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Review

A review: Production and postharvest management of *Volvariella volvacea*

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Abstract

Volvariella volvacea (Family: Plutaceae), also more commonly known as paddy straw mushroom, is an edible mushroom with high nutritional content. It is usually cultivated using lignocellulosic-based materials for enhanced production. However, *V. volvacea* is highly perishable and easily deteriorates in terms of quality and appearance after harvest. The present paper thus aimed to provide a critical review on aspects related to the production of *V. volvacea* using palm oil empty fruit bunch as cultivation substrate. The different stages of *V. volvacea* development are also highlighted. The present review also provides some information on the preservation techniques and appropriate postharvest management in extending *V. volvacea* shelf life to further boost the paddy straw mushroom industry.

Introduction

Over the recent decades, *V. volvacea* (paddy straw mushroom) has become one of the most preferable cultivated mushrooms which contributed to the top commercial mushrooms in the world with 5% of total production (Chang, 1999; Ahlawat *et al*., 2010; Roy *et al*., 2014). *V. volvacea* is a popular mushroom variety because it produces aromatic and pleasant flavour and tastes, as well as shorter cropping period (Thiribhuvanamala *et al*., 2012; Roy *et al*., 2014; He *et al*., 2018). It is commonly known as paddy straw mushroom because it grows best on paddy straw. It was also called Chinese mushroom as it was believed that the Chinese were the first who cultivated it (Chang, 1977). The fruiting body of *V. volvacea* appears white with large cap and short stipe underneath, and it is cultivated mainly in China, India and Southeast Asian countries.

As Malaysia is a tropical country with hot and humid climate and average temperature of 30-35°C, *V. volvacea* has been well cultivated in this region, and the surrounding temperature enhances its cultivation thereby leading to harvest as early as 10 days after cultivation (Thiribhuvanamala *et al*., 2012). The yield of *V. volvacea* depends on the cultivation methods and substrates used. *V. volvacea* is normally grown on paddy straw and few other plant wastes that contain cellulose, hemicellulose and lignin (Roy *et al*., 2014). *V. volvacea* is harvested at the button stage when it is considered to have the best flavour and texture. Usually, *V. volvacea* is marketed locally as fresh produce through night markets, wet markets and grocery outlets.

V. volvacea typically contains 85-90% moisture and rapidly respire (Rai and Arumuganathan, 2008), hence is highly perishable. Therefore, it would easily deteriorate as a result of biochemical degradation and improper handling during harvest, packaging and transport as occurred in shiitake mushroom (Antmann *et al*., 2008). One of the major problems that limit the shelf life of *V. volvacea* is browning and shrivelling which are related to the loss of water. As a result, most of the fresh *V. volvacea* can only stand for 1-2 days at ambient temperature. Therefore, the present paper aimed to review the cultivation of *V. volvacea* and its postharvest management in extending its shelf life.

Part 1: Nutritional aspect of Volvariella volvacea

Proximate composition

Mushrooms are rich in nutrients and provide medicinal properties. Protein is one of the important nutritional components highly found in most edible mushrooms (Hung and Nhi, 2012). Some people consume mushrooms as source of protein essential

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to their body. Mushrooms also contain medicinal properties and functional foods for human health in which they contain high level of proteins, few vitamins (vitamin C, riboflavin, biotin, niacin and thiamine), and source of dietary fibre (Chang and Miles, 2004; Rai and Arumuganathan, 2008; Guo *et al*., 2012; Roy *et al*., 2014). In addition, *V. volvacea* does not contain cholesterol (Belewu and Belewu, 2005; Rajapakse, 2011). *V. volvacea* is also high in moisture content ranging from 88 to 90% of fresh weight. According to Ghosh (1993), *V. volvacea* produces protein intercellularly. *V. volvacea* enzymatic activities are high on the first day of growth and decline on the next day onwards. Table 1 summarises the proximate composition of *V. volvacea* at button stage from different investigations.

