Eliminating Extreme Poverty through Forest-Fungi Agroforestry System in Rural Asia

—Good practice and lessons learned from a small-grant project under SSDC Project

By Dr. SU Yufang, Deputy Director

Centre for Mountain Futures, Kunming Institute of Botany, Chinese Academy of Sciences

March 2020

Contents

Preface 3

1. Background 5

1.1 Global South-South Development Center Project 5

1.2 Centre for Mountain Futures (CMF) 5

1.3 Opportunities of Mushrooms 6

2. Review of the Small-grant Project under SSDC 8

3. Detailed Introduction to the Small-grant Project under SSDC 9

3.1 Field trip and mushroom cultivation investigation in India 10

3.2 Assessment of mushroom production and field trip in Nepal 15

3.3 History of mycological work and role of mushroom in Myanmar 21

3.4 Training programme on the selected mushrooms cultivation in Kunming 23

4. Conclusion 33

5. Follow-up works 35

6. Recommendations 36

Eliminating Extreme Poverty through Forest-Fungi Agroforestry System in Rural Asia

—Good practices and lessons learned from a small-grant SSDC Project

Preface

China's success in poverty reduction has attracted worldwide attention. In 1982, China launched the "Sanxi Program" in the poorest regions of Gansu and Ningxia, marking the beginning of planned, organized and large-scale poverty alleviation efforts nationwide. In 1986, the government established the State Council Leading Group Office on Poverty Alleviation and Development, identified poor counties, set a national poverty line, and created special funds for poverty alleviation. In 1994, China launched the Seven-Year Priority Poverty Alleviation Program that was designed to lift 80 million people out of absolute poverty within seven years from 1994 to 2000. From 2001 to 2011, two ten-year poverty alleviation programs were launched to continue the war against poverty.[1] Since 2012, China has adopted targeted poverty alleviation methods, focusing on poverty-stricken areas and continuously increasing investment and scope. The income of rural residents in impoverished areas continues to grow rapidly, narrowing the gap between rural and urban residents.

China has contributed more than any other country to global poverty reduction. In the past 40 years, China has pulled 754 million people out of poverty, a figure surpassing the total population of Europe, which was 741 million in 2016. If China achieves its 2020 goal, it would be 10 years ahead of the United Nations Sustainable Development Goals' target of ending global poverty by 2030. China was also the first developing country to meet the UN's Millennium Development Goals (MDGs) target of reducing the population living in poverty by half ahead of the 2015 deadline.

China's poverty alleviation work and achievements offered valuable experiences for the global fight against impoverishment. "Targeted poverty reduction strategies are the only way to reach those farthest behind and achieve the ambitious targets set out in the 2030 Agenda for Sustainable Development," United Nations Secretary-General Antonio Guterres said in a greeting letter to the 2017 Global Poverty Reduction and

[1] World Bank: Ending poverty in China: Lessons for other countries and the challenges still ahead (https://blogs.worldbank.org/eastasiapacific/ending-poverty-in-china-lessons-for-other-countries-and-challenges-still-ahead)

Development Forum. "China has lifted hundreds of millions of people out of poverty, and its experiences can provide valuable lessons to other developing countries."[2]

The Global South-South Development Center Project, jointly initiated by China International Center for Economic and Technical Exchanges and the UN Office for South-South Cooperation, aims to make due contributions at the project level in international poverty reduction cooperation. This sector-specific analysis is documented in a small-grant project under the South-South Development Center Project. Since its establishment, the South-South Development Center Project has promoted economic and technical exchanges among developing countries through training, workshops and small-grants projects. To date, there have been 21 small-grant projects under SSDC, covering various thematic areas including agriculture, forestry, new energy, environmental protection, industrial development, etc. These projects have benefitted more than 30 developing countries. During the implementation of the small-grant projects, parallel funding channeled through PPP reached 1.6 times the amount of the core funds. Partners and participating institutions from developing countries, including China, were provided accesses to technologies, equipment, facilities, and opportunities to gain knowledge and develop. It is thus a situation of mutual benefit.

