Original Research Article

Automated Controlled Environment Mushroom House

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Abstract: Mushroom can be served as flavoursome food, but most importantly, it can be served as nutritional and medicinal value food. Therefore, mushroom is an essential commodity under the Malaysia National Agro-Food Policy. Currently, mushroom cultivation is being done in the conventional method, not in a proper and hygienic condition. Therefore controlled environment mushroom house (CEMH) has been developed by transforming a greenhouse into a controlled environment mushroom house integrated with the internet of things (IoT) system. This CEMH micro-climate is automatically controlled by the combination of data parameters provided by various types of sensors. The integration of the IoT system has further enhanced this system to overcome extreme weather changes and override the control anytime and anywhere. The computation and monitoring process can be done either locally or remotely. The current system is set up for Grey Oyster mushroom (*Pleurotus pulmonaris)* cultivation to identify the best isolate to be proposed for mass production. The interconnection of sensors, mechanical and electronic systems is to optimize the growth condition. The developed system manages to control the temperature consistently and relative humidity (% RH) in the range of $18^{\circ}C$ to $27^{\circ}C$ and % RH not lower than 70%, respectively. For this condition, this system can produce at least 30% more yield than ordinary mushroom houses. Moreover, the contamination rate is successfully kept below 2% and is considered very low compared to ordinary entrepreneur mushroom houses, usually more than 10%. This system can provide the research facility for the high nutritional and medicinal value mushrooms.

1. Introduction

The world population is estimated to be about 9.7 billion in 2050 (Max, 2013). Thus, food production will have to be significantly increased to support the population. In addition to this, human beings also face problems of diminishing natural resources and lands, global warming, and unpredictable weather conditions, which make food security a primary concern globally. Mushrooms have been served as food and medicine for the last few decades. Currently, the usage of mushrooms has expanded up beyond food and in the area of pharmaceuticals, nutraceuticals, and cosmeceuticals (Himanshi *et al*., 2017). Approximately 35 edible mushroom species are commercially cultivated, whereas nearly 200 wild species have been used for medicinal purposes (Beulah *et al.*, 2013). Mushrooms contain 50% to 65% total carbohydrate, 19% to 35% proteins (with various biological and medicinal activities such as lectins), and 2% to 6% fat content of their dry matter (Rathore *et al.*, 2017). Mushrooms rich in fat-soluble vitamins and ergosterol content are thought to be the only vegetarian source for vitamin D (Aida *et al.*, 2009). Therefore, the mushrooms industry is considered one of the most booming industries. From those domesticated and commercially grown mushrooms, the best-known specialty mushroom and most manageable to market is Oyster mushrooms and Shiitake (Barney, 2015). Oyster mushrooms are a diverse group of saprotrophic fungi belonging to *Pleurotus* (Kong, 2004). The protein content varies from 1.6 to 2.5%, and the niacin content is about ten times higher than that of any other vegetable (Ahmed *et al*., 2016). Moreover, oyster mushrooms have been reported rich in Vitamin C, B complex, and the mineral salts required by the human body (Randive, 2012). Mushroom production in rural communities can alleviate poverty, for instance, developing young agropreneur (Khairul, 2015).

The demand for mushrooms in Malaysia is projected to increase, and the demand is estimated to increase from 20,000 tonnes in 2008 to around 48,000 tonnes in 2020. The demand for grey mushrooms is greater or over than supply production in Malaysia. This has led Malaysia has to import fresh and processed mushrooms from other countries (Islam *et al.* 2016). Malaysia imported 2.71 million tonnes of fresh mushrooms valued at more than RM 6.2 million and 3.11 million tonnes of dried mushrooms valued at more than RM 11.99 million from China in 2012. The import of mushrooms from China increased steadily at an annual average of 9.23% for the fresh ones and 12.93% for the dried ones from 2009 (Amin *et al.*, 2014).

