007/s00204-011-0774-2

Gupta, S., Summuna, B., Gupta, M. and Mantoo, A. (2016). Mushroom cultivation: a means of nutritional security in India. *Asia-Pacific Journal of Food Safety and Security*, 2(1), 3–12.

Haq, I.U., Khan, M.A., Khan, S.A. and Ahmad, M. (2011). Biochemical analysis of fruiting bodies of *Volvariella volvacea* strain Vv pk, grown on six different substrates. *Soil and Environment*, 30(2), 146–150.

He, B.L., You, L.R., Ye, Z.W., Guo, L.Q., Lin, J.F., Wei, T. and Zheng, Q.W. (2018). Construction of novel cold-tolerant strains of *Volvariella volvacea* through protoplast fusion between *Volvariella volvacea* and *Pleurotus eryngii*. *Scientia Horticulturae*, 230, 161-168. https://doi.org/10.1016/j.scienta.2017.12.003

Higgins, C., Margot, H., Warnquist, S., Obeysekare, E. and Mehta, K. (2017). Mushroom cultivation in the developing world: a comparison of cultivation technologies. In *2017 IEEE Global Humanitarian Technology Conference (GHTC)* (pp. 1-7). IEEE. https://doi.org/10.1109/GHTC.2017.8239314

Hu, H., Chen, Z. and Wu, P.W. (2021). Internet of things-enabled crop growth monitoring system for smart agriculture. *International Journal of Agricultural and Environmental Information Systems*, 12(2), 30–48. https://doi.org/10.4018 /IJAEIS.20210401.oa3

Islahudin, N., Suprikono, H., Yusianto, R. and Rahadian, H. (2022). Utilization of control technology for mushroom production houses using the internet of things (IoT) in SMEs Omah Jamur Ungaran. *Community Empowerment*, 7(2), 298–305. https://doi.org/10.31603/ce.5785

Jamjumroon, S., Wongs-Aree, C., McGlasson, W.B., Srilaong, V., Chalermklin, P. and Kanlayanarat, S. (2012). Extending the shelf-life of straw mushroom with high carbon dioxide treatment. *Journal of Food, Agriculture and Environment*, 10(1), 78–84.

Kamaliah, N., Salim, S., Abdullah, S., Nobilly, F., Mat, S., Norhisham, A.R., Tohiran, K.A., Zulkifli, R., Lechner, A.M. and Azhar, B. (2022). Evaluating the experimental cultivation of edible mushroom, *Volvariella volvacea* underneath tree canopy in tropical agroforestry systems. *Agroforestry Systems*, pp.1-13. https://doi.org/10.1007/s10457-021-00685-9

Karsid, K., Aziz, R. and Apriyanto, H. (2015). Aplikasi kontrol otomatis suhu dan kelembaban untuk peningkatan produktivitas budidaya jamur merang. *Jurnal Aplikasi Teknologi Pangan*, 4(3), 2015. https://doi.org/10.17728/jatp.2015.16

Kassim, M.R.M., Mat, I. and Yusoff, I.M. (2019). Applications of internet of things in mushroom farm management. In *2019 13th International Conference on Sensing Technology (ICST)* (pp. 1-6). IEEE. https://doi.org/10.1109/icst46873.2019.9047702

Liu, Z., Zhang, K., Lin, J.F. and Guo, L.Q. (2011). Breeding cold tolerance strain by chemical mutagenesis in *Volvariella volvacea*. *Scientia Horticulturae*, 130(1), 18-24. https://doi.org/10.1016/j.scienta.2011.06.020

Mahmud, M.S.A., Buyamin, S., Mokji, M.M. and Abidin, M.S.Z. (2018). Internet of things based smart environmental monitoring for mushroom cultivation. *Indonesian Journal of Electrical Engineering and Computer Science,* 10(3), 847–852. https://doi.org/10.11591/ijeecs.v10.i3.pp847-852

Mau, J.L., Chen, P.R. and Yang, J.H. (1998). Ultraviolet irradiation increased vitamin D2 content in edible mushrooms. *Journal of Agricultural and Food*

Chemistry, 46(12), 5269-5272. https://doi.org/10.1021/jf980602q

Maurya, A.K., Kumar, P., Singh, V. and Kumar, S. (2016). Evaluation of substrates and supplements for enhancing the productivity of paddy straw mushroom (*Volvariella volvacea*). *Research in Environment and Life Sci*ences, 9(6), 717-720.

