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The nutrition, cultivation and biotechnology of *Stropharia rugosoannulata*

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Abstract

Stropharia rugosoannulata contain polysaccharides, sterols, lectins, flavonoids, vitamins and minerals. Various bioactivities are reported from this mushroom, such as antidiabetic, antimicrobial, antioxidant, antiproliferative, antitumor, immunomodulatory and suppressing osteoclast formation properties. The mushroom has also been cultivated to increase rural and urban incomes and remediate soils. Soils contaminated by organic pollutants have been remediated by fungal extracellular enzymes, such as laccase and manganese peroxidase. The present review summarizes the nutritional value of the mushroom, bioactive compounds, cultivation methods and biotechnology. This review also provides suggestions for its future applications.

Keywords – agroforestry – bioactive compounds – bioremediation – field cultivation – fungi

Introduction

Stropharia rugosoannulata Farl. ex Murrill is commonly known as the Wine-cap mushroom, King *Stropharia,* Winter mushroom, Garden giant, or Burgundy mushroom (Yang et al. 2021). It is an agaric mushroom of *Strophariaceae*, which is distributed across northern temperature zones (Suzuki et al. 2019). Basidiomes are terrestrial, solitary or gregarious and can be found on humus- and nitrogen-rich soils, particularly in gardens, parks, grasslands and can even grow on manure. *Stropharia rugosoannulata* is edible, cultivated for household consumption (Pegler 2001, Bruhn et al. 2010) and grown commercially (He et al. 2012). The Food and Agriculture Organization (FAO) recommends the consumption of this mushroom because it can help mitigate a variety of cancer-related illnesses (de Oliveira et al. 2020). Research performed on *S. rugosoannulata* has revealed applications of this fungus as a functional and medical food via suppressing osteoclast formation as well as having antidiabetic, antimicrobial, antioxidant, antiproliferative, antitumor and immunomodulatory properties (He et al. 2012, Zhai et al. 2013, Zhang et al. 2016, Liu et al. 2020).

Stropharia rugosoannulata was first domesticated in 1969 in Germany, followed by Poland, the former Czechoslovakia (Czech Republic or Slovakia), Hungary and the former Soviet Union (Stamets & Chilton 1983, Sharma et al. 2007). By 1989, the annual commercial production of *S. rugosoannulata* in Europe reached approximately 1300 tons (Domondon et al. 2000). China started the cultivation industry of *S. rugosoannulata* in 1990 (Wan & Bau 2005, Yan et al. 2020). By 2019, the cultivation area in China had reached approximately 1300 hectares, with a production of about

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30–45 tons per hectare, and the export volume reached 3,000 tons in 2018 (CEMBN 2019). It is currently cultivated at large scale in many provinces in China, such as Hebei, Shandong, Yunnan and Zhejiang (Tian et al. 2002, Jin et al. 2020, Hua et al. 2021).

Traditional cultivation of *S. rugosoannulata* occurs from September to April of the second year, featuring an in-depth management strategy. It is often cultivated under economic forests or orchards in field conditions. The main steps include spawn production, composting, bed preparation, inoculation, management and harvest, with optimal temperatures and humidity between 20–30°C and 70–85%, respectively (Bruhn et al. 2010). This mushroom can be cultivated with various kinds of raw materials, such as cereal straw, sawdust, sugarcane, rice husk, cottonseed hull and corncobs (Bao 2015). Cereal straw such as paddy, corn and soybean are widely used to cultivate *S. rugosoannulata* (Szudyga 1978, Yu et al. 2014). Wood chips of *Alnus*, *Hevea*, *Populus*, *Quercus*, *Tilia* have been reported to produce considerable *S. rugosoannulata* yields (Domondon et al. 2000, Stamets 2011), and a yield of around 4 kg/m^2 was reported when using *Hevea* sawdust as a growing substrate (Huang et al. 2019). However, wood chips from trees like *Salix* contain a high amount of salicylic acid and are not suitable for the cultivation of *S. rugosoannulata* because this compound suppresses the growth of fungal mycelium (Raskin 1992). After all the beds are well colonized by fungal mycelium, the substrate is overlaid with a 3–5 cm deep soil casing layer. The casing layers are kept humid in case the substrates lose water. It takes 40–60 days for mushrooms to form after placing the soil casing layer. In general, the raw materials and climatic conditions for large-scale cultivation of *S. rugosoannulata* are critical, since farmers could reduce costs with cheap raw materials and increase yields with suitable climatic conditions, improving the economic performance of their land.

