

Chapter 6

Rice-Straw Mushroom Production



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Abstract The rice-straw mushroom (*Volvariella volvacea*) has a distinct flavor, pleasant taste, and rich protein content. It has low production costs and a cropping duration of approximately 45 days—making it an effective means for poverty alleviation for those farmers who grow it. Farmers in Vietnam, the Philippines, and Cambodia grow it. Rice straw is one of the most common substrates used for growing this mushroom. The mushroom can grow well in both outdoor and indoor conditions; however, outdoor cultivation has risks of exposure to rain, wind, and/or high temperatures, all which reduce yield. The yield of indoor mushroom production is higher and more stable, as such, indoor growing is preferred. In addition to cultivation, this chapter also covers straw mushroom characteristics, cultivation principles and techniques, and rice straw substrate preparation.

Keywords Rice-straw mushroom · Indoor cultivation · Outdoor cultivation

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6.1 Overview of Rice-Straw Mushroom (RSM)

Mushroom is considered an important food to address food and nutrition security and human health (Ishara et al. 2018; Cuesta and Castro-Rios 2017; Feeney et al. 2014a) and climate change adaptation issues (Gellerman 2018; Langston 2014). *Volvariella volvacea* (Fig. 6.1), also known as the straw mushroom or rice-straw mushroom (RSM), is one species of edible mushroom cultivated throughout East and Southeast Asia (Sudha et al. 2008).

RSM production adds value to rice production and increases the income of the poor farmers in developing countries (Imtiaj and Rahman 2008; Shakil et al. 2014; Zhang et al. 2014).

Among more than 38,000 known mushroom species, such as *Agaricus bisporus*, *Lentinus edodes*, *Flammulina velutipes*, *Auricularia polytricha*, etc., RSM is one of the most common mushrooms cultivated (Walde et al. 2006) and ranks third among important mushrooms due to its delicious taste (Ramkumar et al. 2012; Thiribhuvanamala et al. 2012), as well as its short growing time compared to other species (Rajapakse 2011). In terms of production, RSM ranks sixth among edible mushrooms, accounting for about 5–6% of world production (Ahlawat et al. 2011).

RSM is known as a healthy food (Belewu and Belewu 2005; Feeney et al. 2014b; USITC 2010). It has high protein, potassium, and phosphorus contents (Ahlawat and Tewari 2007) while being salt-free and low in alkalinity, fat, and cholesterol. Mushroom also contains selenium (Solovyev et al. 2018) and niacin (Ahlawat and Tewari 2007; Eguchi et al. 2015), which are two essential compounds in the immune system and the thyroid that have a role in cancer prevention (Hobbs 1995). Its fiber content is important for physiological functions in the gastrointestinal tract (Manzi et al. 2001). In addition, RSM has significant antimicrobial activity (Chandra and Chaubey 2017). It also provides good sources of polypeptide, terpene, and steroid (Shwetha and Sudha 2012) and phenolic compounds, such as flavonoids, phenolic

Fig. 6.1 *Volvariella volvacea* (Bull.; Fr.) Singer is an edible mushroom also known as the straw mushroom and, for our purposes, the rice-straw mushroom (RSM)



Table 6.1 Chemical composition of RSM

Content	Unit	Value
Moisture content	% in wet basis	88–91.1
Crude protein	% of dry weight	30–43
Crude fat	% of dry weight	1–6
Fiber	% of dry weight	4–10
Ash	% of dry weight	5–13
Carbohydrate	% of dry weight	12–49.3
Energy value	Kcal/kg of dry weight	2760

Adapted from Chang and Quimio (1989), Eguchi et al. (2015)

acid, and tannins that contribute to its high antioxidant properties (Hung and Nhi 2012). Other sources of antioxidants in RSM are catalase, superoxide dismutase, glutathione peroxidase, peroxidase, glutathione-S-transferase, and glutathione reductase (Ramkumar et al. 2012). Table 6.1 summarizes the chemical composition of RSM.

Due to its many benefits and advantages, mushroom production and consumption have significantly increased in many countries (Vizhanyo and Jozsef 2000; Bernaś et al. 2006). The top mushroom producers are China, USA, and The Netherlands, contributing 47%, 11%, and 4%, respectively of the world's total mushroom production.