Moreover, local mushroom industries are facing challenges, such as enhancing yield, quality of spawn or good mushroom seed (mycelium), green fungus diseases, and pest attack (rats, ants, lizards, and cockroaches) (Haimid *et al.,* 2013; Rosmiza *et al.,* 2016). In addition, the natural environmental conditions of Malaysia or in similar regions are not suitable for indoor mushrooms cultivation due to its low humidity and high temperature (Islam *et al.,* 2016). In the environmental profile of Malaysia, it must need to apply any artificial system to provide an optimum growing environment for mushrooms (Islam *et al.,* 2016). However, most of the controlled environment mushroom house researches in Malaysia (Kassim *et al.,*

2017; Marzuki & Ying 2017; Mohammed *et al.*, 2018; Kassim *et al.,* 2019) are mainly for controlling the relative humidity condition and not so much for the temperature control, only using fans and misting for reducing the temperature (not more than 3°C different between controlled and non-controlled environment). Even with controlled humidity, the contamination rate can research as high as 30% (Islam *et al.,* 2017). IoT systems combined with data analytics have been currently used in agriculture worldwide to meet the world's food demands in the coming years (Dlodlo & Kalezhi, 2015). IoT device installations in the agriculture sector were predicted to increase from 30 million in 2015 to 75 million by 2020 (Elijah *et al.*, 2018). There are challenges in mushroom cultivation, such as a lack of skills in mushroom cultivation and less quality of mushroom production (Ibrahim *et al.,* 2018). Utilizing IoT technology, which consists of sensors and feedback systems, will optimize climate conditions for optimum growth of mushrooms (Ibrahim *et al.,* 2018). For the study to prove that that temperature (which is controlled by the air-conditioning system and not by fans) and humidity can reduce the contamination rate and increase the yield, an automatic IoT controlled environment mushroom house (CEMH) is developed especially for the sudden weather change which is usually happening in Malaysia. Oyster mushrooms were selected for this study. The substrate and mushroom strains were standardized for the experiments carried out in the non-controlled and controlled environments as different mushroom strains also have different growth and yield performance (Dundar *et al.*, 2008).

2. Materials and Methods

The CEMH was transformed from a controlled environmental greenhouse. Development of CEMH and facilities are for the production of high-quality selected mushrooms and seeds in MARDI to provide good quality and diseases resistance spawn for the local mushroom industries. CEMH is an automatic IoT building where environmental parameters can be controlled and manipulated to suit the growth of mushrooms. This project focuses on developing the CEMH technology as proof of concept in meeting modern and prolific agricultural production needs, specifically for selected mushroom production and quality mushroom seed production. The development of this technology enables the mushrooms to be produced in a state of growth that is manipulated independently of the diversity of the external environment. The system facilitates the research to screen and identify the best strains of Grey Oyster mushroom (*Pleurotus pulmonaris*) available in MARDI.

CEMH, developed is the controlled environment mushroom house integrated with components of Industry Revolution 4.0 (IR 4.0) technological pillars; internet of things (IoT) system and cloud computing. The IoT system and cloud computing were set up with the assistance of Signal Transmission (M) Sdn Bhd. Figure 1 shows an overall system of CEMH. Advantech ADAM-3600, a remote terminal unit (RTU), is implemented as a microprocessor-controlled electronic device with built-in software called Edgelink (one type of the supervisory control and data acquisition (SCADA) software) that interfaces objects in the

physical world to a distributed control system or SCADA system by transmitting telemetry data to a master system, and by using messages from the master supervisory system to control connected objects. This RTU supports the local raw data translation and digitizes the raw analog data sent by the sensors by using Modbus communication protocols. For that, it communicates and receives information from light meters (providing light intensity information inside the building), humidity meters (providing relative humidity information inside the building), thermocouple temperature sensors (providing temperature information inside the building), and CO_2 meters (providing CO_2 concentration information inside the building). After ADAM-3600 has gathered all the input/output (I/O) reading from another module (sensors and meters), it converts the raw data from the sensors to Message Queuing Telemetry Transport (MQTT) protocol. It sends the data to the cloud or Virtual Machine (VM) (in the cloud server) through Global System for Mobile Communications (GSM) network. This virtual machine runs in Microsoft Azure Portal with built-in software called WebAccess/SCADA, a web-based SCADA software application. WebAccess/SCADA is Advantech's core IoT application platform. It provides a unique environment for development and remote maintenance, allowing access to and manipulating data stored on the cloud (Virtue Machine or central server). The data which is sent by ADAM-3600 to the cloud will be stored in PostgreSQL databases. Once the data reaches the cloud database, the data can be displayed using Dashboards (WebAccess App) shown in Figure 1. The data can be sent to Dropbox using WebAccess/SCADA from Virtue Machine or Edgelink from ADAM-3600 software's scripting to write code to save certain logged data as a CSV format file for easy access.