[2] CGTN: Ending China's poverty by 2020 (https://news.cgtn.com/news/2019-10-17/Graphics-Ending-China-s-poverty-by-2020-KREfWKGkIU/index.html)

1. Background

1.1 Global South-South Development Center Project

In 2008, the China International Center for Economic and Technical Exchanges (CICETE) and UNOSSC jointly launched the China South-South Development Center Project (China SSDC). The China SSDC aimed to facilitate systematic sharing of Chinese expertise and knowledge on South-South Cooperation with other developing countries and consolidate resources and mobilize partnerships within China in a coordinated manner. The China SSDC project (2008-2018) concluded with a comprehensive independent evaluation indicating that the project was well aligned with the principles of South-South Cooperation; represented good value for money/resource allocation; comprehended strong management arrangements; positively impacted beneficiaries; had high prospects for sustainability; and addressed cross-cutting issues such as gender equality and the environment.

Building on the success of China SSDC, the Government of China has committed its continued institutional and financial support to UNOSSC in the second phase (2019-2023) entitled Global South-South Development Center Project (Global SSDC). CICETE will continue to serve as the national implementing partner in China and host of the Project Office for Global SSDC.

The Global SSDC will:

- place greater emphasis on two-way sharing of knowledge and expertise for mutual learning between China and other countries;
- align Global SSDC's support with the UN SDGs, and other global development frameworks;
- expand the existing network beyond China and reposition itself as a true global network of centers of excellence for SSC; and
- provide advocacy and advisory support and conduct sector-specific research and analysis to inform global policy discourse for SSC.

Going forward, the Global SSDC project will, as always, position itself as a platform and global knowledge hub for South-South cooperation to make contributions to the UN Sustainable Development Goals.

1.2 Centre for Mountain Futures (CMF)

Established in 2004, the Centre for Mountain Futures (CMF), formerly known as the Centre for Mountain Ecosystem Studies (CMES), is an applied research centre jointly established by the Chinese Academy of Sciences and World Agroforestry (ICRAF)，hosted by the Kunming Institute of Botany. Its work involves leveraging large-scale field research to develop innovative solutions to ecological and social problems facing mountains and their communities as well as the equitable distribution of scientific knowledge to enhance sustainable livelihoods in ecologically vibrant landscapes.

Based out of Southwest China for the last 15 years, work at CMF has primarily focused on the mountains of Asia and highlands of East Africa, with particular focus on undertaking cutting-edge germplasm and agroforestry research. With an eye to interdisciplinary collaboration, the professors at CMF have trained dozens of scientific pioneers in agrarian mountain systems, spanning fields as diverse as molecular biology, soil biology, ethnobotany, restoration ecology and eco-industrial development. They also provide scientific and technological advisory for the sustainable development of mountain communities across China.

In 2016, with support from the United Nations Academy of Sciences, Chinese Academy of Agricultural Sciences, UNESCO, UNEP and other institutions, CMF proposed the "Mountain Futures Initiative" platform to facilitate intercultural knowledge exchange, improve food security and enable smart farming. In 2017, CMF and the Honghe County Government of Yunnan Province broke ground on the Honghe Innovation Centre for Mountain Futures, starting construction in 2019. The Centre will serve as a repository for woody germplasm resources, demonstrate the efficacy of composite agroforestry systems and build a circular system that integrates agronomy, forestry and animal husbandry while promoting the important role biomass recycling plays in ecological systems. Additionally, the Centre will function as a station for monitoring montane agricultural ecosystems, such as the Honghe Hani rice terraces UNESCO cultural landscape and offer critical training to scientists and policymakers. Its ultimate goal is to facilitate the development of a shared global vision for mountain communities.

At present, the team is composed of over 50 employees and students, 2 "Highly Cited Researchers", 5 professors, 2 associate professors, and 15 young postdoctoral scientists. They publish over 50 SCI papers annually. The Centre has trained more than 35 PhD students in tandem with the "Belt and Road" policy. Over the past decade, they have published over 500 SCI papers.

1.3 Opportunities of Mushrooms

Mushrooms are an excellent source of food and medicine for humans, rich in proteins, fiber, vitamin B-complex, essential amino acids and medicinal compounds such as antioxidants and immune system boosters. Current researches indicate more than 3000 species of edible mushrooms exist, emphasizing the wide variety and availability of mushrooms for consumption. This diversity coupled with the nutritional and health properties make mushrooms an ideal food source for rural communities, as they can be cultivated in a sustainable, low cost fashion, or simply harvested from the wild without additional costs. Cultivation can make use of agricultural waste products, bolstering to the sustainability of the production line, and the spent substrates from which mushrooms grow can in turn be used to fertilize crop plants, closing the production cycle.

Globally, there has been a marked increase in the consumption of mushrooms, resulting in a growing demand for both wild and cultivated mushroom species.