6.2 Physical Characteristics of RSM

RSM is best adapted in tropical and subtropical regions (Bao et al. 2013) and grows at relatively high temperatures (Obodai and Odamtten 2012). Its total crop cycle, under favorable growing conditions, is within 4–5 weeks (Biswas 2014). It belongs to the Fungi kingdom, Plutaceae family, Agaricales order, Agaricomycetes class, and Basidiomycota division (Chang 1969, 1974; Rajapakse 2011). RSM has an umbrella-shaped cap (pileus) ranging from dark grey to brown and a diameter of 8–10 cm. When young, its cap has an egg-like shape and, as it matures, it becomes cone-like and nearly flat. The stalk (stipe) ranges in color from silky white to brown, which develops to a brownish gray sack-like cup (volva) (Chang and Miles 2004). The mycelia, the vegetative parts, comprise of threads and cord-like strands branching out through the substrate.

When the mycelia come together, the mushroom begins its first stage of development called the *pinhead stage*. It is characterized by tiny clusters in white circular structures of interwoven thread-like hyphae. This is followed by the *button stage* in which buttons encircling the egg-shape structures are covered by a layer of tissue or a universal veil (volva). The stalk (stipe), cap (pileus), and gills (lamellae) are seen inside the button when it is cut lengthwise. Commercially, the button stage is pre-

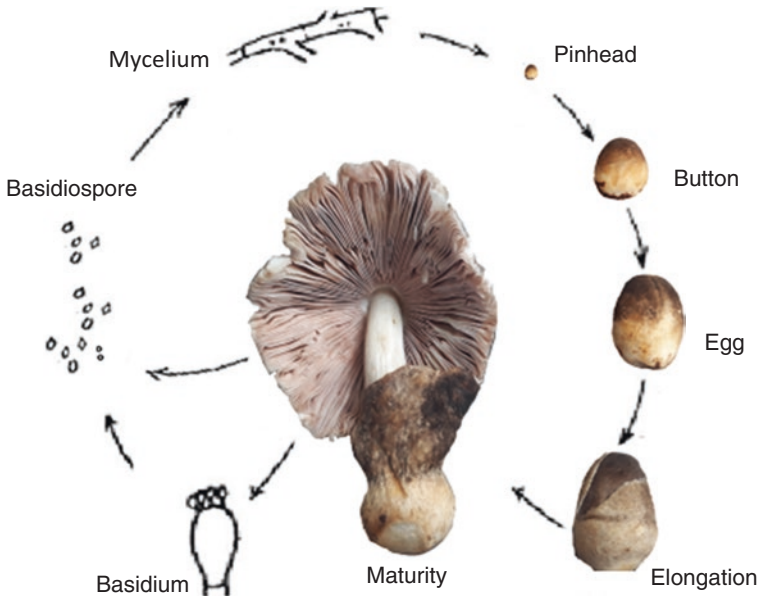


Fig. 6.2 RSM life cycle. (Adapted from Le-Duy-Thang 2006; Bao et al. 2013)

ferred for harvesting because of the mushroom's high-protein content at this point (about 25%), best palatability, and longer shelf life. The *elongation stage* occurs after the universal veil (volva) ruptures, exposing the stalk and the cap. The last stage, *maturity*, is characterized by the fully expanded cap exposing the brownish-pink gills of its lower surface. At this stage, the spawns (basidiospores) begin to discharge. Figure 6.2 shows the mushroom lifecycle starting from generation of the spawns and ending with the formation of the ear.