Table 1. Comparison of proximate composition of *V. volvacea*

Components (%)	Chang and Quimio (1982)	Chang and Miles (2004)	Ul-Haq *et al*. (2011)	Hung and Nhi (2012)
Moisture	88.7 – 89.5	89.1	86.1 – 89.9	90.7
Carbohydrate	40.0 – 50.6	45.3	-	52.3
Fat	1.1 – 3.7	2.4	-	2.2
Fibre	5.1 – 13.4	9.3	7.9 – 11.9	-
Protein	21.3 – 30.5	25.9	20.3 – 34.2	28.6
Ash	8.1 – 9.5	8.8	10.8	9.0

Amino acids composition

Generally, protein in mushrooms, including *V. volvacea*, provides all the essential amino acids required for human dietary intake especially lysine and leucine which are present in other staple foods (Chang and Busswell, 1996). The essential amino acids should be present simultaneously to complete the process of protein synthesis, while the non-essential amino acids can be synthesised and converted by the human body (Chang and Miles, 2004).

Minerals and vitamins

Mushrooms are also good sources of minerals which are vital for the absorption by the sporophores through a growing mycelium (Chang and Quimio, 1982; Chang and Miles 2004). Minerals are divided into two categories which are major and minor mineral constituents. However, *V. volvacea* has also been found to be contaminated by heavy metals such as cadmium and lead which could accumulate in the body. This should be taken into considerations for estimation of daily intake of this mushroom. Nevertheless, there is also large amount of vitamin C found in *V. volvacea*. Other vitamins include riboflavin, biotin, niacin and thiamine (Chang and Miles, 2004; Roy *et al*., 2014). Table 2 shows the summary of mineral and vitamin contents at button stage of *V. volvacea*.

Table 2. Components of minerals and vitamins in button stage of *V. volvacea*

Components	Concentrations (mg)	References
Minerals		
Phosphorus	1322	Chang and Quimio, (1982); Chang and Miles (2004).
Sodium	347	
Potassium	4136	
Calcium	325	
Magnesium	180	
Copper	5.92	
Zinc	10.27	
Iron	11.59	
Vitamins		
Thiamine	0.35	FAO (1972); Chang and Miles (2004);
Niacin	64.88	
Riboflavin	1.63 – 2.98	
Vitamin C	1.4	

Phenolic compounds and antioxidant properties

Oxidation is vital for living organisms for energy production to perform all the necessary biological process in the body (Yang *et al*., 2002; Gan *et al*., 2013). According to Javan *et al*. (2015), phenolic compounds are multifunctional in clinical aspects which serve as prevention against harmful microorganisms in the body. According to Hung and Nhi (2012), among other edible mushrooms, *V. volvacea* has showed the highest phenolic content which was 4,122.7 µg GAE/g sample of dry weight. The other mushrooms such as *Auricularia polytricha* yielded only 474.4 µg GAE/g DW. The amount of phenolic compounds in mushrooms plays a major role towards their antioxidant capacity which help their consumers fight against the risks of chronic diseases and cancers. Mushrooms could also become functional foods and great sources for pharmaceutical medicines. The radical-scavenging activity of DPPH in *V. volvacea* was parallel to the amount of phenolic content, and yielded high antioxidant activity of approximately 82.9% (Hung and Nhi, 2012).

Boonsong *et al*. (2016) have used several extractants to extract five edible mushroom samples include *V. volvacea* at mature stage. The results indicated that the highest amount of total phenolic

compounds and flavonoids were found when extracted using 50% (v/v) ethanol. About 27.89 mg GAE/g DW and 7.29 mg QE/g DW were analysed from *V. volvacea* extract which in turn led to strong DPPH radical-scavenging activity due to the ability to donate electrons to scavenge the DPPH radicals.

Part 2:Preharvest management of Volvariella volvacea

Development stages of V. volvacea

V. volvacea typically comprises of six maturity stages which are pinhead, tiny button, button, egg, elongation, and mature stages. Different developmental stages have different morphological and anatomical characteristics (Ahlawat and Tewari, 2007). Figures 1a-f show the structure of *V. volvacea* at the mentioned six different growth stages.