Research over the past three decades has shown the importance of mushrooms as a food group, providing excellent nutrition and contributing towards improved immune systems. As such, the cultivation of mushrooms is becoming popular as a means of rural development, providing alternative, sustainable sources of income and household nutrition for rural and impoverished communities.

In 2018, global mushroom consumption was reported as 12.74 million tons, of which 80% were consumed in Asia, and it is predicted to reach 20.84 million tons by 2026[3]. This suggests great potential for its utilization in rural Asia. There have been a number of projects focused on training farmers to grow mushrooms for household nutrition and income generation, especially in regions characterized by low income households and areas with low agricultural productivity and difficult market access. Mushroom growing and processing may allow farmers to overcome these constraints. Mushroom growing requires little time each day, enabling farmers to continue other agricultural or household duties at the same time, allowing mushroom cultivation programs to run in parallel with other production processes.

Research into mushroom cultivation has boomed as the industry has grown, leading to new techniques for producing quality cultures, spawn, substrates and mushroom fruiting, as well as research into the domestication and hybridization of mushroom species. Traits are sought after, selected and bred into new lines, such as traits that encourage higher levels of nutrition, broader tolerance to climate variables and higher consistent yields over the course of the growing season. All of these traits lead to more robust production lines and a healthier end product. Much of this research is focused towards large-scale production systems, but there is a natural flow of knowledge and practice allowing for improvements to be seen in rural, small-scale production lines as well (Chang 2006).

Globally, billions of people depend to varying degrees on trees for their food security and nutrition. Agroforestry, or the use of trees in agriculture, is a traditional farming practice in Asian countries. The modern trend of moving towards commercial mono-cultures has meant that fewer resources and less attention has been paid to this indigenous system. However, efforts to use modern scientific research to revitalize traditional agroforestry have demonstrated the benefits of planting multipurpose trees together with other economically important crops. Therefore, adding seasonal and annual harvests available from the first year could be a vital boost to the viability of agroforestry systems. This is possible through the integration of agroforestry with mushroom cultivation.

The practices and experiences of mushroom production in China and other countries like Uganda (Ibrahim Mayanja, Tolga Tipi, 2017) have shown that mushroom production is more suitable for women, as it entails less intensive labor, and may thus

[3] https://www.fortunebusinessinsights.com/industry-reports/mushroom-market-100197.

serve as a tool for feminine economic empowerment. The developed technologies not only could increase farmers/women's livelihoods in China, but also could be applied throughout other countries. The projects have demonstrated the numerous positive impacts on gender equality and the importance of gender-inclusive vocational training. Supporting local women to cultivate mushrooms by providing materials, training and extension services would be essential to achieve these goals.

2. Review of the Small-grant Project under SSDC

In 2018, Nepal, India and Honghe County of China expressed interest in developing forest-fungi agroforestry systems. In June 2018, following preliminary research and consultations, CMF implemented a six-month small-grant project, entitled "Training stakeholders in Forest-Fungi System Agroforestry in Nepal, India and China", under the SSDC Project framework.

India: Jorhat district in Assam, India has been selected as the project site. Over one million people live in this district. Agriculture is the major occupation, and more than 130 tea gardens form the backbone of the local economy. Rising temperatures mean that tea gardens in this area are already experiencing problems, including declining yields. Several gardens have planted trees to provide shade to the tea plants, but farmers otherwise derive no significant economic benefits from the trees. Smallholder farmers and workers, especially women and children, need small-scale economic opportunities to increase access to adequately nutritious food and living standards.

Nepal: Kathmandu Valley is the main center of mushroom cultivation in Nepal. There are over 6000 registered mushroom farmers in Kathmandu and many other small holder mushroom farmers. Mushroom are gaining popularity in Nepal as nutritional supplement and medicine. However, cultivation is limited to three species of mushrooms because gaps in technology and quality spawn. Historically, several mushroom types collected from forests were consumed in Nepal, but recently wild mushrooms have not been collected as before. New cultivation techniques for such a wide range of edible mushroom is necessary and providing training to community-forest groups in Nepal could be beneficial for forest-fungi systems.