Fungal biotechnology can play a crucial role in agroforestry systems, capable of producing resilient sources of food, feed, chemicals, fuels and materials (Meyer et al. 2020). In addition, the cultivation of *S. rugosoannulata* supplements local income streams through building a more efficient circular economy while also amending and remediating soils for sustainable landscape management (Fig. 1). This review summarizes current knowledge of nutrients, cultivation, and biotechnology of *S. rugosoannulata*. Its roles in circular economies and bioremediation are discussed, as they could be helpful for the full utilization of this mushroom.

Fig. 1 – Cultivation of *Stropharia rugosoannulata* supplements local income in Yunnan, China. Scale bar: 5cm. Photo credit: Hu Y.

Food resources and nutritional value

Stropharia rugosoannulata basidiomes contain abundant macro- and micro-nutrients. The nutritional components of *S. rugosoannulata* have been described in previous studies (Liu et al. 2012, 2019a), with the main components featuring ash, protein, crude fat, carbohydrates, minerals, coarse cellulose, energy, vitamins, fatty acids and amino acids. Table 1 lists the composition of macronutrients and minerals in the basidiomes of *S. rugosoannulata* and compares the composition with *Agaricus bisporus*, *Lentinula edodes* and *Pleurotus ostreatus*, which are some of the most popular and common edible mushroom species. Based on the data from Table 1, the ash content of wild and cultivated *S. rugosoannulata* (6.04–8.72%) is higher than *L. edodes* (4.29–6.24%), while no significant difference existed between *A. bisporus* (6.04–9.74%) and *P. ostreatus* (7.62–9.65%). It is clear that basidiomes from both wild and cultivated *S. rugosoannulata* contain a high amount of crude protein (25.75–25.89%) when compared with *A. bisporus* (3.05–14.08%), *L. edodes* (12.76–16.00%) and *P. ostreatus* (18.35–25.68%). The crude fat content of wild and cultivated *S. rugosoannulata* (2.19–3.72%) is higher than *L. edodes* (1.01–1.14%), wild *P. ostreatus* (2.08%) and cultivated *A. bisporus* (1.78%), while being lower than wild *A. bisporus* (7.18%). The carbohydrates and fibers content of *S. rugosoannulata* (61.91–64.35%) is lower than *A. bisporus* (74.00–89.13%), *L. edodes* (76.62–81.94%), and *P. ostreatus* (62.54–71.26%). Moreover, the micronutrient mineral content of *S. rugosoannulata* is abundant compared to *A. bisporus*, *L. edodes* and *P. ostreatus*. For example, *S. rugosoannulata* basidiomes contain abundant Fe (195.00–244.10 μg/g, dry weight), Mn (40.60–59.00 μg/g, dry weight) and Cu (16.00–29.00 μg/g, dry weight), reaching higher levels than the other three species (Table 1). The Zn content of *S. rugosoannulata* (54.40–102.00 μg/g, dry weight) is higher than *A. bisporus* (17.80–22.98 μg/g, dry weight) and *P. ostreatus* (29.80–42.83 μg/g, dry weight), while being similar to *L. edodes* (53.82–94.40 μg/g, dry weight). From the above data, it can be concluded that both wild and cultivated *S. rugosoannulata* are prized sources of nutrients owing to high amounts of protein, crude fat and micronutrient minerals.