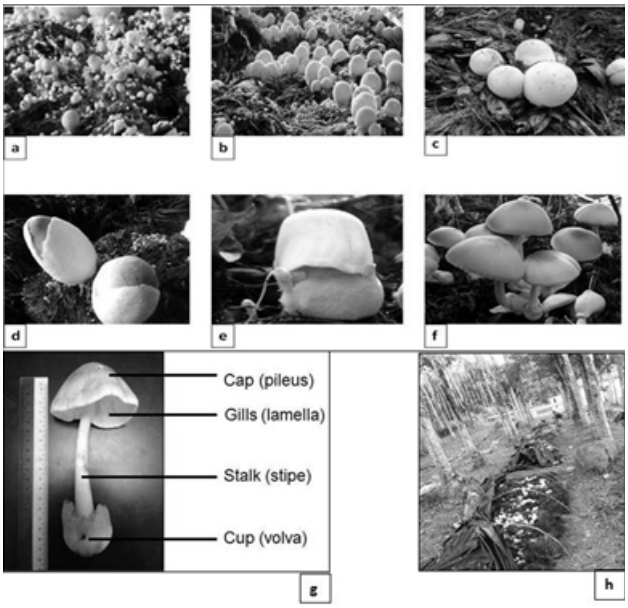

Figure 1. (a-f) shows growth stage of *V. volvacea* which comprise of a (pinhead stage), b (tiny button stage), c (button stage), d (egg stage), e (elongation stage), and f (mature stage). Figure 1(g) shows complete structure of mature *V. volvacea.* Figure 1(h) shows intercrop plantation of rubber and mushroom.

Pinhead and tiny button stages

Pinhead and tiny button stages of *V. volvacea* (Figures 1a and 1b) begin from the development of interwoven hyphal growth on the substrate. Pinhead has thicker veil and is evenly white at the margin (round edge) and darker colour at the underneath centre (Ahlawat and Tewari, 2007). Tiny button stage (Figure 1b) has rounded shape with brown universal veil at the top and white at the rest part through a vertical cut, lamellae (gills) under the pileus (cap) (Chang and Miles, 2004).

Button and egg stages

Both button and egg stages (Figures 1c and 1d) have ovoid shape and they are most preferred by consumers, and sold at premium price through commercialisation (Chang and Miles, 2004; Ahlawat and Tewari, 2007; Jamjumroon *et al*., 2012). The structure called pileus is wrapped by a coat known as universal veil with smaller size at button stage (Ahlawat and Tewari, 2007). The pileus and stipe (stalk) can be seen through a longitudinal structure cut where the universal veil formed with ruptured volva (cup) at the base (Chang and Miles, 2004).

Elongation stage

The elongation stage (Figure 1e) refers to the increasing length of the stipe. The pileus remains unopened (Ahlawat and Tewari, 2007). The lamellae appear as thin tissue projected from margin area towards the stipe, and can be seen hanging below the pileus (Chang and Miles, 2004).

Mature stage

According to Ahlawat and Tewari (2007), at mature stage (Figure 1f), *V. volvacea* has complete structure of pileus, stipe and volva. Figure 1(g) shows the complete structure of *V. volvacea*. Volva with bulbous base has fleshy texture, white colour and cup-shaped with rhizomorph for nutrient absorption from substrate and serve as food storage. Stipe is an interconnected structure holding between volva and pileus, and the length of the stipe depends on the size of the pileus. Pileus is circular shape when it expands to maximum size with an entire margin and soft surface which can be recognised by darker grey colour at the centre and light grey at the margin. It has diameter of about 6 to 12 cm which might vary due to environmental factors and absorption of nutrition from substrates used.

Cultivation of Volvariella volvacea

Nowadays, the cultivation of *V. volvacea* uses various types of substrates especially paddy straw waste which is usually used for the vegetative growth and fruit body development of *V. volvacea*. Paddy straw and few other plant wastes contain cellulose, hemicelluloses and lignin which are derived from the polysaccharides of the plant cell wall. They help bacteria in composting by attacking the cellulose and hemicellulose during favourable conditions. The metabolic actions by bacteria and microorganisms enable the conversion of nitrogenous materials into proteinaceous structure and thus elevated the protein supply for later growth of mushrooms. The action of bacterial activities also might cause the compost

substrate to become acidic (Chang and Miles, 2004). Other bed cultivation media such as sugarcane bagasse, oil palm bunch waste, maize stubbles, cotton waste, water hyacinth, and banana leaf waste have also been used in the cultivation of *V. volvacea* (Thiribhuvanamala *et al*., 2012). The agricultural wastes used in the cultivation medium of *V. volvacea* are quite important because they affect the nutrient content in the mushrooms (Roy *et al*., 2014).