China: Honghe County is located in the south of Yunnan Province, and features mountainous terrain that accounts for 96% of its total land area (2028.5 square kilometers); it is also a remote region in which ethnic minorities comprise 96.2% of the total population, including Hani, Yi, Dai and Yao; and it is also a national-level impoverished county home to 80,000 impoverished citizens who fall below the national poverty line of 3535 yuan/year/capita out of approximately 340,000 in 2018.[4] The area has been widely deforested, and local communities lack viable livelihood

[4] http://www.hhx.hh.gov.cn/hhgk/xqjj/201708/t20170807_47651.html

options. Tackling local poverty therefore requires solutions which can be applied to a degraded landscape and provide secure local incomes.

The project aims to identify sites and provide training to agro-technician and community forestry members, who in-turn will focus on providing training to farmers in their community on the following: mushroom cultivation and dry-fruit processing of *Choerospodias axillaris* in Honghe; edible mushroom cultivation and seed production techniques in tea gardens and backyards in Jorhat; and economic mushroom cultivation, drying and seed production technique in Godavari.

During the project, representatives from India and Nepal visited the Honghe site, where training on various mushroom cultivation technique was provided and Nepalese partners shared their experience working with the *Choerospondias* tree in agroforestry, representing an instance of reciprocal learning.

The project was particularly appreciated by the participants from different countries, as it provided new knowledge, skills and income-earning opportunities. The trained participants mentioned that the practical sessions, such as identification of wild mushrooms and mushroom cultivation techniques were quite interesting and useful, and it has been observed that women participants were more enthusiastic than men. Some of the participants started to build their own mushroom farms with only basic facilities.

3. Detailed Introduction to the Small-grant Project under SSDC

With support from the SSDC Project and other projects, CMF scientists have conducted need assessment of partner countries and provided targeted training workshops for the promotion of officers and/or community forest members on high-value mushroom growing technologies, with an aim to disseminate knowledge to farmers in their respective communities. Community members and farmers in the villages affiliated with those attending the training workshop in Kunming are direct beneficiaries. The cultivation and management techniques developed by CMF scientists may also spread to other villages in Nepal, India, and Myanmar through interconnected farmer networks. The transfer of knowledge regarding the cultivation, collection, seed production, drying and storage of valuable and edible mushrooms such as morels (Morchella) can directly provide extra income opportunities for farming communities in the project areas.

To this end, CMF has developed a unique agroforestry system where various medicinal plants and mushrooms are successfully grown with multipurpose trees. This technique is truly a climate-smart practice and it can be utilized to enhance rural livelihoods. The Chinese government recently launched its Rural Revitalization Strategy, which is making major investments with the aim of improving the livelihoods of rural communities, including Honghe County. These investments operate through various

programs, of which agroforestry system development is one of the most highly-regarded.

CMF has started to cultivate edible mushrooms and build a platform for industry, training and research in Honghe together with the local government, companies and communities since 2017. This collaboration has been possible due to the technical expertise CMF holds in the research and development of new wild edible fungi species, the breeding of high-quality fungi species and industrial-scale cultivation. It thereby integrates the rich fungal diversity, pristine geographical environments, and strong work ethic of mountain communities in Honghe County toward this goal. It now has seven high-quality product offerings that include *Morchella* (morels), *Ganoderma* (lingzhi) and *Hymenopellis raphanipes* (black Termite mushrooms) etc. The introduction of similar mushroom cultivation practices along with agroforestry systems are applicable to India, Nepal, Myanmar and other countries.

Figure 1. Mushroom training with ethnic minorities in Honghe County

Mushroom consumption in China is both high and increasing year-on-year, and global mushroom consumption patterns present excellent opportunities to farmers and NGOs in developing nations to lift communities out of poverty through the sustainable and environmentally friendly cultivation of certain economically viable mushroom species. Please see more detailed activities and baseline studies below.

3.1 Field trip and mushroom cultivation investigation in India

In order to understand the current situation of mushroom cultivation and research in India, the team from the Centre for Mountain Futures (CMF), led by Prof. Peter Mortimer and assisted by Asanka Bandara, visited NE India. Facilitated by the Balipara Foundation, Peter Mortimer, Asanka Bandara and Gautum Baruah visited a number of sites in Assam, Nagaland, and Meghalaya to assess the current status, challenges, and practices of mushroom cultivation in the region. This knowledge will help guide any future endeavors to further improve and develop the mushroom industry in the

region by providing technical support, quality materials and assistance in market development.