Bioactive compounds

Stropharia rugosoannulata contains promising bioactive compounds in both its fungal mycelia and basidiomes. The main bioactive components of this mushroom include monosaccharides, polysaccharides, sterols, lectins, flavonoids and phenols, some of them have the ability of antioxidant, antibacterial, antitumor and antidiabetic effects (Wang et al. 2018, Liu et al. 2020). The main bioactive components in the basidiomes are monosaccharides and polysaccharides, which vary in their properties based on extraction methods and different parts of basidiomes (Wang et al. 2018). Monosaccharides including mannose, ribose, glucuronic acid, glucose and galactose were detected from fresh basidiomes of *S. rugosoannulata*, and glucose was the main monosaccharide (Liu et al. 2020). The monosaccharide composition included galactose and glucose with a 3:1 ratio in fresh *S. rugosoannulata* (Jiang et al. 2020). In addition, Jiang et al. (2020) also isolated a new polysaccharide from *S. rugosoannulata* and showed this polysaccharide stimulates immunological activities such as the growth of T lymphocytes, B lymphocytes and RAW264.7 cells as well as the secretion of IgA, IgD, and IgG by B lymphocytes. The main two types of polysaccharides and antioxidant characterizations from *S. rugosoannulata* were studied by Liu et al. (2020). α-type and β-type glycosidic linkages were detected in one kind of polysaccharide, while the β-constitution dominated in the other polysaccharide; moreover, both polysaccharides showed potential antioxidant activities on $ABTS^+$, DPPH and OH^- radicals (63.29–100%, 46.67–62.50% and 39.28–98.59%, respectively). Exopolysaccharide production from pure fungal mycelium of *S. rugosoannulata* was investigated by Zhou et al. (2010), and the authors concluded that the optimized conditions for the cultivation temperature, time and volume of media for exopolysaccharide production were around 28°C, 6–7 days and 110 ml, respectively. Under optimal conditions, the maximal production of exopolysaccharide and dry mycelium weight was 1.50 gl^{-1} and 9.88 gl^{-1}, respectively. An exopolysaccharide produced by submerged culture of *S. rugosoannulata* was studied by Zhai et al. (2013), and the maximum dry mycelial biomass (around 16.35 gl^{-1}) was detected after five days of incubation. Exopolysaccharide production reached its maximal level (10.83 gl^{-1}) after eight days of incubation. The hypoglycemic effect of exopolysaccharides was studied on diabetic rats, and the results showed some promising effects of exopolysaccharides on hyperglycemia prevention in diabetic patients (Zhai et al. 2013).

Table 1. Macronutrients and mineral composition in both wild and cultivated *Stropharia rugosoannulata*, and compared with *Agaricus bisporus*, *Lentinula edodes* and *Pleurotus ostreatus*.

Species	Growing condition	Ash (%)	Crude protein (%)	Crude fat (%)	Carbohydrates and fibers (%)	Fe (µg/g, dry weight)	Zn (µg/g, dry weight)	Ca (µg/g, dry weight)	Mn (µg/g, dry weight)	Cu (µg/g, dry weight)	References
Stropharia rugosoannulata	Wild	6.04	25.89	3.72	64.35	195.00	102.00	1,371.00	59.00	29.00	Liu et al. (2012)
	Cultivated	8.72	25.75	2.19	61.91	244.10	54.40	151.90	40.60	16.00	Wang (2007)
Agaricus bisporus	Wild	9.74	14.08	7.18	74.00	126.00	17.80	74.50	22.30	5.22	Demirbaş (2001), Jedidi et al. (2017)
	Cultivated	6.04	3.05	1.78	89.13	21.36	22.98	nd	4.16	16.40	Owaid (2015), Stojković et al. (2014)
Lentinula edodes	Wild	4.29	12.76	1.01	81.94	41.68–60.62	53.82–70.72	165.00–295.00	nd	9.99–13.60	Carneiro et al. (2013), Guo et al. (2010)
	Cultivated	6.24	16.00	1.14	76.62	148.00	94.40	1,749.00	10.00	14.80	Heleno et al. (2015), Mallikarjuna et al. (2012)
Pleurotus ostreatus	Wild	7.62	24.90	2.08	65.40	86.10	29.80	106.00	6.27	13.60	Demirbaş (2001), Beluhan & Ranogajec (2011)
	Cultivated	7.82–9.65	18.35–25.68	2.34–2.58	62.54–71.26	80.18–129.88	42.83–52.10	391.00–821.00	3.09–7.44	9.67–14.60	Jin et al. (2018)

nd, not determined.