6.3 Environmental and Nutritional Requirements

RSM is considered as one of the easiest mushrooms to cultivate because of its short production duration (Zikriyani et al. 2018) and advantages of having less fat. As mentioned, this species grows in warm weather, typically in the tropics and subtropics. The optimal temperature is from 30 to 35 °C for the RSM's mycelial growth and from 28 to 30 °C for its fruiting body production (Le-Duy-Thang 2006). The suitable temperature for growing mushrooms is between 25 and 40 °C with the optimum being 35 °C (Fasidi 1996). Relative humidity in the range of from 70% to 90% is best for RSM growth (Biswas and Layak 2014). The optimal pH is 6.5; anything

Table 6.2 Environmental requirements for RSM growth

Parameter	Mycelium		Fruiting	
	Range	Optimal	Range	Optimal
Temperature, °C	15–42	35 ± 2	25–30	28 ± 2
Relative humidity, %	50–70	60 ± 5	80–100	90 ± 5
pH	6–7	6.5	6–7	6.5

Adapted from Fasidi (1996), Chang and Miles (2004), Akinyele and Adetuyi (2005), Le-Duy-Thang (2006), Biswas and Layak (2014)

higher hampers mycelia growth (Akinyele and Adetuyi 2005). This species grows well on a number of cellulosic substrates, such as rice straw, wheat straw, sugarcane bagasse, banana leaves, water hyacinth, etc. RSM production can be intensified with the development of cutting-edge technologies. It can be grown outdoors or indoors. Growing practices are described Sect. 6.4. Table 6.2 summarizes the main parameters that enhance RSM growth.

Traditionally, RSM is mostly cultivated outdoors because of the low investment cost. However, outdoor cultivation has low and unstable productivity due to exposure to changing weather conditions (Reyes 2000). Although controlled indoor mushroom cultivation requires more investment, it usually results in higher and more stable yields (Chang 1996). In addition, through environmental control, RSM can be intensively cultivated, growing from six to eight crops annually. Palitha (2011) reported that the yield of indoor RSM cultivation can be 2.7 times higher than that of outdoor practice with the same application of feedstock.

Biological efficiency (BE) is an important parameter used in the mushroom industry to evaluate the effectiveness of a mushroom strain on different substrates (Chang et al. 1981; Biswas and Layak 2014; Girmay et al. 2016). It is calculated as follows:

$$BE = \frac{FWm}{DWs} * 100\%$$

where:

BE is the biological efficiency

FWm is the total fresh weight (g) of mushroom yield across all flushes, and

DWs is the substrate dry weight (g)

As already mentioned, RSM can be cultivated on several lignocellulose materials; however, RSM productivity is attributed to substrates of the best quality (Ahlawat et al. 2011). Table 6.3 shows the biological efficiency of RSM production on different substrates.

Table 6.3 Biological efficiency of RSM on different substrates

Substrates	Biological efficiency (%)	References
Rice straw	10.2–15.0	Chang et al. (1981), Biswas (2014), Chang and Miles (2004)
Cotton waste	17.7–40.0	Chang et al. (1981), Zikriyani et al. (2018)
Banana leaves	8.6–15.2	Belewu and Belewu (2005), Zikriyani et al. (2018)
Sugarcane trash	13.2	Thiribhuvanamala et al. (2012)
Wheat	12.1	Tripathy (2010)
Water hyacinth	8.7	Thiribhuvanamala et al. (2012)

6.4 Current Practices for Growing Mushroom

6.4.1 Outdoor RSM Cultivation

The steps for outdoor RSM production (Fig. 6.3), as it is done in Vietnam, are shown in Fig. 6.4.

6.4.1.1 Rice Straw for Mushroom Growing and Preparation of the Growing Location

Rice straw intended for growing RSM should be dry, clean, without mold contamination, and should not have been exposed to rain or should not have started rotting in the field. Rice straw contaminated with molds may have mycelia or spawns with a white color. To minimize contamination and for best quality, the straw should be collected right after harvest. The location for growing RSM should be cleaned and treated with 300–500 kg ha⁻¹ (3–5 kg 100 m⁻²) of lime (CaCO₃) 3 days before incubation.