The yield of *V. volvacea* also depends on the nutrient content in the cultivation medium, as investigated by Thiribhuvanamala *et al*. (2012). Different substrates have various lignocellulosic enzymes that help in the vegetative growth and fructification of mushrooms. The usage of paddy straw combined with empty fruit bunch of oil palm waste had resulted in significant increase in the production of vegetative body of *V. volvacea* as compared to other treatments. High amount of energy present in cellulose, hemicellulose and lignin are useful as recyclable biomass components. These enzymes play a vital role in the development of *V. volvacea* (Chang and Miles, 2004; Roy *et al*., 2014).

The best condition of substrate should have several criteria such as good anchorage. A substrate with good anchorage can hold water for the mushroom's survival and provide good aeration for its development. Besides, compost substrate should have good chemical content for the optimum absorption of nutrients, suitable pH, proper drainage, and good condition for microbial activity which further enhances the mushroom growth (Chang and Miles, 2004). In Malaysia, *V. volvacea* are not widely cultivated as compared to Philippines and Thailand where the yield could reach 2 million tonnes annually (Chang and Quimio, 1982). However, adding 908 g rice bran and 12% nitrogen and phosphorus per bed of 31.8 kg dry weight had increased the production to 100% and this has been practiced by some farmers in Malaysia.

Lignocellulose derived from organic materials such as timber and plant residues and their compounds are complex and insoluble. Since lignocellulosic materials are very resistance to breakdown, treatments with calcium chloride ($CaCl_2$) and hydrochloric acid (HCl) could increase the digestibility by and nutritional qualities for mushrooms. They also help in the production of sugar which is utilised as carbon source. Other than using chemicals, the use of microbiological techniques is quite practical with low handling cost to enhance better quality of nutrients and increase the commercial worth from organic wastes (Chang and Miles, 2004). Tripathy *et al*. (2011) revealed that the use of wheat bran and rice husk had significantly increased *V. volvacea* production to about 1,360 g/bed with 13.60% biological efficiency.

Cultivation of Volvariella volvacea using empty fruit bunch of oil palm

The use of empty fruit bunch (EFB) as a substrate for bed cultivation of *V. volvacea* gives a lot of benefits. EFB is a cheap recyclable residue and easily accessed since Malaysia has a wide palm oil plantation. According to Ukoima *et al*. (2009), the use of EFB has increased the production of *V. volvacea*. Besides, this also reduces the biomass waste in the environment. In Malaysia, the cultivation of *V. volvacea* is usually done by intercropping with rubber tree. This helps the farmers to gain extra income and maximise the utilisation of rubber plantation. Figure 1h shows the intercropping plantation of rubber and mushroom in a rubber estate in Padang Terap, Kedah. According to Chang and Miles (2004), the technology introduced would increase the mushroom's production yield and shorten the cropping period. The organic cultivation substrates could come from industrial, agricultural or household wastes.

There are three main stages in cultivating *V. volvacea* which are composting, incubating and formation of fruiting body. The Department of Agriculture in Padang Terap, Kedah has proposed the '3T concept' to *V. volvacea* growers and producers which are "*Tanam*" (cultivate), "*Tunggu*" (wait) and "*Tuai*" (harvest)".

Composting empty fruit bunches

In cultivating *V. volvacea*, the cultivation bed composting medium is prepared by incubating the fresh EFB under closed poly sheet plastics to create warm atmosphere of around 30-35°C. This temperature range is agreed as optimum for *V. volvacea* cultivation as reported by Thakur and Singh (2014). The optimum pH would be 7-8 along the composting period until the end of fructification (Chang and Miles, 2004). The successful composting of EFB can be seen if the EFB compost is within the preferable warm temperature and there is no other fungal growth such as *Coprinus* sp. on it. Composted EFB would then be arranged closely in the bed for *V. volvacea* to grow. According to Chang and Miles (2004), *V. volvacea* would have higher yield if the growth substrates are herbaceous materials rich in cellulose and hemicellulose. The mushroom production on the EFB bed would last for about three to four weeks from the first flush. As the production stops, the used EFB substrate could be re-composed and used as fertiliser.