Aside from polysaccharides, *S. rugosoannulata* contains sterols, lectins, flavonoids and other compounds that constitute active ingredients of edible and medicinal mushrooms. The functional constituents of sterols in *S. rugosoannulata* were reported by Wu et al. (2011), with five sterols isolated from basidiomes of *S. rugosoannulata* showing anti-fungal activity, inhibition of osteoclasts formation or thapsigargin toxicity. Wu et al. (2012, 2013a, b) extracted particular steroids from the basidiomes of *S. rugosoannulata* by ethyl alcohol and acetone, sterols A-D from *S. rugosoannulata* were obtained from fresh basidiomes, and a distinct sterol with an unprecedented ether ring from this mushroom was isolated. Sterol A may protect neuronal cells and showed weak anti-Methicillin-resistant *Staphylococcus aureus* activity (Wu et al. 2012). Zhang et al. (2014) isolated a type of novel lectin with a unique N-terminal sequence from the basidiomes of *S. rugosoannulata*, representing the first purified protein from this mushroom species, and this lectin shows antiproliferative activity toward cancer cells and anti-HIV reverse transcriptase activity compared with lectins isolated from other mushrooms such as *A. bisporus*, *Cyclocybe aegerita* and *Coprinopsis cinerea*. Yan et al. (2020) investigated the basidiomes of *S. rugosoannulata*, leading to a total of sixteen compounds being isolated and identified, including six types of steroids, one type of steroidal saponins, three types of fatty acids, one type of alkane, one type of ceramide, one type of ester, one type of pyrimidine, one type of vitamins and one type of flavonoid. However, the functional activities of these compounds remain unclear and is in need of further study. Based on the existence of potentially undiscovered bioactive compounds, future studies could focus on the mechanisms and actions of the components in *S. rugosoannulata* that benefit human health and could be developed into functional chemical components for foods or used in the prevention and treatment of chronic diseases.

Cultivation methods of *Stropharia rugosoannulata*

Culture

Solid and liquid culture media can both be used in the cultivation of *S. rugosoannulata*. Solid culture media is often prepared with potato dextrose agar, malt extract agar or yeast mannitol agar (Zhang et al. 2005, Nie et al. 2016). Another solid medium uses agricultural waste as the main component, such as wheat straw (Yan et al. 2001). Liquid culture media are often prepared with potato dextrose broth and glucose-based broth media (Wang & Li 2008). After the media are inoculated via tissue isolation of basidiomes or culture collection, cultures are incubated for mycelium growth. Optimal incubation conditions for the solid culture of *S. rugosoannulata* include 25–30℃, pH 5–6 and a water content of 75% for 10–30 days (Yan et al. 2001). The optimal incubation conditions for liquid culture include 25℃, pH 6 and a rotation speed of 120 rpm for 12 days (Liu et al. 2019b).

Spawn production

Spawn production for commercial cultivation of *S. rugosoannulata* includes cereal-based spawn and agricultural waste-based spawn; the former type is applied for small-scale cultivation, and the latter is used for large-scale cultivation. Cereal-based spawns are prepared with well-cooked wheat or rice with a pH 6.5–7 and 65–70% water content (Li et al. 2012). Agricultural waste-based spawns are mainly prepared using corn wastes, rice straw or soybean straw (Sun 2013). Sawdust-based spawns are mainly used for large-scale *S. rugosoannulata* cultivation (Li et al. 2013). Spawn bags or bottles should be sterilized at 121℃ and 105 kpa for 2 hours before inoculation of solid or liquid culture, and the optimal temperature for incubation is 25℃ (Sun 2013).

Compost preparation

The materials used for compost preparation come from various agricultural wastes, such as cereal straw, wood sawdust, wheat bran and rice bran (She et al. 2007). Typical formulas for composting include the following:

i. Mulberry branch sawdust 100% (Li et al. 2012);

ii. Rice straw 50%, rice husk 50% (Chen et al. 2010);
iii. Rice husk 49%, wood sawdust 49%, gypsum 1%, phosphate 1% (Jiang et al. 2017); and
iv. Spent mushroom substrate 40%, rice husk powder 18%, wood sawdust 20%, cottonseed hull 10%, wheat bran 10%, gypsum 1%, sugar 1% (Jiang et al. 2017).

