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Original Research Article

Effect of Packaging Materials on Antifogging Film Properties and Quality of Oyster Mushrooms at Different Storage Temperatures

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Abstract: Mushroom is highly perishable and easily damaged within a day after harvesting due to their high respiration rate which leads to the release of water vapour. The most effective way to preserve fresh mushrooms is by packaging. However, excessive water vapour inside the packaging can cause condensation or fog and subsequently, lead to product damage. Hence, appropriate material for packaging mushrooms is important to maintain the quality and prolong the shelf-life. The main objective of this study is to compare the effect of different packaging material types on the fogging effect. The studied materials are low-density polyethylene (LDPE), polypropylene (PP), nylon, and gelatin-based film. Based on the market survey prior to the study, it showed that the most plastic material used in the market is polypropylene (PP) compared to other materials. The experimental study then proceeded by comparing the different types of materials used for the packaging of mushrooms. Samples of 20 g mushrooms were filled in a cup covered with four different types of films and stored at three different storage temperatures (5 °C, 10 °C, 30 °C) for 7 days. It was observed that the gelatin-based film showed good antifogging behaviour when compared to other films. Additionally, the mushrooms showed high weight loss and severe browning for all types of packaging materials after 7 days of storage at high temperatures (30 °C). In conclusion, the gelatin-based film has revealed excellent water-adsorbing with antifogging behaviour to maintain the quality and shelf life of mushrooms at low temperatures for storage and distribution.

Keywords: antifogging; mushroom; petroleum-based film; gelatin based film

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1. Introduction

Perishable vegetables are living products that undergo a process of ripening and eventually a process of ageing in which the tissue of the plant is broken. Perishable vegetables such as mushrooms, undergo various physiological processes even after harvesting, including growth, maturation, senescence, weight loss, veil opening, browning, and wilting (Rai & Arumuganathan, 2008). All of these processes can gradually deteriorate the quality of the mushrooms and shorten their shelf life. It has been reported that the number of recognised mushroom species is 14,000, which accounts for only 10% of the total estimated species of existing mushrooms in the world (Cheung, 2008; Koushki *et al*., 2011).

According to Aida *et al*., (2009), there are several types of mushrooms commonly cultivated such as *Agaricus bisporus* (button mushroom), *Lentinus edodes* (shiitake mushroom), *Pleurotus spp.* (oyster mushroom), *Auricula spp* (wood ear), *Flamulina velutipes* (enokitake) and *Volvariella volvacea* (straw mushroom). In Malaysia, around 1,000 tons of mushrooms are grown each year for domestic and export markets, with grey oysters being the most popular variety followed by the white oyster, ganoderma, shiitake and button. Generally, oyster mushrooms are grown in the lowlands, with Selangor having the largest production area, followed by Johor and Kedah (Zaffrie *et al*., 2014).

It is known that most of the mushrooms have a poor shelf life with the oyster mushrooms having an extremely short shelf life after a few hours at ambient conditions (Billoria & Mishra, 2016). The short shelf life span is mainly due to several factors, including a high respiration rate and moisture content as well as a thin epidermal structure (Wei *et al*., 2017; Nur Sakinah *et al*., 2020; Castellanos-Reyes *et al*., 2021). The colour, texture, and appearance of mushrooms have a significant impact on their quality and customer acceptability. These qualities degrade quickly after harvest as mushrooms are among the most perishable horticultural crops. This is related to the maturation process and all the quality attributes will be affected such as colour, microbial changes and texture. Moreover, the respiration process of the mushrooms is still occurring, causing the continuous release of water vapour.