Incubation

The ideal temperature for the formation of mushroom fruit bodies is about 32 ± 2°C (Thakur and Singh, 2014). Incubation at optimum temperature enhances the mycelial growth and fructification. After the completion of mycelial growth, the spawn needs good access to light to trigger the fruit body formation. Besides, good air ventilation also enhances mushroom fructification where they get oxygen and eliminate the excess carbon dioxide produced during the incubation period (Chang and Miles, 2004). High amount of energy present in cellulose, hemicellulose and lignin are useful as recyclable biomass components. The enzymes play a vital role in the development of *V. volvacea* (Chang and Miles, 2004; Roy *et al*., 2014). Stake of curved pipes are built on the bed medium to provide areas for the mushroom growth. Within a week, the mushroom production can be seen growing on the EFB bed medium. However, the formation of fruit body might occur early due to the environmental factors such as temperature and humidity.

Formation of fruiting body

V. volvacea is usually harvested at the button stage because at this stage the mushroom is more chewy with good texture and flavour which receive high demand from the consumers (Jamjumroon *et al*., 2012; He *et al*., 2018). Thakur and Singh (2014) stated that the formation of fruit body might occur as early as the 12th and 13th days of the cultivation. *V. volvacea* is the only mushroom that can be harvested within a short planting period as compared to the other mushrooms (Thiribhuvanamala *et al*., 2012; Thakur and Singh 2014). The button stage of *V. volvacea* takes about 12-24 hours to reach the veil opening stage. Sharp blade or knife is highly recommended to be used during harvest to minimise the mechanical damage.

In Malaysia, the common practice is to harvest at both button and egg stages since both are acceptable in the market. This is also due to the button stage of *V. volvacea* which grows very fast into the egg stage (within 6-7 hours). Therefore, growers tend to market the mushrooms immediately after harvest.

Part 3: Postharvest management of Volvariella volvacea

There are several undesirable appearances of *V. volvacea* after harvest such as fast veil opening, elongation of the stalk, browning, and weight loss. All these lead to the mushrooms becoming unattractive in their appearances and deteriorating in quality which in turn decrease the economic value of *V. volvacea* (Mercado and Alabastro, 1989).

V. volvacea respiration rate is higher during the button stage and at high temperature (Jamjumroon *et al*., 2012). Therefore, the temperature should be reduced to ±15°C to slow the respiration rate, control its physiological weight loss, preserve their quality, and prolong their shelf life after harvest. Therefore, temperature control can be considered as one of the postharvest management methods. The postharvest losses of *V. volvacea* could be reduced if proper, suitable and practical postharvest management methods are being employed.

Pre-cooling

Pre-cooling functions to remove the field heat from the surrounding environment of the harvested fresh produce. This is to fulfil the refrigeration capacity to cool the fresh produce towards or near the required temperature. The fresh produce would have longer storage life if the temperature is quickly reduced to the optimum storage temperature. This will help the harvested fresh produce to remain longer, avoid freezing, minimise desiccation and maximise their storage life. The rapid or fast cooling of fresh produce is known as pre-cooling, and this method usually benefits the perishable and sensitive fresh produce (Wills *et al*., 2007). Generally, mushrooms are sensitive to temperature changes and have high respiration rate which could further accelerate their deterioration. Therefore, rapid respiring commodities which have short postharvest life should be quickly cooled to remove their field heat right after they were harvested. According to Jamjumroon *et al*. (2012) rapid forced-air cooling might help in maintaining the fresh state quality of *V. volvacea*. The forced-air cooling should be conducted within the suitable temperature range to avoid chilling injury which might also affect the mushrooms' quality during the storage period.

Packaging

Packaging is one of the important processes in maintaining the survival and freshness of fresh produce. The fresh produce should reach the consumers in fresh and good conditions. They must be fresh in terms of their texture such as colour, firmness and water content. *V. volvacea* has a short shelf life of just 1-2 days at room temperature (Jamjumroon *et al*., 2012). This is due to the high respiration rate which eventually leads to high water loss. Besides, *V. volvacea* is also easily exposed to browning (Jamjumroon *et al*., 2013). Therefore, suitable packaging materials should be applied to prolong the storage period and delay the deterioration of *V. volvacea*.

Low Density Polyethylene (LDPE) plastic packaging material is made from the polymerisation of ethylene. This is the cheapest and simplest plastic. It acts as good moisture barrier (Mangaraj *et al*., 2009), and has high permeability ratio for carbon dioxide and oxygen which helps in minimising or preventing water vapour accumulation in the packaging. Furthermore, *V. volvacea* has high respiration rate of about 100-280 CO_2/kg/h (Jamjumroon *et al*., 2012) which could cause watery microenvironment inside the packaging, which also eventually leads to deterioration in quality.