Minh, N.P. and Hang, L.P. (2019). Several factors affecting to shelf-life of paddy straw mushroom (*Volvariella spp*.) in preservation. *Plant Archives*, 19, 444–448.

Misaki, A., Nasu, M., Sone, Y., Kishida, E. and Kinoshita, C. (1986). Comparison of structure and antitumor activity of polysaccharides isolated from fukurotake, the fruiting body of *Volvariella volvacea. Agricultural and Biological Chemistry*, 50(9), 2171–2183. https://doi.org/10.1271/bbb1961.50.2171

Mohammed, M.F., Azmi, A., Zakaria, Z., Tajuddin, M.F.N., Isa, Z.M. and Azmi, S.A. (2018). IoT based monitoring and environment control system for indoor cultivation of oyster mushroom. In *Journal of Physics: Conference Series*, 1019(1), 012053. IOP Publishing. DOI: 10.1088/1742-6596/1019/1/012053

Nayga-Mercado, L. and Alabastro, E.F. (1989). Effects of irradiation on the storage quality of fresh straw mushrooms (*Volvariella volvacea*). *Food Quality and Preference*, 1(3), 113-119. https://doi.org/10.1016/0950-3293(89)90015-3

Payapanon, A., Suthirawut, S., Shompoosang, S., Tsuchiya, K., Furuya, N., Roongrawee, P., Kulpiyawati, T. and Somrith, A. (2011). Increase in yield of the straw mushroom (*Vovariella volvacea*) by supplement with *Paenibacillus* and *Bacillus* to the compost. *Journal of Faculty Agriculture Kyushu University,* 56, 249–254.

Philippoussis, A., Zervakis, G., Diamantopoulou, P. and Ioannidou, S. (2000). Potential for the cultivation of exotic mushroom species by exploitation of Mediterranean agricultural wastes. *Mushroom Science*, 15, 523–530.

Rai, R.D. and Arumuganathan, T. (2008). Post harvest technology of mushrooms. *National Research Centre for Mushroom (ICAR). Indian Council of Agricultural Research*, 1–84.

Raja, S.P., Rozario, R., Santhanakrishnan, N. and Kavitha, N.S. (2018). Intelligent mushroom monitoring system*. International Journal of Engineering and Technology*, 7(2.33), 1238–1242.

Rajapakse, P. (2011). New cultivation technology for paddy straw mushroom (*Volvariella volvacea*). *In Proceedings of the 7th International Conference on Mushroom Biology and Mushroom Products (ICMBMP7*) 1, 446-451.

Ramkumar, L., Ramanathan, T. and Johnprabagaran, J. (2012). Evaluation of nutrients, trace metals and antioxidant activity in *Volvariella volvacea* (Bull. Ex. Fr.) Sing. *Emirates Journal of Food and Agriculture*, 24(2), 113–119.

Reyes, R.G. (2000). Indoor cultivation of paddy straw mushroom, *Volvariella volvacea*, in crates. *Mycologist,* 14(4), 174–176. https://doi.org/10.1016/S0269-915X(00)80037-3

Rosmiza, M., Davies, W., Aznie, R.C., Jabil, M. and Mazdi, M. (2016). Prospects for increasing commercial mushroom production in Malaysia: challenges and opportunities. *Mediterranean Journal of Social Sciences,* 7(1), 406–415. https://doi.org/10.5901/mjss.2016.v7n1s1p406

Sakinah, N.M.J., Misran, A., Mahmud, T.M.M. and Abdullah, S. (2019). A review: production and postharvest management of *Volvariella volvacea*. *International Food Research Journal*, 26(2), 367–376.