Besides that, ADAM-3600 acts as a program logic controller (PLC) to control the equipment in this system. The equipment includes rooftop ventilation fans, misting system (20–40 µm size water droplets), and an air conditioning system (four units 12.5 HP). Rooftop ventilation fans remove the hot air from the building, create air flow, avoid the air becoming stagnant, and reduce the CO_2 level below 600 ppm. The misting system maintains the pre-set air wetness inside the mushroom house, whereas the air conditional system controls the air temperature inside the mushroom house. ADAM-3600 has a quick and easy connection-friendly user function. It lets users see all the reading and control the equipment using their remote devices like handphones or tablets by logging in to the WebAccess App platform. All the data from the I/O reading from a light meter, humidity meter, thermocouple temperature sensor, and CO_2 meter are stored in Dropbox and backed up in ADAM-3600 as well.
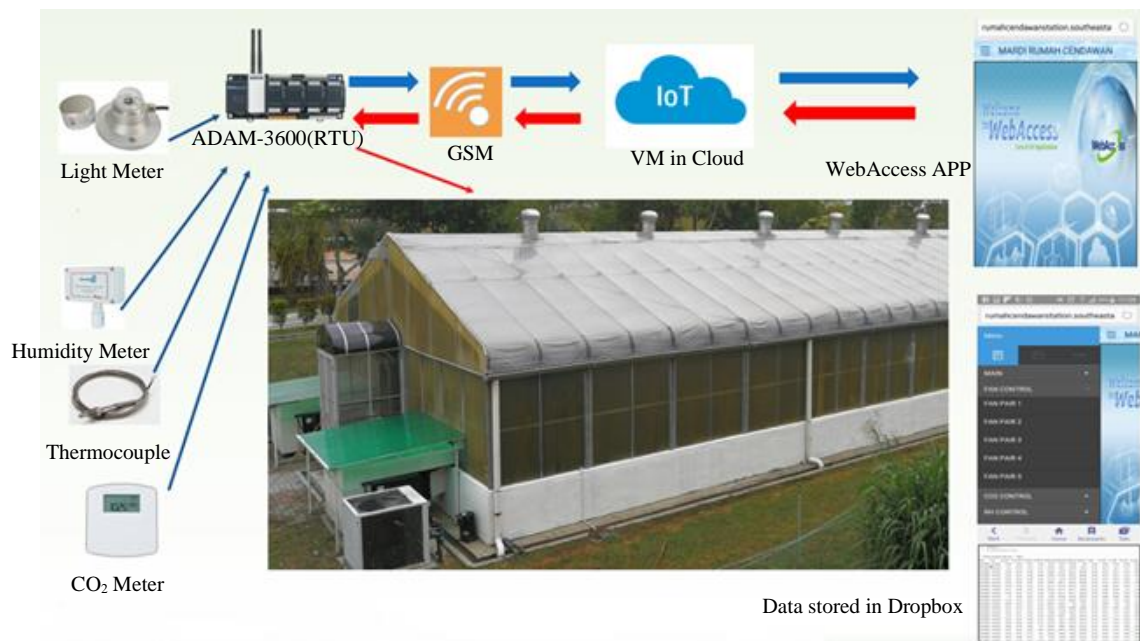
Figure 1. Overview IoT system for the smart mushroom house.

With the enhancement of the IoT system, the CEMH micro-climate is automatically controlled by the ADAM-3600, conditional air system, misting system, and rooftop ventilation system with the combination data parameters provided by various types of sensors. The system can be overridden anytime remotely to pursue the interconnection of machines and systems for being the intelligent farming system to overcome the unpredictable extreme weather changes. The developed system is capable to consistently control the temperature and humidity in the range of $18^{o}C$ to $27^{o}C$ and relative humidity (RH) not lower than 70% respectively and light intensity in the range of 8–500 Lux, where 15–350 Lux is suitable for various varieties mushrooms (Kibar & Peksen, 2008). For these conditions, the intelligent mushroom house can cater to the growing research of various kinds of mushrooms, as shown in Table 1.