Modified atmosphere packaging (MAP) is another simple, economical and practical method in retaining the mushroom quality and shelf life (Kim *et al*., 2006). According to Dhalsamant *et al*. (2015), MAP with perforations could prolong the shelf life of *V. volvacea* up to six days within storage temperature of 12 ± 1°C. The introduction of MAP to the mushrooms during storage could accumulate as well as circulate the concentration of carbon dioxide in and out of the packaging. Accumulation of carbon dioxide might reduce the browning activities in *V. volvacea* tissues and therefore increases its shelf life. According to Jamjumroon *et al*. (2012), MAP also reduces *V. volvacea* browning during storage by controlling the rate of oxygen and carbon dioxide content in the packaging. Excessive carbon dioxide of about 40-60% for a duration of 12 hours might increase the browning activities. It is called high carbon dioxide shock. The implementation of 10-20% carbon dioxide with 15% oxygen could provide optimum condition throughout the storage period, and has shown a decrease in browning activities and reduction of PPO enzymes in treated *V. volvacea* as compared to samples exposed to normal air where their PPO activity was above 0.25 Abs/min/ g fresh weight.

According to Gorris and Peppelenbos (1992), unsuitable packaging of samples might also lead to quality loss and product deterioration. They suggested vacuum packaging system because it could reduce the microbial metabolism thereby slowing down spoilage and/or pathogenic activities.

Calcium chloride ($CaCl_2$)

In a research conducted by Dhalsamant *et al*. (2015), it was found that *V. volvacea* treated with $CaCl_2$ showed lower total bacterial count as compared to the untreated samples. This treatment helped in reducing the effect of spoilage and lowering the deterioration rate. As a result, the *V. volvacea* had longer postharvest life up to six days with the combination with other treatment such as perforated packaging to allow the exchange of gaseous, and storage temperature within 12 ± 1°C. The treatment combination of $CaCl_2$ and packaged in 40 perforations (6.8 × 10−4% area of MAP-based packaging) showed significantly higher amount of total phenolic content of about 2,423.75 ± 96.94 as compared to control of only 1,083.16 ± 59.14 mg of GAE/g DW. The addition of $CaCl_2$ has also been shown to increase *V. volvacea* texture and firmness (Moon and Lo, 2013). Approximately 0.5% $CaCl_2$ could be the optimum concentration to be applied on *V. volvacea*.

According to Miklus and Beelman (1996), $CaCl_2$ treatment benefited both the pre- and postharvest. The pre-harvest treatment was conducted during the irrigation to supply the $CaCl_2$ to the mushroom. This resulted in a better postharvest production quality where it significantly decreased browning. Barden *et al*. (1990) found that introducing 0.5% $CaCl_2$ during the irrigation of *Agaricus bisporus* had increased its shelf life by 64%.

The implemented optimum amount of $CaCl_2$ during irrigation also reduced bacterial growth on *V. volvacea*. Mau *et al*. (1993) supplied the irrigation water with 0.3% $CaCl_2$ which significantly reduced the enzymatic activity to less than 50% at day 9 of storage at 3-12°C. The postharvest treatment of $CaCl_2$ to *V. volvacea* resulted in increase of weight loss during storage which was up to 12.35 ± 2.23%. This might be due to the fact that 0.5% $CaCl_2$ concentration which was sprayed on the mushrooms triggered the water to loss into the surrounding (Dhalsamant *et al*., 2015).

Storage temperature

V. volvacea should be stored in cooler storage temperature as compared to ambient to prolong their shelf life. The storage at ambient temperature would easily deteriorate their quality (browning, weight loss) and therefore decrease their shelf life (Jamjumroon *et al*., 2012). *V. volvacea* stored at ambient temperature could only retain their quality for less than one day. According to Bernas *et al*. (2006), the inappropriate storage temperatures for *V. volvacea* at ambient temperature could negatively affect the content of the amino acids in the mushroom. Therefore, *V. volvacea* should be kept cool after harvest. The optimum temperature might help *V. volvacea* to reduce their respiration rate and thus decrease their deterioration rate. Table 3 shows the conditions of *V. volvacea* at button stage stored at different storage temperatures.