Sao Mai, D., Tri, T.L.M., Van Vu, N., Phu, N.T., Van Do, K. and Khanh, D.T. (2014). Comparison of the effect of different composting materials on the yield of paddy straw mushroom (*Volvariella volvacea*) cultivation in Vietnam. *In Proceeding of 2nd AFSSA Conference on Food Safety and Food Security.*

Sermkiattipong, N. and Charoen, S. (2014). Development of straw mushroom strain for high yield by gamma radiation*. Journal of Agricultural Technology*, 10(5), 1151–1164.

She, Q.B., Ng, T.B. and Liu, W.K. (1998). A novel lectin with potent immunomodulatory activity isolated from both fruiting bodies and cultured mycelia of the edible mushroom *Volvariella volvacea. Biochemical and Biophysical Research Communications,* 247(1), 106-111. https://doi.org/10.1006/bbrc.1998.8744

Singh, C., Pathak, P., Chaudhary, N., Rathi, A., Dehariya, P. and Vyas, D. (2020). Mushrooms and mushroom composts in integrated farm management. *Research Journal of Agricultural Sciences*, 11(6), 1436–1443.

Srikram, A. and Supapvanich, S. (2016). Proximate compositions and bioactive compounds of edible wild and cultivated mushrooms from Northeast Thailand. *Agriculture and Natural Resources*, 50(6), 432–436. https://doi.org/10.1016/j.anres. 2016.08.001

Sudha, A., Lakshmanan, P. and Kalaiselvan, B. (2008). Antioxidant properties of paddy straw mushroom (*Volvariella volvacea* (Bull. ex Fr.)) Sing. *International Journal of Applied Agricultural Research*, 3(01), 9–16. https://doi.org/10.20546/ijcmas.2019.802.355

Sumiati, E. and Djuariah, D. (2007). Teknologi budidaya dan penanganan pascapanen jamur merang, *Volvariella volvacea*. Monografi No. 30. Balai Penelitian Tanaman Sayuran.

Sze, S.C.W., Ho, J.C.K. and Liu, W.K. (2004). *Volvariella volvacea* lectin activates mouse T lymphocytes by a calcium dependent pathway. *Journal of Cellular Biochemistry*, 92(6), 1193-1202. https://doi.org/10.1002/jcb.20153

Thiribhuvanamala, G., Krishnamoorthy, A.S., Kavitha, C., Shwet, K., Anil, K. and Sharma, V. (2021). Strategic approaches for outdoor cultivation of paddy straw mushroom (*Volvariella volvacea*) as intercrop under different cropping systems. *Madras Agricultural Journal*, 108(March), 1–6. https://doi.org/10.29321/maj. 10.000486

Thiribhuvanamala, G, Krishnamoorthy, S., Manoranjitham, K., Praksasm, V. and Krishnan, S. (2012). Improved techniques to enhance the yield of paddy straw mushroom (*Volvariella volvacea*) for commercial cultivation. *African Journal of Biotechnology*, 11(64), 12740–12748. https://doi.org/10.5897/ajb11.4066

Thuc, L.V., Corales, R.G., Sajor, J.T., Truc, N.T.T., Hien, P.H., Ramos, R.E., Bautista, E., Tado, C.J.M., Ompad, V., Son, D.T. and Van Hung, N. (2020). Paddy-straw mushroom production. *Sustainable Paddy Straw Management* (pp. 93-109). Springer, Cham. https://doi.org/10.1007/978-3-030-32373-8_6

Triyono, S., Haryanto, A., Telaumbanua, M., Dermiyati, Lumbanraja, J. and To, F. (2019). Cultivation of straw mushroom (*Volvariella volvacea*) on oil palm empty fruit bunch growth medium. *International Journal of Recycling of Organic Waste in Agriculture*, 8(4), 381–392. https://doi.org/10.1007/s40093-019-0259-5