Nowadays, plastic film packaging has been used to provide protection and is increasingly used for vegetables to restrict the transpiration potential. Typically, the types of plastic films used for packaging are polyethylene (PE), polypropylene (PP), and polyvinyl chloride film (PVC). The common plastic films used for fresh produce have lower water vapour permeability compared to the mushroom’s transpiration rate. Thus, excessive moisture accumulates inside the package, resulting in condensation (Geyer *et al*., 2015). However, the condensation or fogging inside the mushroom packaging is the most unwanted phenomenon and is usually not pleasing to the eye depending on the application and may cause food spoilage. The fogging effect would be elevated when the surface temperature of the plastic material falls below a certain temperature, which is under the dew point of water. The air can no longer retain all the water vapour at this temperature, and condensed water vapour begins to form small discrete water drops on the surface of the plastic film. The severity of the phenomenon depends on the relative humidity and temperature of the enclosed air mass and the plastic film temperature (Wagner, 2001; Wypych, 2017). Therefore, proper packaging methods are required to extend shelf life, preserve quality, and minimise the loss of nutritional constituents in fresh oyster mushrooms (Castellanos-Reyes *et al*., 2021).

Gelatin-based films may be used in the food industry for a variety of purposes, including the transportation of gases (O_2 and CO_2), water vapour, and flavour for fruit and vegetables. For example, refrigerated Red Crimson grapes were coated with gelatin and as a result, it increased in water vapor permeability (WVP) and mechanical resistance while reducing the total weight loss without influencing consumer acceptance (Fakhouri *et al*., 2015). Another study also showed that gelatin-based film can preserve perishable vegetables by reducing weight loss and browning index values (Halim *et al*., 2018). The use of gelatin for the application of perishable food packaging is based on some particular properties such as operational cost, availability, functional attributes, mechanical (flexibility, tension) and optical (brightness and opacity) properties, barrier effect against the gas flow, structural resistance to water and microorganisms, and sensory acceptability (Ramos *et al*., 2016). Gelatin films exhibit some good advantages as film properties and poor mechanical properties can be improved by the addition of plasticisers (Thomazine *et al*., 2005; Nor *et al*., 2017; Weng & Wu 2015; Azmi *et al*., 2020). Among all the possibilities of plasticisers that are compatible to be used in gelatin-based film is glycerol (Limpisophon *et al*., 2009; Tongnuanchan *et al*., 2012; Azmi *et al*., 2020).

There is still limited information available on the quality and fogging behaviour of the mushrooms in the package of different materials in correlation to the antifogging properties at different storage temperatures. The objective of this study is to compare the effect of different packaging material types on the fogging effect at different temperatures. Five types of film materials namely LDPE, PP, nylon and gelatin-based film (with and without glycerol as plasticiser) were used in this study. As for the gelatin-based film, the gelatin was derived from the partial hydrolysis of collagen, a fibrous protein found primarily in the tilapia fish scales (Azmi *et al.*, 2020). The outcomes of this study provided a comprehensive knowledge of packaging systems for increasing the shelf life of mushrooms.

2. Materials and Methods

2.1 Market and Customer Survey

Three different categories of markets were surveyed to gain an overview of the use of mushroom packaging and consumers' demand, specifically the big market (supermarket), medium market (fresh mart) and small market. The data was collected from an online survey filled by 32 Malaysian respondents. The online survey was designed for correspondents who consistently utilise mushrooms as a part of ingredients in their recipes. The questions in the survey were divided into 3 sections; general demographic information, general perceptions of the packaging and people's choice for mushroom packaging.

2.2 Antifogging Properties of Different Types of Films

20 g of mushrooms were placed in the cup containers that were covered with five different types of film materials which were LDPE, PP, nylon and gelatin-based film (with and without glycerol as plasticiser). Then, the cup containers were placed at three different temperatures 5, 10 and 30℃ for 7 days to monitor the fogging behaviour.

2.3 Mushroom Weight Loss Evaluation

The weight loss was determined by weighing each package before and after storage. The weight loss data were taken on day 1 and day 7 and all measurements were done in duplicates. The weight loss was calculated using Equation 1:

$$\text{Weight loss (\%)} = \frac{\boldsymbol{Weight\ initial - weight\ after}}{\boldsymbol{Weight\ initial}} \text{x}100 \tag{1}$$

3. Results and Discussion

3.1 Market and Consumer Survey

The most used conventional film in all market categories for mushroom packaging was PP with different ways of packaging based on the different market categories. The mushrooms were packed in 100–200 g and lasted for about two to four days on the shelf. From the observations, it can be seen there was fogging inside all three types of mushroom packages.