6.4.1.2 Growing Preparation and Maintenance of Planting Spawn

The most commonly used spawn substrate is a mixture of tobacco midrib and sawdust. The tobacco midribs are first soaked in clean water overnight. After soaking, they are washed at least three times, drained, and then chopped into lengths of from 2 to 4 cm. The chopped midribs are boiled for 30 minutes and then drained until the moisture content reaches around 65%. Next, the midribs are mixed with the sawdust. About 350 g of mixed spawn substrate is placed inside a 6- × 12-in. polypropylene (PP) bag. For easier handling, a plastic ring may be placed as a “bottle neck” on the PP bag. This can be done by pulling out the PP bag end through the polyvinylchloride (PVC) ring then folding the pulled-out part outward to make an open-



Fig. 6.3 Growing RSM outdoors

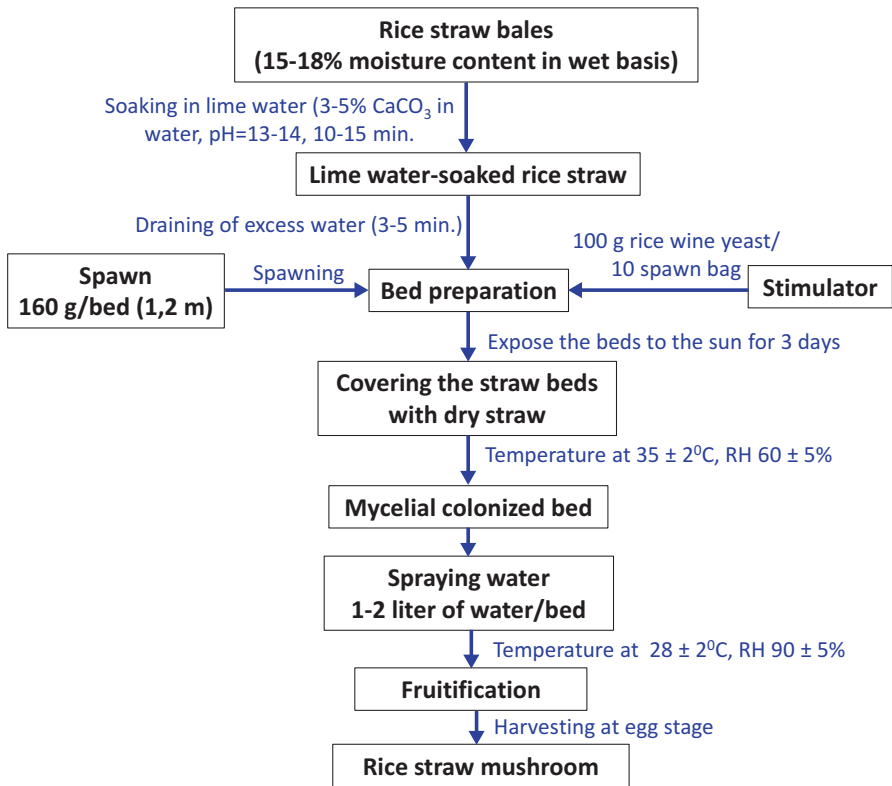


Fig. 6.4 Process of RSM production from rice straw preparation to mushroom harvesting. (Adapted from Thuc et al. 2019)

ing. Next, the folded part is secured by tying with a rubber band. The PVC neck opening is plugged with a rolled cotton waste then covered with paper secured with rubber band.

The PP bags containing the spawn substrates are sterilized using an autoclave at 15 psi pressure and 121 °C for 30 min. The sterilized PP bags with the spawn substrates are then transferred to the inoculation room and allowed to cool down.

The sterilized bags are kept inside the laminar flow under a UV tube or inoculation chamber for 20–30 min. Inoculation is done by removing the cotton plug of each bag, then placing a 1-sq mm pure culture mycelial block on top of the spawn substrate using a sterilized inoculation needle, then replacing the cotton plug. The process is repeated until all the bags with substrates have been inoculated.

The inoculated bags are kept in the incubation room at 32 °C temperature for 2 weeks, or until mycelial growth reaches the bottom of each bag. The bags should always be checked for contamination during the incubation period. The shelf life of the spawn is about 4 weeks at room temperature. It can also be refrigerated at 4 °C to prolong storage. The refrigerated spawn should be primed at room temperature before using in order to activate spawn growth.