Umor, N.A., Abdullah, S., Mohamad, A., Ismail, S. Bin, Ismail, S.I. and Misran, A. (2021). Energy potential of oil palm empty fruit bunch (EFB) fiber from subsequent cultivation of *Volvariella volvacea* (bull.) singer. *Sustainability (Switzerland),* 13(23), 13008. https://doi.org/10.3390/su132313008

Wakchaure, G.C. (2011). Postharvest handling of fresh mushrooms. *Mushrooms: Cultivation, Marketing and Consumption. Solan, India: Directorate of Mushroom Research, Indian Council of Agricultural Research (ICAR),* 197-206.

Wu, J.Y., Chen, C.H., Chang, W.H., Chung, K.T., Liu, Y.W., Lu, F.J. and Chen, C.H. (2011). Anti-cancer effects of protein extracts from *Calvatia lilacina, Pleurotus ostreatus* and *Volvariella volvacea*. *Evidence-Based Complementary and Alternative Medicine,* 2011, Article ID 982368. https://doi.org/10.1093/ecam/neq057

Yoo, Y.B., Oh, M.J., Oh, Y.L., Shin, P.G., Jang, K.Y. and Kong, W.S. (2016). Development trend of the mushroom industry. *Journal of Mushroom*, 14(4), 142–154. https://doi.org/10.14480/jm.2016.14.4.142

Yue, L.L. and Qing, F.L. (2011). Identification and cultivation of a wild mushroom from banana pseudo-stem sheath. *Scientia Horticulturae*, 129(4), 922–925. https://doi.org/10.1016/j.scienta.2011.06.002

Zainol, M.A., Sh Abdul Nasir, S.M.F., Abdullah, N.S., Koay, M.H., Mohd Halidi, S.N.A., Ismail, H. and Leiahs, L. (2021). Iot based monitoring system for oyster mushroom farming Pondok Seri Permai Pasir Putih Kelantan.*International Exhibition and Symposium on Productivity, Innovation, Knowledge, Education and Design (i-SPiKe 2021).*

Zervakis, G., Philippoussis, A., Ioannldou, S. and Dlamantopoulou, P. (2001). Mycelium growth kinetics and optimal temperature conditions for the cultivation of edible mushroom species on lignocellulosic substrates. *Folia Microbiologica,* 46 (3), 231–234. https://doi.org/10.1007/BF02818539

Zhao, F.Y., Lin, J.F., Zeng, X.L., Guo, L.Q., Wang, Y.H. and You, L.R. (2010). Improvement in fruiting body yield by introduction of the *Ampullaria crossean* multi-functional cellulase gene into *Volvariella volvacea*. *Bioresource Technology*, 101(16), 6482–6486. https://doi.org/10.1016/j.biortech.2010.03.035

Zhao, X., Chen, M., Li, Z., Zhao, Y., Yang, H., Zha, L., Yu, C., Wu, Y. and Song, X. (2020). The response of V*olvariella volvacea* to low-temperature stress based on metabonomics. *Frontiers in Microbiology,* 11, 1787. https://doi.org/10.3389/fmicb.2020.01787

Zhao, X., Song, X., Li, Y., Yu, C., Zhao, Y., Gong, M., Shen, X. and Chen, M. (2018). Gene expression related to trehalose metabolism and its effect on *Volvariella volvacea* under low temperature stress. *Scientific Reports,* 8(1), 1–14. https://doi.org/10.1038/s41598-018-29116-z

Zikriyani, H., Saskiawan, I. and Mangunwardoyo, W. (2018). Utilization of agricultural waste for cultivation of paddy straw mushrooms (*Volvariella volvacea* (Bull.) Singer 1951). *International Journal of Agricultural Technology,* 14(5), 805–814.