Table 1. Growing condition for different variety mushrooms.

Mushroom Type	Temperature ($^{\circ}C$)	Relative Humidity, RH (%)
King Oyster (*Pleurotus eryngii*) (Ryu *et al*., 2015)	15–22	65–95
Black Jelly Mushroom (*Auricularia auricula-judae*) (Priya *et al*.,2016)	25–26	85–90
Grey Oyster Mushroom (*Pleurotus pulmonaris*) (Stanley *et al*., 2011)	25–28	80–85

Different types of substrate materials can influence the mushroom growth and yield performance, and the substrate weight can also contribute to the mushroom yield by the biological efficiency (Sharma *et al*., 2013). Other than that, different mushroom strains also

have different growth and yield performance (Dundar *et al.*, 2008). In order to prove that the temperature and humidity control can reduce the contamination rate and increase the yield, the same standard of substrate preparation, Grey *(Pleurotus pulmonaris)* and White *(Pleurotus florida)* Oyster mushroom spawn were used in CEMH and non-controlled environments, Jenjarom and MARDI Klang, Selangor as ordinary mushroom houses. The preparation of the mushroom substrate bag was done at CEMH, Engineering Research Centre, MARDI Headquarters Serdang, Selangor. Mushroom substrate bag preparation was according to the pre-set standard (Khairul *et al.,* 2012). The sawdust, rice bran, and lime were mixed (in the ratio of 100:10:1). The mixtures were added to water and made dense. 650 ±50 g of substrate mixture was fill in each autoclavable polypropylene plastic (6×9 inches) bag and covered with a PVC cap to protect loss of moisture content from inside the bags (Islam *et al.,* 2016). Five hundred mushroom substrate bags were steamed at $95 \pm 3^{o}C$ in steamer 5 hours before use. Inoculation of oyster mushroom spawn was done aseptically. Each experiment was replicated four times. Grey (*P. pulmonaris*) and White (*P. florida*) Oyster mushroom spawns were obtained from Spawn Laboratory, Soil Science, Water, and Fertilizer Research Centre, MARDI Headquarters Serdang, Selangor. Statistical Analysis, Descriptive statistics were applied to find maximum, minimum, mean, and standard deviation (SD) in all collected data.

As the current system is set up for identification, the best *P. pulmonaris* isolate cultivation is proposed for mass production. Thus, the controlled temperature and relative humidity ranges are set between $21^{o}C$ to $27^{o}C$, and the % RH is not lower than 70%, respectively. The temperature in CEMH is controlled by the four-unit 12.5 HP air conditional system and is based on the Specific Air-space Stratification Techniques (SAST) (Ismail, 2006). The cool air is channeled to CEMH through underground dusting. This method has the advantage of maintaining the optimum growing temperature range at the mushroom growing area from the ground level and at the same time avoiding direct heat contact with the hot air from the top. The misting system controls the relative humidity in CEMH (20–40 µm size water droplets). The light intensity is set below 350 Lux by closing the almost 90% light transmission around the building. The CO_2 level is kept below 600 ppm by the rooftop ventilation system to suit the optimum growing condition for *P. pulmonaris*.

3. Results

The comparison results of temperature and relative humidity between control and non-controlled environments are shown in Figure 2 and Figure 3, respectively. Figure 2 shows that the maximum temperature outside a non-controlled environment could reach as high as $35.2^{o}C$, minimum of $24.4^{o}C$ and an average of $28.6^{o}C$ and standard deviation (SD) of $3.24^{o}C$, which is high and vast vary between day time and night time. Figure 2 also shows the maximum temperatures for the controlled environment were $24.4^{o}C$ and $26.3^{o}C$ at the height of 1.0 m and 1.5m, respectively, whereas the minimum temperature of $21.2^{o}C$ for both heights in CEMH. It shows that the system can maintain average temperatures $22.16^{o}C$ (SD of $0.71^{o}C$) and $22.65^{o}C$ (SD of $1.17^{o}C$) at the height of 1.0 m and 1.5 m, respectively CEMH