Table 1. Types of packaging in three categories of market

Types of market	Types of packaging and specifications	Observations/remarks
1. Big Market 	Type of packaging: Plastic (polypropylene) Market: Tesco Size: M Weight: 200 g Duration in the market: 3-4 days	Fogging inside the package
2. Medium Market 	Type of packaging: Plastic (polypropylene) Market: Fresh mart Size: M Weight: 100 g Duration in the market: 3-4 days	Fogging inside the package
3. Small Market 	Type of packaging: Plastic (polypropylene) Market: Morning market Size: M Weight: 100 g Duration in the market: 2-3 days	Slightly fogging inside the package

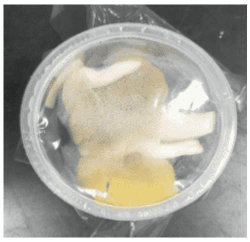
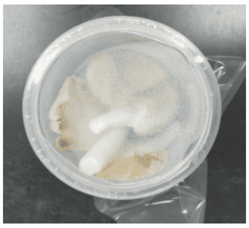
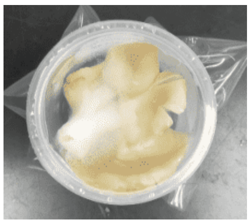
Based on the survey, more than 87% of participants were concerned about having to deal with the amount of packaging. This was because 50% of participants stated that they would need store the mushroom in the refrigerator for about 1–2 days. Meanwhile, 34.4% have stored the mushroom for 3-4 days and the rest chose to store the mushrooms for more than 5 days. According to the survey, consumers prefer the appearance and texture of mushrooms. Besides that, the type of packaging was one of the criteria for consumer selection. Nowadays, consumers are becoming more aware and concerned about the type of packaging, especially with the use of environmentally friendly packaging. One of the reasons could be due to personal concerns, such as an excess of materials in every household, or it could be related to broader environmental issues, such as being concerned about the amount of waste polluting the environment (Velez, 2015). In the survey, about 40.6% preferred to choose reusable and recyclable packaging.

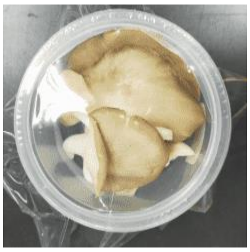
Taken altogether, the results of the customer survey have shown that the consumer preferences on the mushroom packaging were based on the quality appearance of the mushroom. Therefore, types of packaging and storage temperature play an important role in ensuring the quality of mushrooms. The main factor that causes the quality deterioration of mushrooms is the excessive water accumulation inside the package which would damage the texture and promote microbial growth.

3.2 Antifogging Behaviours

Fogging behaviour can be observed by monitoring the accumulation of water inside the packages. Table 2, 3 and 4 showed the timeline observation of the cup filled with mushrooms and covered with different types of plastic materials stored at different temperatures. As can be observed in Table 2–4, the clear surface can be seen for all types of film used which did not show any fogging effect before the mushroom was stored at different temperatures on day 0.

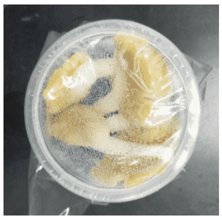
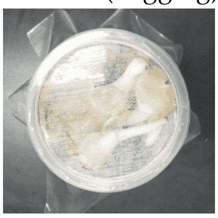
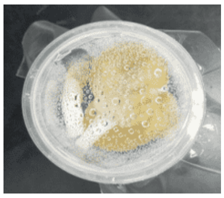
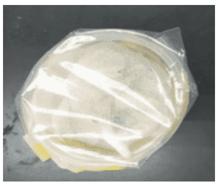
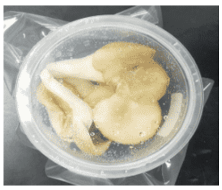
Table 2. Observation on the surface of different film materials covered the cup containing mushrooms that were stored at 5°C