Table 1: Itinerary for the India trip

Date	Venue	Tasks
20.08.2018	Balipara, Tezpur, Assam	Arrive to Wild Mahseer
21.08.2018	Tarajan, Jorhat, Assam	Visited to Dr. A. K. Bordoloi's mushroom farm
22.08.2018	Jalukie, Peren, Nagaland	Visited to community-owned mushroom farms
24.08.2018	Umiam, Meghalaya	Presentations done in Central Agricultural University
24.08.2018	Umiam, Meghalaya	Visited to a mushroom farm
25.08.2018	Mawphlang, Shillong, Meghalaya	Collecting visit to the forest in Mawphlang
25.08.2018	Nongwah, Tyrsad, Meghalaya	Visited to a household mushroom cultivation
25.08.2018	Jakrem, Mawkyrwat, Meghalaya	Talk with a local woman who collected wild edible mushrooms
26.08.2018	Guwahati, Assam	Returned to Guwahati

Visit Balipara Foundation and Botanic Ark

The team spent a part of the first morning walking the campus of Balipara Foundation, mostly discussing the program with Prabir. However, in the course of our walk and discussions we found 3 species of mushroom (*Ganoderma*, *Auricularia*, and *Tremella*) which have market potential and are easily cultivated. This was a good sign that the local environment is conducive to growing mushrooms.

Visit to Dr. A. K. Bordoloi's mushroom farm at Jorhat, Assam

Dr. A. K. Bordoloi, a mycologist, runs a small-scale mushroom enterprise with his own lab set-up for producing *Pleurotus ostreatus* spawn. Spawn are distributed among the local people, who then cultivate and sell the mushrooms back to Dr Bordoloi. Mushrooms are packed in plastic bags as dried or as pickled products and are sold in local markets. Currently Dr. Bordoloi has conducted more than 500 trainings on mushroom cultivation, with an existing network of around 200 growers.

Species : *Pleurotus ostreatus* (Oyster mushroom, resistant variety)
Method : Bag cultivation
Main substrate used : Rice straw
Weight of the substrate : 7 kg of damp rice straw per bag
Sterilization capacity : 4 bags at a time (around 80 bags per month)
Yield : 1 - 2 kg of fresh mushrooms per bag

Harvesting period : 3 months maximum harvesting time
Income : Rs. 8000 - 9000/month

Figure 2. *Pleurotus ostreatus* cultivation in Bordoloi's mushroom farm a. Laminar air flow, b. Laboratory, c. Incubator, d. Spawn inoculated bags in incubation room, e & f. Mushroom growing house, g. Dried and pickled products of mushrooms.

Visit to community-owned mushroom farms in Jalukie, Nagaland

The Rongmei Baptist Association of Nagaland in Jalukie village has been cultivating *Pleurotus ostreatus* as well as supporting local women to cultivate mushrooms by providing materials and training. These women have been working as teams, and each woman has her own growing house containing 500 mushroom bags. They are selling fresh mushrooms in the village markets and they have great interest in cultivating other species. A major challenge for this group is securing a steady supply of spawn, low quality spawn and quality control for mushroom growing. A small degree of extension work would make a big difference to the quality and yields of the mushroom growers we visited in this area.

Species : *Pleurotus ostreatus* (Oyster mushroom)
Method : Bag cultivation
Main substrate used : Sawdust
Weight of the substrate : 1 kg of wet sawdust per bag
Sterilization capacity : 145 - 150 bags at a time
Yield : 3 - 3.5 kg of fresh mushrooms per bag

Harvesting period : 6 - 8 months (after 30 - 45 days incubation period)
Income : Rs. 5000 - 7000/month

Figure 3. Community-owned *Pleurotus ostreatus* cultivation in Jalukie a & b. Mushroom growing houses, c, d & e. Mushroom bags on bamboo racks, f. bags with yellow color mycelium, g. insect attacked fruiting body.

Visit Central Agricultural University and mushroom cultivation demonstration farm, Umiam, Meghalaya

We met with Dr Shwarmi and colleagues at the Central Agricultural University to discuss their program for growing mushrooms and meet local farmers who were currently cultivating mushrooms. The meeting at the university was useful in order to see what is being done at a more academic level, the types of research they are conducting, and the level of training their students receive. Basic cultivation is taught to undergraduate students, so most students have some knowledge about cultivation.

We were taken to a farm where a local farmer was cultivating *Pleurotus ostreatus*, a very nice demonstration of village-level cultivation, with potential for high production. The farmer said his biggest challenge was spawn supply and quality (spawn supplied by the Indian Council for Agricultural Research - ICAR). The farmer also expressed interest in learning how to make his own spawn and supply this to other growers in the area.