Before the composting process, all agricultural waste should be ground into pieces approximately 1–3 cm in diameter. Next, agricultural waste should be soaked until reaching adequate water absorption before draining surplus water. Then, agricultural wastes are mixed and placed in a compost heap, with the dimensions of the compost heap ranging from 1.5m in width, 1.5m in height and the length is determined by the total amount of compost. After building the heap, the temperature of the heap will increase to 60–70°C between the third to fifth day. The compost should be first turned on the eighth day, the second turning should be conducted on the eleventh day and the third and fourth turnings should be conducted on the fourteenth and seventeenth days, respectively, before the compost enters phase II–the pasteurization stage. In this stage, the compost is turned every three days, and after 26 days it is ready for use in cultivation. The optimal water content of compost is 65–75% (Wan & Bau 2005). The composting process is briefly summarized in Table 2. The process of composting for the cultivation of *S. rugosoannulata* is similar to *Agaricus subrufescens* (Wisitrassameewong et al. 2012).

Table 2. Composting process in the cultivation of *Stropharia rugosoannulata*.

Calendar	Work content	Compost phase
-	Gather the ground (1–3 cm) raw materials	Preparation
Day 0	Wet the raw materials until adequate water absorption	Temperature increase
Day 1	Mix the compost and build the heap	Composting begins
Day 8	Turn the compost	Phase I
Day 11	Turn the compost	Phase I
Day 14	Turn the compost	Phase I
Day 17	Turn the compost	Phase I ends; phase II begins
Day 20	Turn the compost	Phase II
Day 23	Turn the compost	Phase II
Day 26	Spread and cool the compost in the field	Ready to use for cultivation

Cultivation process

The best sites for the field cultivation of *S. rugosoannulata* are vacant lands, orchards or plantations; the optimal temperature for mushroom growing ranges between 20–30°C; and the cultivation site should be close to a water source, with good drainage, fertile soil, shelter and protection from strong wind. Beforehand, weeds must be removed, and soil must be flattened. Then, drainages ditches should be dug and land beds arranged using a grid width of 0.8–1.2 meters. Finally, quicklime should be spread on the bed and drainage ditches before beginning spawn inoculation (Bao 2015).

During the inoculation process, a 10-cm-thick first layer of compost should be spread on the bed. Then, the spawn should be inoculated by the dibbling method before spreading one more layer of compost on the bed after both applications. The total compost will be approximately 20–35cm thick with 2–3 layers, and a casing soil layer around 2–5 cm thick will cover the bed. Finally, spreading one layer of quicklime on the casing soil is needed to prevent contamination and provide insect repellant (She et al. 2007). The amounts of compost and spawn should range between 20–25 kg/m^2 (dry weight) with 5% spawn (w/w) (Tian et al. 2002, Yan & Jiang 2005). The illustration of *S. rugosoannulata* cultivation in field conditions is shown in Fig. 2.

Management

The best temperature range for the mycelial growth of *S. rugosoannulata* in compost is 23–27°C; the humidity for compost should be around 70–75%; and the ideal humidity is 90–95% when entering the fruiting stage (Wan & Bau 2005). Water content and humidity should be maintained through watering the growing lands. Light control in the fields is conducted via black sunshade plastic nets with over 80% shading coverage or rice straw with over 90% shading coverage. In practice, it is also possible to place rice straw on the land surface or hang 2 m above the soil via a sunshade net (Gong et al. 2016). Yellow luring boards are often used for insect control, such as diptera and lepidoptera in fields cultivating *S. rugosoannulata* (Zhu 2018).