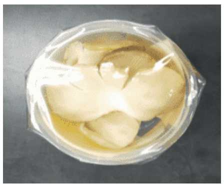
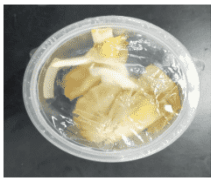
Type of film	Day 0	Day 1	Day 7
PE	 Clear	 Less clear	 Not clear (Fogging)
PP	 Clear	 Less clear	 Not clear (Fogging)
Nylon	 Clear	 Not clear (Fogging)	 Less clear

Type of film	Day 0	Day 1	Day 7
Gelatin without glycerol	 Clear	 Clear	 Clear
Gelatin with glycerol	 Clear	 Clear	 Clear

*PP -Polypropylene; PE - Polyethylene

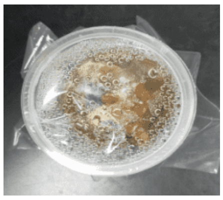
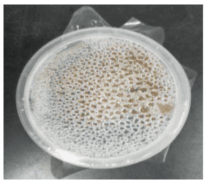
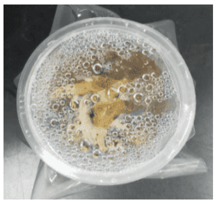
Table 3. Observation on the surface of different film materials covered the cup containing mushrooms that were stored at 10°C

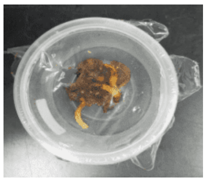
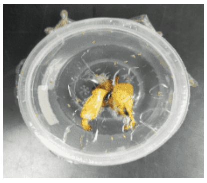
Type of film	Day 0	Day 1	Day 7
PE	 Clear	 Not clear (Fogging)	 Not clear (Fogging)
PP	 Clear	 Not clear (Fogging)	 Not clear (Fogging)
Nylon	 Clear	 Not clear (Fogging)	 Less clear

Type of film	Day 0	Day 1	Day 7
Gelatin without glycerol	 Clear	 Clear	 Clear
Gelatin with glycerol	 Clear	 Clear	 Clear

*PP -Polypropylene; PE - Polyethylene

Table 4. Observation on the surface of different film materials covered the cup containing mushrooms that were stored at 30 °C

Type of film	Day 0	Day 1	Day 7
PE	 Clear	 Not clear (Fogging)	 Not clear (Fogging)
PP	 Clear	 Not clear (Fogging)	 Not clear (Fogging)
Nylon	 Clear	 Not clear (Fogging)	 Not clear (Fogging)

Type of film	Day 0	Day 1	Day 7
Gelatin without glycerol	 Clear	 Clear	 Clear
Gelatin with glycerol	 Clear	 Clear	 Clear

*PP -Polypropylene; PE - Polyethylene

The antifogging performance of the film was evaluated at various temperatures (5°C, 10°C and 30°C) for 1 and 7 days of storage. As expected, the conventional film materials such as PP, PE and nylon were covered by fog as shown in Tables 2, 3 and 4. PE, PP and nylon have high moisture barriers and can be categorised as hydrophobic material as it does not adsorb water in a pure state (Pehlivan *et al*., 2003). Moreover, mushrooms are still respired even after harvesting and contain approximately 90% water. As a result, mushrooms emitted a substantial amount of water vapour, causing condensation on the film's surface (fogging). The accumulation of the vapour encourages spoilage bacteria to grow and turns the mushrooms brown and spotted (Pogorzelska-Nowicka *et al*., 2020). In addition, most of the evaporated water molecules from the product do not escape through the film, and remain within the package, thereby increasing water vapour pressure inside the package microenvironment (Mahajan *et al*., 2016). Even minor fogging behaviour was higher due to the increasing water accumulation inside the package particularly for conventional film packaging as shown in Tables 3 and 4. This is due to the high respiration rate of the mushrooms at high temperatures. The high rate of respiration encourages a high relative humidity inside the package, which leads to water condensation and discolouration of the mushrooms (Kader *et al*., 1989). In addition, water-vapour transmission rates (WVTR) are low in most polymeric materials used in fresh-product packaging, such as PE and PP relative to the transpiration rates of fresh produce. Therefore, most of the evaporated water molecules from the product do not escape through the film, and remain within the package, increasing water vapour, decay, microbial growth, and browning of the product's surface (Linke &