and achieved the pre-set temperatures with very small vary when compared with the non-controlled environment. Figure 3 shows the lowest %RH for the non-controlled environment was as low as 53.87% with an average of 63.00% (SD of 5.03%), which is very dry and with SD of 5.03% is considered vast vary compared to SD of 1.76% in the controlled environment. The lowest %RH in controlled environment mushroom house was 70.32%, with average RH at 73.71% (SD of 1.76%) during the daytime hot and dry condition, proving that the system could maintain according to the pre-set relative humidity, not lower than 70%.
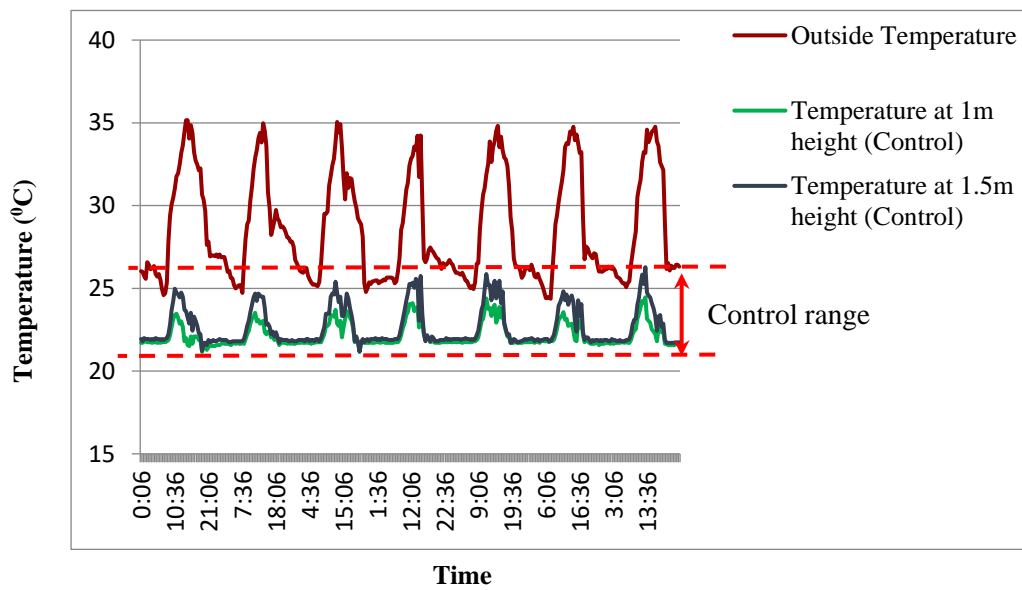
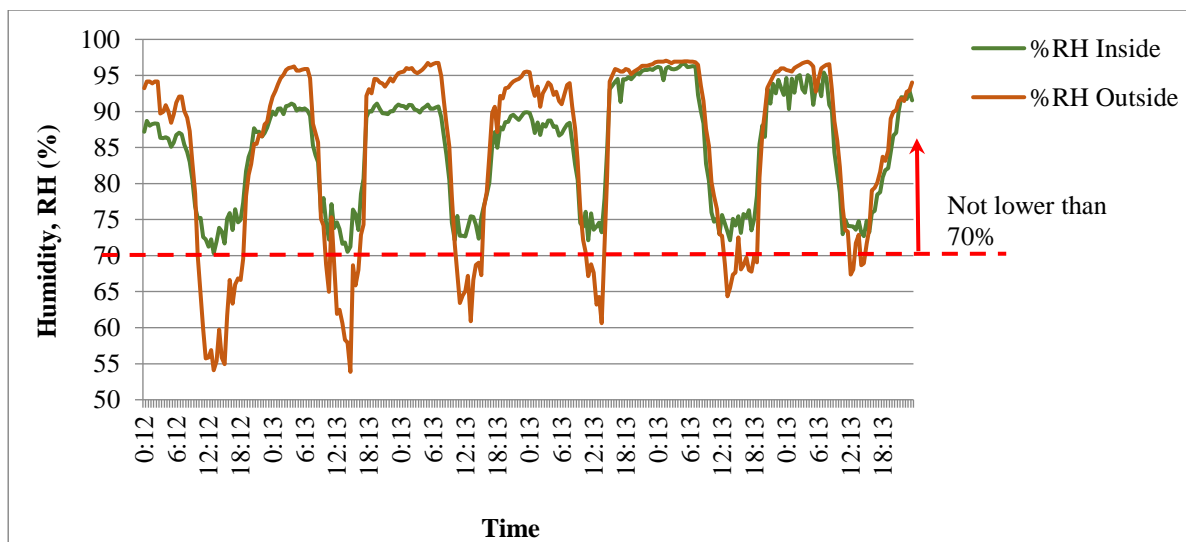**Figure 2**. Temperature comparison between outside and inside smart CEMH (control).