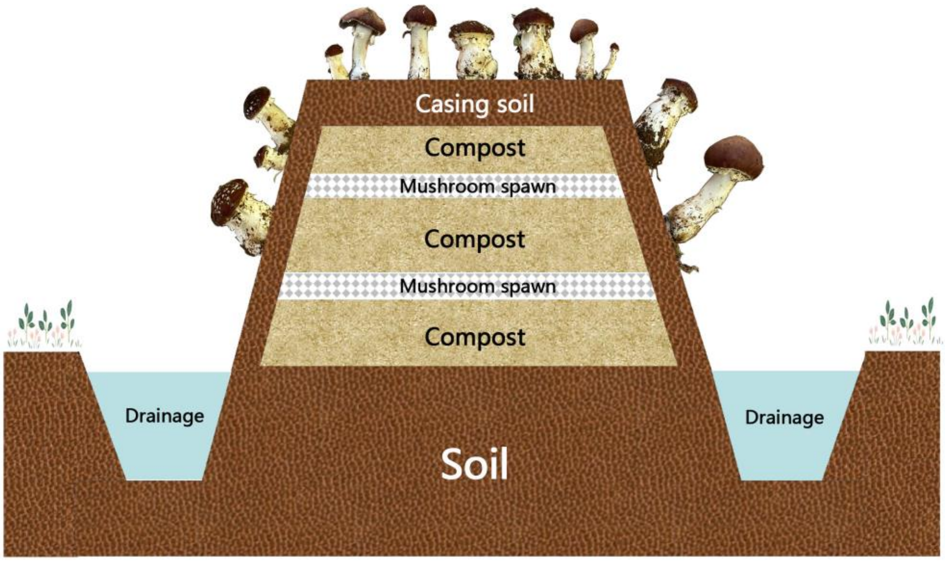

Fig. 2 – Profile of *Stropharia rugosoannulata* cultivation in the field. Three layers of compost and two layers of mushroom spawn are incubated. Drainage can help bolster and maintain humidity in the system.

Harvest and yield

After 30–60 days, the first flush of the harvest will appear. Mushroom collection should be done carefully to avoid disturbing the compost and casing soil. After each harvest, the soil remaining at the surface of mushrooms should be cleaned by using a sharp knife and tissue paper. The products should be sold or processed as soon as possible, using techniques like salt processing with a 40% saturated salt solution or drying in an oven (Wan & Bau 2005). A total of 3–4 mushroom flushes over 3–4 months can be conducted throughout the cultivation process. Chen et al. (2010) reported 81.74% biological efficiency when using rice straw 50% and rice husk 50% as compost formula, which is higher than rice straw 100% (biological efficiency 44.04%) and rice husk 100% (biological efficiency 56.72%). Gong et al. (2016) reported a yield of 5.325 kg/m^2 using 50% rice husk, 30% corn cobs and 20% sawdust as the compost formula. Bao (2015) reported the optimal formula is sawdust 68.2%, wheat straw 20.3%, and corn cobs 11.5%, which yielded 4.71 kg/m^2. Zhang et al. (2017) reported a yield of 6.98 kg/m^2 and biological efficiency of 52.3% using spent mushroom substrate 40%, corn cobs 25%, soybean straw 25%, rice bran 8% and calcium oxide 2% as the compost formula.

Agroforestry circular economy

Cultivation of *S. rugosoannulata* mushroom has become a standard forest-farming practice in agroforestry. This mushroom is produced on lignocellulosic materials such as wood sawdust, cereal straw and seed husk, and low-quality agricultural waste can be converted into high-quality food (Bruhn et al. 2010, Hu & Zhang 2013). Spent mushroom substrates left over after harvesting basidiomes contain a high level of organic matter, nitrogen, phosphorus, potassium and other nutrients, which are byproducts of edible mushroom cultivation. Spent mushroom substrates obtained after mushroom cultivation are thus reused as a resource for other agricultural products, such as fertilizer for seedling growth, animal feed and the growing substrate of other mushroom species (Hyde et al. 2019, Meyer et al. 2020). The outdoor cultivation of *S. rugosoannulata* allows for its agricultural production to be more efficient and sustainable. Duan et al. (2018) conducted *S. rugosoannulata* undergrowth cultivation across eight different forest types in Kunming, China, and results showed a significant correlation between mushroom yield and forest canopy. Thus, *S. rugosoannulata* cultivation benefits agro-food production, and at the same time, growing mushrooms under planted forests such as apple trees (*Malus* Mill), waxberry (*Myrica* L.) and walnut trees (*Juglans regia* L.) increases fruit and biomass yield in artificial forest ecosystems, bolstering economic and ecological benefits. Cultivation of *S. rugosoannulata* has become a staple practice in agroforestry, and there is now a range of applications for *S. rugosoannulata* mushrooms (Bruhn et al. 2010). Two programs run in Honghe and Luliang County, Yunnan Province, China (Fig. 3) assisted local farmers with the cultivation of *S. rugosoannulata*, planting it with passion fruit (*Passiflora edulia*) and intercropping with lettuce (*Lactuca sativa*). The spent mushroom substrates did not produce more mushroom basidiomes while still containing abundant nutrient elements (Gong et al. 2018) that were usable as organic fertilizer for passion fruit and lettuce production. At the same time, the branches and stems of plants can be used as raw materials for compost in the mushroom cultivation process, forming a circular economy.