Table 3. Physiological changes of *V. volvacea* stored at different temperatures

Temperature storage (°C)	Conditions	Shelf life (days)	Authors
< 15	Browning, water-soaking body tissue, chilling injuries	1-2	Rai and Arumuganathan (2008); Jamjumroon *et al.* (2012)
~ 15	Maintain good quality, avoid chilling injuries	3	Rai and Arumuganathan, (2008); Jamjumroon et al. (2012); Bao *et al*. (2013)
> 25	Rapid deterioration of pilei part, browning, weight loss	1-2	Bernas *et al*. (2006); Jamjumroon *et al*. (2012)

The optimum storage temperature for *V. volvacea* is 15°C (Jamjumroon *et al*., 2012; Bao *et al*., 2013; Rai and Arumuganathan, 2008). *V. volvacea* stored at 8-12°C was found to have short shelf life of less than two days. *V. volvacea* is rather sensitive to lower temperature because it is usually grown in tropical climate rather than other mushrooms such as oyster, white button, and shiitake that undergo their vegetative growth in cooler climate and prone to chilling injury (Jamjumroon *et al*., 2012; He *et al*., 2018).

Pre-treatment prior to consumption

Since *V. volvacea* has shorter shelf life as compared to other mushrooms, growers also practice several preservation processes to retain its quality and preserve it for a longer storage period. This is to ensure the economic viability during lower mushroom production (off season) when the prices of *V. volvacea* fluctuates. These processes involve freezing, drying and pickling.

Freezing

Freezing of *V. volvacea* can be performed below -20°C. Usually, mushrooms are frozen below -18°C (Rai and Arumuganathan, 2008). According to Thiribhuvanamala *et al*. (2012), freezing can preserve the mushroom's structure and quality, reduce bacterial contamination, and lead to the opening of veil for about two days storage, and no spoilage occurred within 36 hours of storage. After two days storage at -20°C, it will give a particular smell and prevent the mushroom from a slimy fluid on the mushroom surfaces. Freezing has led to a significant decrease in sliminess in *Boletus edulis*. However, freezing could also alter the mushroom tissue in which it would lose its turgor pressure after thawing, thereby losing in hardness and crispiness after 12 months storage (Jaworska and Bernas, 2010). According to Czapski and Szudyga (2000), freezing has also been shown to decrease the whiteness of *Agaricus bisporus* by 17%.

Drying

Drying of mushrooms includes air drying, freeze drying and oven drying (Rai and Arumuganathan, 2008; Moon and Lo, 2014). All these drying methods help to remove water content in the mushrooms and preserve them for a longer period. Drying method could minimise the cost of conducting and also could promote an environmental friendly impact in postharvest processing. Besides, removal of moisture by drying could also maintain the quality by reducing microbial contamination and biochemical activities which contribute to deterioration (Rai and Arumuganathan, 2008; Mujumdar and Law, 2010). In advanced technology, microwave vacuum drying method has been investigated and shown to improve the texture and colour of mushrooms as compared to air drying (Mujumdar and Law, 2010).

Pickling

Pickling is one of preservation methods of *V. volvacea*. In terms of economic-saving, pickling is more suitable for long-term storage (Rai and Arumuganathan, 2008). In Padang Terap, Kedah, Malaysia, the growers usually use salt as the preservative medium. *V. volvacea* is boiled before soaked in salty medium of sodium chloride. Furthermore, blanching and soaking could also preserve the colour of *V. volvacea* after storage and are able to maintain the production during off season when the prices are going up (Rai and Arumuganathan, 2008; Moon and Lo, 2014). Figure 2 shows the summary of postharvest management on *V. volvacea*.