Figure 3. Relative humidity (%RH) comparison between outside and inside CEMH (control).

The effects of the non-controlled and control system on the growth of the mushrooms are shown in Figure 4 and Figure 5. The non-controlled environments were done in Jenjarom and MARDI Klang as ordinary mushroom houses. The controlled environment was done in

CEMH. Figure 4 shows the average yields of mushrooms on different mushrooms and spawns either in grain or liquid form in non-controlled and controlled environments. The highest average yield of mushrooms was shown in CEMH compared to Jenjarom and MARDI Klang mushroom houses. CEMH produced 30% significantly higher (average of 149.1 g/bag with SD of 2.32 g) mushroom yield growth compared to other mushroom houses, which Jenjarom obtained an average of 114.3 g/bag with an SD of 2.12 g. In contrast, MARDI Klang obtained an average of 98.2 g/bag with an SD of 1.96 g for the Grey Oyster Mushroom.

Moreover, CEMH also managed to produce more than 115 g/bag of the White Oyster mushrooms regardless of the types of spawns. Figure 5 shows the lowest contamination percentage of the mushroom bag, less than 2% of bag contamination in CEMH compared to Jenjarom grower (11.32%) and MARDI Klang (3.17%) mushroom house. The condition in CEMH was also able to keep the contamination rate less than 2% for the White Oyster and Grey Oyster mushrooms regardless of the different spawns, either in grain or liquid form.
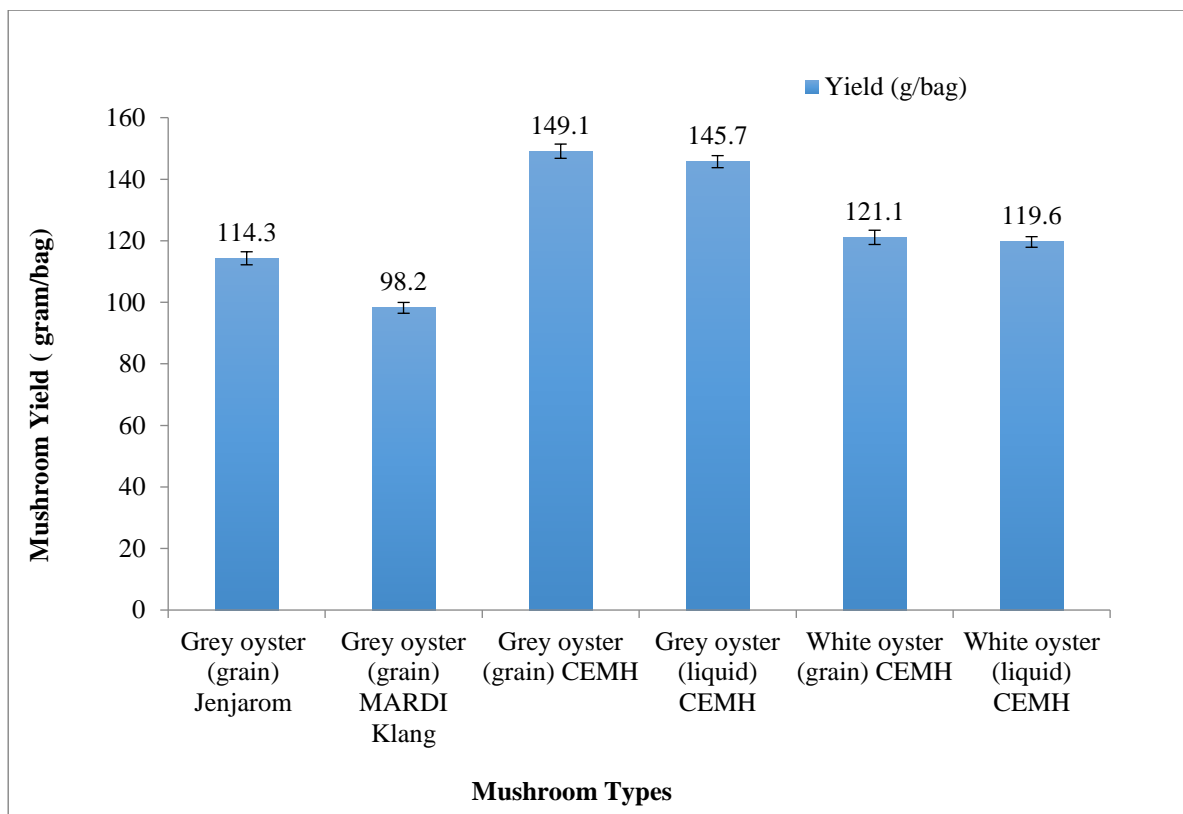