Geyer, 2013). Temperature fluctuations also result in condensation under these conditions, further resulting in sliminess

On the other hand, the cups covered with both gelatin film without and with glycerol, have demonstrated antifogging behaviour as no fog can be seen on the surface of the films either after day 1 or day 7 of storage at any temperature. It was due to the low moisture barrier and hydrophilicity of the gelatin-based film producing antifogging properties and capabilities in adsorbing the water condensed on the surface. In addition, hydrogen bonds and dipole-dipole interaction were believed to quickly absorb the water molecules in the condensed droplets into the hydrophilic domains of the film (Hu *et al*., 2018). The addition of glycerol to the gelatin film also gives an advantage in antifogging properties by facilitating water absorption due to their hygroscopic nature (Rivero *et al*., 2010, Azmi *et al*., 2020). Glycerol was described as a hydrophilic plasticiser that increases the water vapour permeability of hydrocolloid-based films (Al-Hassan & Norziah, 2012).

In addition, based on Table 3 and 4, the mushrooms were not safe to be stored at 10 and 30°C until day 7 as the mushrooms turned wet and slimy in texture especially when the mushrooms were packaged in PE film. This was due to the unwanted postharvest water condensation inside the package. This observation was in agreement with the results reported by the previous studies on the packed fruit or vegetable surfaces which caused defects in the external appearance such as skin colour, surface structure and texture (Feng *et al*., 2003; García *et al*., 1998; Srinivasa *et al*., 2004). Such a problem can also promote microbial growth (Linke & Geyer, 2013).

3.3 Weight Loss

One of the major problems encountered during postharvest storage of mushrooms is the dehydration and rapid water loss from the mushroom which leads to weight loss. Figures 1 and 2 showed the weight loss of mushrooms stored at different temperatures in the cup covered with different film materials after 1 and 7 days of storage. Based on the result obtained, after 1 day of storage, the mushroom in the cup covered with gelatin-based films (with and without glycerol) showed significant weight loss in the range of 8% to 16% than the other films irrespective of storage temperature. As anticipated, the same observation was obtained after 7 days of storage period whereby the mushroom in the cup covered with gelatin-based film showed a high weight loss of up to 70%. This is probably due to the high water vapour permeability and hydrophilic properties of the gelatin-based film (Limpan *et al*., 2010; Tongnuanchan *et al*., 2012; Azmi *et al*., 2020). Hence, the water on the surface of the mushroom was absorbed by the gelatin which resulted in high water loss and became dried.

Overall, there was a significant weight loss of the mushroom during the storage period at a higher temperature. This study was in agreement with Aday (2006) and Nur Sakinah *et al*. (2020) who stated that there were gradual losses in the weight of mushrooms along with storage periods with increasing in storage temperature. This is due to the high respiration rate of the mushrooms at high temperatures. Higher temperatures would produce a higher rate of water loss to the surroundings concerning its relative humidity (Azedevo *et al*., 2017). This phenomenon can be related to the fogging properties of the film where a thick fogging can be seen on the surface of the film irrespective of the type of materials at the higher temperature.

Meanwhile, for the temperatures of 5°C and 10°C, the highest water loss was obtained at 5°C for all types of materials. This is due to the chilling injury of the mushrooms. The mushrooms became susceptible to the chilling temperature of 5°C, which resulted in tissue shrivelling and water loss (Jitareerat *et al*., 2018; Nur Sakinah, *et al*., 2020). Furthermore, the thin epidermal layer of mushrooms did not provide support to prevent fast water evaporation into the environment, resulting in weight loss over time (Singh *et al*., 2018; Nur Sakinah *et al*., 2020). In comparison to leafy vegetables with stomata for balanced transpiration and respiration, the outer surface structure of mushrooms might cause a significant increase in water loss. Therefore, the mushrooms can be stored at 10°C for 7 days to reach the acceptable limit of weight loss.