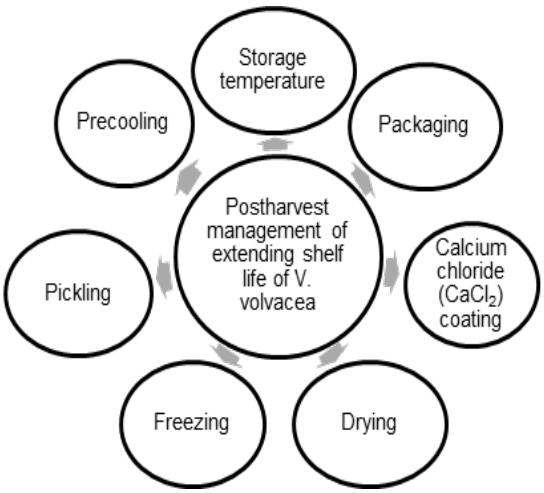

Figure 2. Postharvest management of *V. volvacea*

Part 4: Research related to Volvariella volvacea

Protein composition in V. volvacea

Whole-genome sequencing is considered a powerful method to understand the biological characteristics related to *V. volvacea*. Bao *et al*. (2013) has successfully sequenced *V. volvacea* genome. The *V. volvacea* whole genome sequence has been assembled into 62 scaffolds with a total genome size of 35.7 megabase pairs (Mbp) and around 11,084 predicted models of gene. This study has provided us with a model for future study on the progression of specific molecular mechanisms which correlated with the physiological and biochemical characteristics of *V. volvacea*.

An immunomodulatory protein (Fip) has been purified from *V. volvacea*, and designated as Fip-*vvo* (Hsu *et al*., 1997). FIP-*vvo* has been seen to stimulate maximum proliferation of human peripheral blood lymphocytes, and agglutinate erythrocytes in rat and rabbit. In another study, the gene that encodes for the FIP-*vvo* has been cloned from *V. volvacea* mycelia, and its recombinant was further expressed in the *Pichia pastoris* expression system (Sun *et al*., 2014). *P. pastoris* is a type of yeast responsible for protein production through recombinant DNA method. In vitro assays of biological activities discovered that the reFIP-*vvo* showed the same immunomodulating capabilities as their natural form.

There are 41 differentially expressed genes of *V. volvacea* encoding for FAD-binding proteins in homokaryons and heterokaryons (Meng *et al*., 2013). Using quantitative real-time PCR, the expression levels of these genes were found to be different. It is suggested that these differentially expressed genes are highly responsible in supporting the differences in genetic and phenotypic between homokaryons and heterokaryons in *V. volvacea*.

Polysaccharides composition in Volvariella volvacea

Based on the beneficial characters and importance of *V. volvacea* and *Pleurotus florida* nowadays, a study has been conducted by Chakraborty and Sikdar (2008) which showed that the possibility to combine both mushrooms using protoplast fusion approach. About 12 somatic hybrid lines were produced via polyethylene glycol-mediated intergeneric protoplast fusion using a double selection method. It turned out that *P. florida* hybrid line demonstrated high biological efficiency and tolerant towards temperature backcross progeny line. Therefore, through this programme a new hybrid of mushrooms could be commercialised in a larger scale of cultivation.

In recent years, polysaccharides from mushrooms have gained the attention of scientists regarding their immunomodulation and antitumor properties (Singdevsachan *et al*., 2016). Different type of extractions have provided a variety of glycan-based polysaccharides with different patterns of branching and type of sugar molecules attached to them (Das *et al*., 2010). Some chemically modified β-glucans from *V. volvacea* have shown inhibitory activity towards the development of mouse-transplanted tumours (Kishida *et al*., 1992).

Three fractions have been obtained from hybrid mushroom which involved backcross mating of *PfloVv12* and *V. volvacea* known as PS-I, PS-II and PS-III (Nandan *et al*., 2011). It was found that PS-I was 1,6-β glucan while PS-II and PS-III were mannoglucogalactan, and they differed by molecular weights. In another study, a water soluble heteroglycan, which was isolated from the fruit bodies of *P. florida* and *V. volvacea*, resulted in the hybrid mushroom consisted of (1→3)-, (1→6)-, (1→3,4)-linked, and terminal β-d-Glcp along with (1→2,6)-α-d-Galp and terminal α-d-Manp (Bhunia *et al*., 2012).

Conclusion

The research about the production and postharvest storage life of *V. volvacea* is still very limited. There are still lacks in information regarding their cultivation, nutritional values, application of effective and affordable treatment in extending the shelf life and delivering their potential benefits to the consumers. This aspect should and could be enhanced since *V. volvacea* can be easily cultivated in tropical countries including Malaysia. Furthermore, the use of empty fruit bunches as a growth medium and source of nutrition fulfils and supports the Government's recommendations in creating green environment with cheap recyclable materials. *V. volvacea* contains high nutritional content including protein, and is highly suggested as a main source of protein in the humans' diet.

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