Figure 4. An average yield of mushrooms on different types and spawn (liquid and grain) of mushrooms at various mushroom houses.
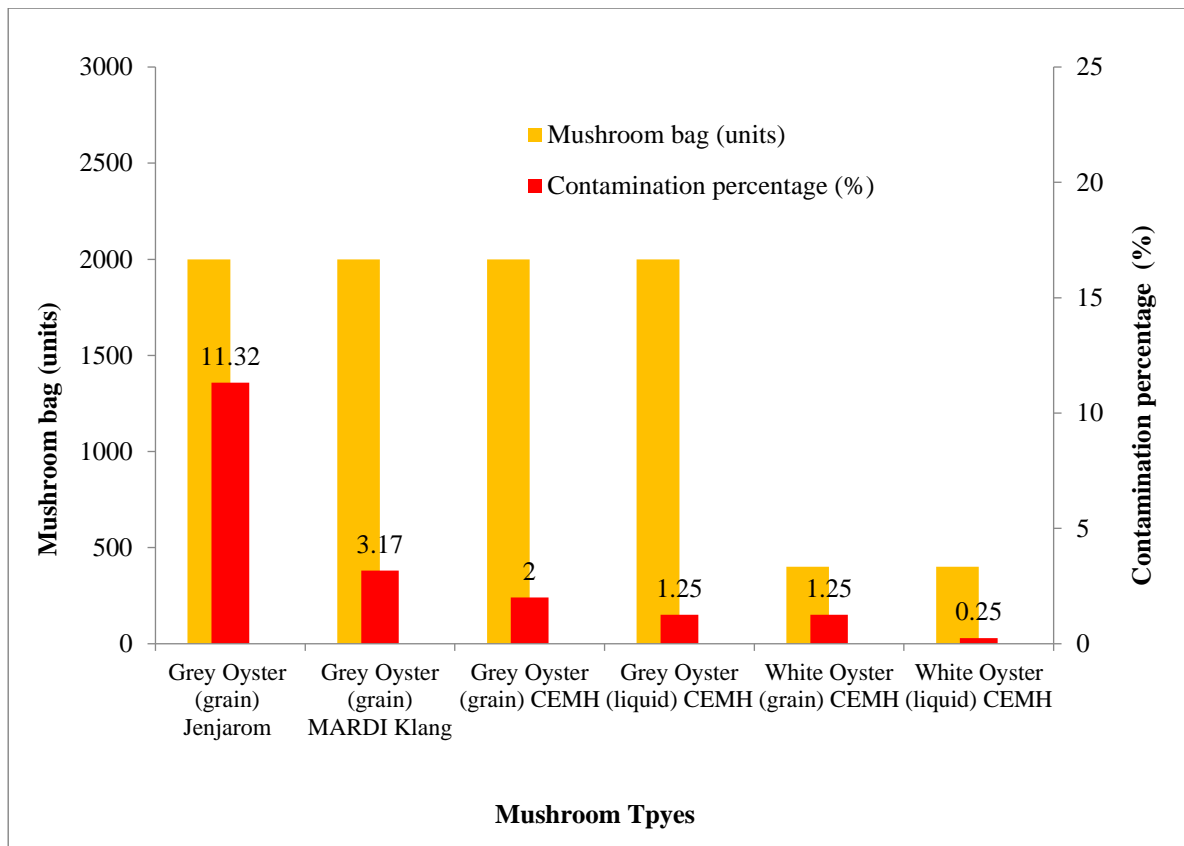
Figure 5. Comparison of contamination percentage of the mushroom bag on different types and spawn of mushrooms at various mushroom houses.