6.4.1.3 Preparation of Growing Beds and Spawning

Rice straw or stubble can be used as bedding materials or substrates. These materials collected from the field must be sun-dried. If bundled substrates are used as bedding, the straw should be cut into 30-cm long strips to make bundles 10 cm in diameter. The beds can be created manually (Fig. 6.5a) or using a

Fig. 6.5a Manual bedding



Fig. 6.5b Bedding using a wooden frame



wooden frame (Fig. 6.5b). The wooden frame size is 0.3–0.4 m in width, 0.35–0.4 m in height, and 1.5 m in length. Straw should be placed into the frame and compacted so that the first layer is 10 cm thick; then the spawn is added to the straw surface. A second layer using similar steps should be done. The two layers of straw are compressed, and then the frame is removed to have the beds on the ground for growing RSM.

The bedding materials are soaked in clean water for 12 h to make them soft and pliable. The soaked substrates are rinsed with clean water to remove the slime, fermenting odor, and to reduce acidity. Soaking is a prelude to composting.

In composting, the soaked substrates are piled up then covered with plastic sheets. The composting period is 14 days and the pile should be turned on the 7th day to ensure even composting. In some cases, 1% molasses and 5% complete fertilizer (14–14–14 NPK) are mixed into the substrate during composting. Agricultural lime (1%) is also added when the compost pile is turned. Through composting, the substrates are converted into a rich medium suitable for mushroom growth.

The moisture content of the substrate during bed preparation must be close to 65%. Growing beds are established by piling the bundled substrates into layers. The spawns are sprinkled thinly over the bundles in each layer. It can also be placed in thumb-size bands 7 cm from the edge of the bed at a distance of 10 cm between bands. Sometimes the spawn is covered with newspaper to protect the spawn from drying and to enhance better mycelial growth. If the substrate were not applied with molasses and fertilizer during composting, a nutrient solution, containing 10 g of urea and 30 g of sugar mixed in 4 L of water, is sprinkled over each substrate layer. The process should be repeated until all layers have been treated. Ideally, the bed should have three layers and should be from 2.5 to 3 m long.

The growing bed is covered with a polyethylene plastic sheet to maintain the desired temperature and relative humidity appropriate for mycelial growth. The optimum temperature for incubation ranges from 30 to 35 °C with a relative humidity ranging from 75 to 85%. The incubation period takes from 10 to 14 days. Mushroom primordia or pinheads usually appear on the side and surface of the growing beds 5 days after spawning. Once pinheads are observed, the plastic sheet cover should be lifted for a while to introduce fresh air. The temperature should be maintained at 30 to 32 °C to synchronize fruiting body formation during the fruiting stage. The surroundings of the beds should be watered to help maintain the desired temperature.

6.4.1.4 Mushroom Growing Care

In the first 3 days after adding spawn to the straw beds, the beds need to be exposed to the sun to increase the temperature inside, which stimulates mycelial growth. Then, the beds are covered with a net and dry straw. Some nutritional supplements or stimulants such as Bioted, HQ, or HVP 301 can be sprayed onto the beds to enhance better mushroom growth. The beds can be watered and covered with rice straw to maintain the temperature and humidity as well as to maximize the yield and quality of RSM production, as indicated in Table 6.2.

6.4.1.5 Harvesting and Processing

The first fruiting flush occurs about 14 days after incubation and continues for about 5 days. After the fruiting flush, water is sprinkled over the bed and covered again with the plastic sheet to build up the temperature. Within 7–14 days, the next fruiting flush will appear. The succeeding fruiting flushes often consist of larger, but fewer fruiting bodies than the first flush. Hand picking is the common method of harvesting and sorting the mushrooms. This guarantees less damage and better quality. The mushrooms are picked from the growing beds with a rotating motion. The harvest is sorted based on quality and size. To enhance higher protein content, better palatability, and longer shelf life, the preferred times for harvesting are during the button to egg-shaped stages.

6.4.2 Indoor RSM Growing

Indoor mushroom growing requires the same preparation and treatment steps as in the outdoors. However, the environmental criteria, such as heap temperature (>70 °C) to sterilize straw, moisture content (60–65%), etc., have to be strictly controlled. Indoor RSM growing uses shelves with two types of bedding, spread (Fig. 6.6a) and compacted (Fig. 6.6b). The ratio of spawn used is about 200 g m⁻².