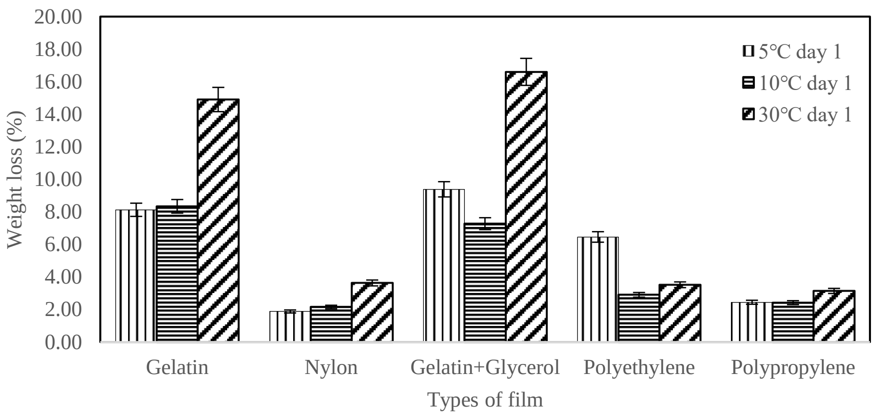


Figure 1. Weight loss of mushroom at different temperatures for cups (day 1).

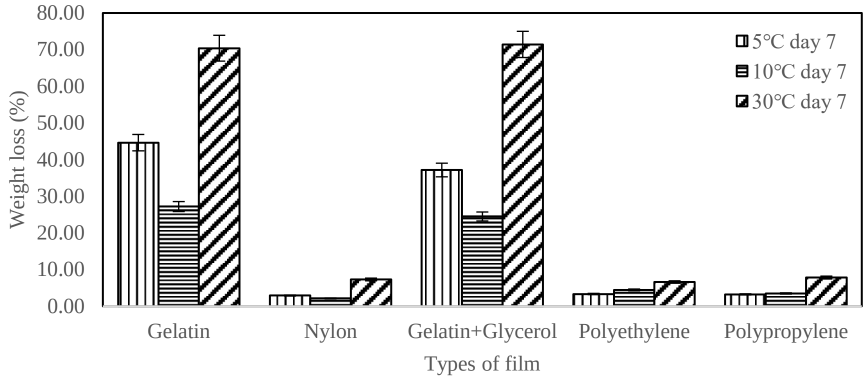


Figure 2. Weight loss of mushroom at different temperatures for cups (day 7).

4. Conclusions

This study has shown that the respiration of the mushroom resulted in condensation inside the surface packaging which was dependent on the temperature and storage conditions. The mushrooms released water vapour even at saturation conditions which could be observed in the package headspace that led to the fogging phenomenon. Additionally, the market and customer survey have shown that there is a need to improve the packaging technique of the mushrooms to extend their shelf life. Hence, this study has also made an effort to test the performance of the gelatin-based film in comparison to the conventional films for possible application as mushroom packaging material. The results showed excellent antifogging properties of the gelatin-based films compared to conventional films (PE, PP and Nylon). This was due to the low moisture barrier and hydrophilic properties of the gelatin-based film. Indeed, the gelatin-based film maintained the quality of the mushrooms. However, there was a huge weight loss for the gelatin-based films after 7 days of storage at 30°C. In conclusion, the gelatin-based film demonstrated excellent water-adsorbing with antifogging behaviour to maintain the quality and shelf life of mushrooms at low temperatures for storage and distribution. For future recommendations, the study on the application of gelatin-based film with modified-atmosphere system packaging can be further investigated in improvising the mushroom packaging.

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