4. Discussion

The results in Figure 2 and Figure 3 show that CEMH managed to control the micro-climate of the mushroom house even under the substantially different temperatures between the hot and dry day and night time. In the typical mushroom house (without a controlled environment), the temperature could reach a maximum of 35.2°C and an average of 28.6°C, which had already exceeded the optimum growth temperature for Grey Oyster mushroom stated in Table 1. On the other hand, the CEMH had shown the ability to maintain average temperatures 22.16°C (SD of 0.71°C) and 22.65°C (SD of 1.17°C) at the height of 1.0 m and 1.5 m respectively, with minimal variations and also in the range of maximum fruiting body condition as stated in the report Grey Oyster mushroom studies (Bano *et al*., 1982) which are 20°C to 26°C. Grey Oyster mushrooms faced extreme dry stress in the non-controlled environment. The relative humidity could drop as low as 53.87% with an average of 63.00% (SD of 5.03%), which is very dry compared to CEMH, with an average RH at 73.71% (SD of 1.76%) during the daytime hot and dry condition. Therefore, the Grey Oyster mushroom experienced high hot temperature and dryness stress in the non-controlled outside condition.

In contrast, the controlled environment mushroom house could maintain the relative humidity to suit the optimal growing condition, especially during the daytime hot and dry condition. Figure 4 proved that CEMH produced 30% significantly higher mushroom yield

growth than non-controlled environment mushroom houses Jenjarom and MARDI Klang. Figure 5 further supports the advantage of CEMH in providing a better environment by showing the lowest contamination percentage (less than 2%) of the mushroom bag compared to Jenjarom grower and MARDI Klang mushroom house. These results are also supported by the indoor Grey Oyster mushroom cultivation studies (Islam *et al.*, 2016). The yield percentages and quality of *P. pulmonarius* increase with the increasing of indoor humidity and have a strong correlation among them.

5. Conclusions

The control system can control the CEMH ambient temperature and relative humidity for optimum growth conditions to overcome the relatively hot environment of Malaysia, which the temperature can rise to 41°C and the low relative humidity by 58% or even much lower during the hot season (Wafi *et al*., 2011) which is clear that temperature and humidity of Malaysia weather are far from the optimal condition for oyster mushroom cultivation. The farmers can also take corrective and preventive measures in advance based on the data provided and alarming status reports anywhere and anything sudden weather change to decide to override regular program basic to reduce the extreme environment change that will affect the mushroom productivity (Elijah *et al.,* 2018). This research can help the local industries produce good quality various varieties mushroom spawns (seeds), especially for the popular, Grey Oyster Mushroom (*P. pulmonaris*) and reduce the imported especially for those have the high nutritional and medicinal value mushrooms. After achieving the proof of concept in reducing contamination and increasing yield, future works will be studying the minimum required commercial productivity scale to minimize the needed person-hours and, at the same time, maximize the profit margin. In the future, this IoT system aims to be applied in the supply chain as it will help provide real-time balancing between the demand and supply (Elijah *et al.,* 2018) to prevent the losses of overproduced oyster mushrooms due to their short shelf life. This automated CEMH also provides the research facility to help the growers identify the most stable, good quality strain and the best isolate to be proposed for mass production.

Conflict of Interest: The authors declare no conflict of interest.

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