Fig. 6.6a Spread bedding



Fig. 6.6b Compacted bedding



It is necessary to cover the substrate beds to secure the moisture content for 2–3 days. Water may be sprinkled upon seeing the fungus grow on most of the beds. Organic fertilizer, such as chicken manure or cow dung, is added to the substrate at a rate of about 0.5–1.5 kg m⁻² to increase the nutrient uptake by the mushrooms. All materials have to be sterilized before adding them to the substrate.

6.4.3 Case Study of Cost-Benefits for Growing Indoor and Outdoor Mushroom

We conducted assessments for indoor and outdoor mushroom growing in the Mekong River Delta (MRD) of Vietnam in 2018 that resulted in the cost-benefit comparison shown in Table 6.4. For the outdoor practice, total input cost was about 1.28 \$US kg⁻¹ of mushroom produced and 1.23 \$US m⁻² of land used. It comprises the main component costs of rice straw (40%), labor (23%), chemical inputs (11%), and the rest for land use, depreciation of net and pump, and watering. On the other hand, for the indoor practice, the total input cost was 1.37 \$US kg⁻¹ of mushroom produced and 10.79 \$US m⁻² of

land used. The indoor practice cost breakdown was depreciation of growing house and facilities, 44%; rice straw, 31%; labor, 7%; and the rest for use, depreciation of net, pump, and growing house (for indoor scenario), and watering. Net profit accounted for 1 kg of mushroom produced was the same for both indoor and outdoor practices at 0.5–0.6 \$US kg⁻¹. Whereas, accounting for a square meter of land

Table 6.4 Comparing cost-benefits between outdoor and indoor RSM growing practices in MRD

Parameters	Outdoor		Indoor	
	\$US kg ⁻¹ of mushroom	\$US m ⁻² of land used	\$US kg ⁻¹ of mushroom	\$US m ⁻² of land used
Inputs				
Land used (rental)	0.15	0.04	0.16	0.35
Rice straw	0.51	0.38	0.54	3.33
Net, pump, depreciation of growing house (indoor only)	0.03	0.54	0.03	4.76
Lime, fertilizer and pesticide	0.12	0.07	0.13	0.60
Spawns	0.14	0.10	0.15	0.83
Watering (power consumption)	0.03	0.02	0.03	0.21
Labor	0.30	0.08	0.32	0.71
<i>Total inputs</i>	1.28	1.23	1.37	10.79
Outputs				
Mushroom	1.67	1.67	1.78	14.58
Spent rice straw	0.15	0.10	0.16	0.83
Total outputs	2.35	2.29	2.51	20.04
Net profit	0.5	0.6	0.5	4.6

used, net profit of the indoor practice was 4.6 \$US m⁻² about 9 times higher than that of the outdoor practice. However, RSM is commonly cultivated in rural areas, near the rice fields to reduce the cost of transporting the rice straw. So, outdoor mushroom growing is still widely done in Vietnam.

6.5 Pest and Disease Problems

RSM is very sensitive to the environment including temperature, sunlight, water, oxygen (O₂), and carbon dioxide (CO₂). Sudden changes in temperature may hamper or even stop mushroom growth. Sunlight is needed from the sphere to the egg stages. With a lack of sunlight, vitamin E will be significantly reduced, vitamin D will not be available, and melanin pigment (black pigment) will not form in RSM.

Green mold (*Verticillium fungicola*), orange mold (*Neurospora* spp.), plaster mold (*Scopulariopsis fimicola*), acne mushroom (*Sclerotium rolfsii*), etc. are the typical diseases that affect RSM. These diseases can be prevented or treated by using lime water with a 0.5–1% concentration and applied by watering on the affected area. Gypsum disease can be treated with potassium permanganate (KMnO₄) or acetic acid (40%). If the disease is severe, it can be treated by fungicides, such as Benomyl 0.1%, 7% Zineb, or Validacin (for acne).

6.6 Preservation and Consumption of RSM

RSM can be used and processed into many different products but it is easily damaged during harvesting and primary processing. The selection of appropriate technology for product storage and processing on a scale that is compatible with production conditions will promote the cultivation of mushrooms and help stabilize consumption.