Fig. 3 – Cultivation of *Stropharia rugosoannulata*. a, intercropping *S. rugosoannulata* with Lettuce (*Lactuca sativa*), b, incorporating *S. rugosoannulata* with Passion fruit (*Passiflora edulia*), c, grading of fruiting bodies of *S. rugosoannulata*. Arrow: location of cultivation. Scale bar: 15cm. Photo credit: Hu Y and Zhu J.

Soil amender and mycoremediation

During the cultivation of *S. rugosoannulata*, growing substrates cannot be fully utilized by mycelia and transferred to mushroom products. Spent mushroom substrates contain abundant hemicelluloses, cellulose, ash, carbohydrates, protein, calcium, phosphorus potassium and other elements that can improve soil quality in various ways, such as *in situ* composting and functioning as a soil amender in agricultural, horticulture and animal husbandry fields (Hanafi et al. 2018). Duan et al. (2019) experimented with the cultivation of *S. rugosoannulata* in an under-forest (*Cunninghamia lanceolata – Pinus armandii*), and results indicated that mushroom cultivation increases soil porosity, organic matter content, hydrolytic nitrogen, available phosphorus and available potassium. Gong et al. (2018) also conducted cultivation experiments of *S. rugosoannulata*. They tested the soil quality and bacterial communities among different farming regimes, with the results showing positive effects on soil physicochemical properties, suggesting that one-year-interval cultivation regimes are potentially the most appropriate system for forest soils. Overall, it is feasible to cultivate *S. rugosoannulata* with a fitting agricultural regimen for soil improvement in food production landscapes.

Since *S. rugosoannulata* can be cultivated in outdoor fields, this saprobic mushroom is a promising candidate for soil bioremediation. *Stropharia rugosoannulata* has been studied concerning the degradation of pollutants in different environments. Anasonye et al. (2015) showed the potential of *S. rugosoannulata* for degrading 2,4,6-trinitrotoluene (TNT) in soils, a toxic and possible human carcinogen, and the activity of manganese peroxidase and laccase were both detected in the soil. Steffen et al. (2007) and Pozdnyakova et al. (2018) reported that *S.*

rugosoannulata can degrade polycyclic aromatic hydrocarbons (PAHs), a large group of organic compounds containing two or more aromatic rings with toxic, mutagenic and carcinogenic properties. PAHs were converted into low molecular compounds with non-toxic or hypotoxic soil by *S. rugosoannulata*. Valentín et al. (2013) and Anasonye et al. (2014) investigated the potential of fungal mycelia to degrade chlorinated phenols, dibenzo-*p*-dioxins and furans on wood and soil in sawmill areas. *Stropharia rugosoannulata* shows 13–73% degradation and mineralization of pollutants and proved to be a suitable fungus for soil mycoremediation. In addition to soils, *S. rugosoannulata* also show promising biodegradation ability in contaminated waters: one study (Castellet-Rovira et al. 2018) showed the fungus reaching over 70% degradation for carbamazepine, a type of pharmaceutically active compound found in contaminated water. In addition, Luo et al. (2006) found *S. rugosoannulata* produces unique spiny cells called acanthocytes, which immobilize and digest the nematode *Panagrellus redivivus* in soils. Thus, *S. rugosoannulata* is a promising candidate for bioattenuation and bioremediation processes.

Conclusion and perspectives

This study reviewed the potential uses of the edible mushroom species *S. rugosoannulata* as a nutritional food resource as well as its bioactive compounds, cultivation, agroforestry circular economy and applications in mycoremediation. *Stropharia rugosoannulata* contains abundant nutrients and bioactive compounds in mycelium and basidiomes, allowing it to function as an outstanding source of nutrients with significant pharmaceutical value. Cultivation of this mushroom could be exploited to remediate soils and waters while simultaneously increasing grower incomes through the development of a circular economy.

Agricultural cropping systems that incorporate *S. rugosoannulata* tend to feature increased primary productivity and crop diversity of certain agricultural land types, enhancing the efficiency of reusable agricultural wastes. In the future, researchers should explore the myriad important roles this mushroom could play in sustainable cropping systems, particularly as farmers increasingly recognize its value as a promising component of modern agricultural practices.

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