RSM spoils very quickly and can be stored at most for 3 days at temperatures between 10 and 15 °C or in controlled atmosphere packaging (Jamjumroon et al. 2012) it loses moisture in 4 days, resulting in a 40–50% loss of mushroom weight when stored under normal ambient temperature. Thus, other methods are used for longer storage, one of which is dried RSM. However, sun drying often changes the color and taste of the product. Furthermore, RSM exposed to the sun outdoors is susceptible to microbial contamination. The drying process takes 24 h at 30 °C. The drying temperature can start at 40 °C and then gradually increase over 8 h to 45 °C. Raw materials of dried mushrooms can be left or cut in half. If cut in half, they must be pretreated before drying. Blanching for 3–4 min in hot water or 4–5 min in hot steam helps mushrooms keep their color better during storage. When RSM is dried at 60 °C for 7 h, the moisture content may reach 5%. Dried mushrooms can be stored or pulverized for use in spices. Other methods recommended for RSM preservation include air-conditioning packaging with storage media

(Lopez-Briones et al. 1992), drying (Izli and Isik 2014), freezing (Murr and Morris 1975), soaking in saline or acid solution (Cliffe-Byrnes and O'Beirne 2008), and canning (Vivar-Quintana et al. 1999).

Storage time can be extended for 3–6 months by soaking the mushrooms in acidic or saline solutions, which help extend shelf life and maintain their color. The mushrooms are washed in plain water before dipping into the saline solution. The mushrooms are then put in the containers and covered with the saline solution.

Mushroom preservation through industrial canning technology is used in many countries around the world. The process of producing canned RSM includes preliminary processing, blanching, stacking, sterilization, cooling, labeling, and packaging. In order to produce canned mushrooms of good quality, it is necessary to process harvested mushrooms as soon as possible. In case of unavoidable delay, mushrooms should be stored at 4–5 °C until processed.

However, all the other preservation methods result in inferior mushroom eating quality compared to that of fresh mushroom, in terms of the original flavor, color, hardness, and so on. Extending the shelf life of fresh mushroom beyond 3 days is most important, as illustrated in the case of the Mekong Delta in Vietnam. In the local market, mushrooms are consumed as a fresh vegetable with the price normally fluctuating from 2 to 4 US\$ kg⁻¹ at the first and 15th day of the lunar month. A small portion of salted or dried RSM is also exported at 2 US\$ kg⁻¹, but is not as much appreciated as fresh mushrooms. For estimating consumer trends, we can look at the American market. In 2012, the share of fresh mushrooms was 87% in quantity and 93% in value; the remaining minor portion is processed mushroom, with a farm gate price of only one half compared to that of fresh mushroom (Phan-Hieu-Hien 2017).

The price of fresh RSM at US supermarkets in 2013 was about 10 US\$ kg⁻¹, while that of salted mushroom was only 5 US\$ kg⁻¹ (personal communication with Mr. Le Duy Thang, mushroom expert). From farms in Vietnam to US supermarkets, fresh RSM needs a minimum of 8 days to “travel”, including 2–3 days through customs and 2–3 days at supermarkets before reaching consumers. The 8-day shelf life of fresh mushroom is the greatest constraint to boost mushroom production, or indirectly to increase the use of rice straw. Luckily after decades of deadlock, some research results are promising (Dhalsamant et al. 2018). Factors to help ensure a successful 8-day storage cycle include: (1) a suitable temperature, say 12 °C; (2) a controlled-atmosphere packaging, which is balanced between oxygen and carbon dioxide content; and (3) a chemical pretreatment, such as CaCl₂. More in-depth research is needed in parallel with pilot testing for economic performance.

6.7 Summary and Recommendations

Producing RSM is a sustainable option for adding value to rice production and reducing environmental harm through avoiding the burning of rice straw in the field. Growing outdoor RSM is a traditional practice with low investment costs but generates low yield and incurs high risk because it is strongly affected by changes in the

weather. On the other hand, growing indoor RSM has higher investment costs but greater productivity and lower risks due to its well controlled environment.

One of the major bottlenecks for developing RSM is its market. Even though fresh RSM has high value, it cannot be stored for more than 3 days because it is highly perishable. Using technology to improve preservation to lengthen the storage time is a key to increasing the market and price and improving RSM's value chain.

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