Figure 4. Mushroom production facilities at Central Agricultural university, Umiam, Meghalya (a,c); and grow room and grow bags on local farm (b,d) production done with support of the university and ICAR.

Visit to a household mushroom cultivation Nongwah, Meghalaya

A group of households have been cultivating *Pleurotus eryngii* in Nongwah village (higher elevation, cooler conditions). We were able to visit the production facilities of two women from this village to learn more about their techniques and challenges. They are following the simplest cultivation technique for producing mushrooms, boiling straw substrate, placing them in large bags and allowing colonization to take place in the bags. Once colonized, straw substrate is kept in a dark room and watered regularly. The temperature required for fruiting body development of *P. eryngii* is relatively lower (< 20 °C) than the *P. ostreatus,* and therefore, the climate in Nongwah is ideal for cultivating *P. eryngii*. The ladies we spoke with are interested in getting different strains and species to grow, and expressed that the lack of spawn quality was affecting production.

Species	: *Pleurotus eryngii* (King oyster mushroom)
Method	: Bag cultivation
Main substrate used	: Rice straw
Weight of the substrate	:10 - 15 kg of damp rice straw per bag
Sterilization capacity	: Boil rice straw 30 minutes in water
Yield	: 3 - 3.5 kg of fresh mushrooms per bag

Harvesting period : 1 month
Income : Rs. 200 per 1 kg

Figure 5. *Pleurotus eryngii* cultivation in Nongwah a. Mushroom growing house b. Fruiting bodies on rice straw bales.

3.2 Assessment of mushroom production and field trip in Nepal

There are a number of ongoing programs in South Asia currently implementing training and demonstration practices for the cultivation of mushrooms at the village level that include developing tree-fungi agroforestry systems. In order to understand the current status, challenges, and practices of mushroom cultivation in Nepal, the project team has done some research.

Status of mushroom in Nepal

Adhikari (2000) documented 26 species of edible mushrooms at markets in Kathmandu, whereas it is estimated that more than 50 species of wild edible fungi are commonly used and sold on markets in Nepal (Christensen and Larsen, 2005). Adhikari (2000) listed the more than 110 wild edible mushrooms, which potentially could be used for food supply in rural areas. Further investigation on Nepalese mycoflora will probably lead to an increase in that number. Collection from wild and consumption of fungi are often restricted to disadvantaged people and certain ethnic groups in Nepal. However, in mountain areas (Mustang, Jumla, etc.) collection and consumption of fungi seem to be much more accepted by a broader group of people (Adhikari, 2000; Christensen and Larsen, 2005).

Mushroom cultivation was initiated by the Division of Plant Pathology, Nepal Agricultural Research Council (NARC) in 1974. The growing technology for white button mushroom (*Agaricus bisporus*) was developed during that early period and extended to general farmers starting in 1977.

Mushroom cultivation is a relatively new concept in Nepal. Nepal Agriculture Research Council (NARC) introduced mushroom cultivation in 1974, and successful cultivation in commercial scale beginning in 1977 with the ‘white button mushroom’. Afterward, the Plant Pathology division of the NARC started distributing spawn. Next, the Oyster

mushroom was introduced to farmers in 1984, which were farmed by only a handful farmers in Bhaktapur and Kathmandu districts of central Nepal.

Mushroom production and market in Nepal

A few decades ago, wild mushrooms were collected during a particular season and sold in town areas. Mushrooms are accepted (for eating) socially and culturally by certain ethnic groups only. The scenario has been changed nowadays, as people are becoming aware of the health benefits of mushrooms, and consumption is increasing. Mushroom farming is gaining popularity among Nepalese farmers. According to the Ministry of Agricultural Development, in 2016, there were over 6000 registered mushroom farmers in Kathmandu producing over 10000 kg a day on average. Other major mushroom producers are located in the Pokhara and Chitwan town areas. These areas are major markets in Nepal for fresh mushroom. Official data on production and marketing of mushrooms outside Kathmandu is not well documented. Dry mushroom is still rare in the Nepalese market, because of lack of proper technology.

Different non-governmental organizations as well as government organizations conduct farmer training programs to teach organic farming techniques. Recently, even

Figure 6. Mushroom cultivation and preparing for local market in Nepal

at the ward level (the lowest governing body that operates in the part of a town or village), such training is conducted. Farmers can cultivate different mushroom varieties, like Shitake, oyster and red mushroom, in natural environments. Farmer training programs are designed to provide knowledge of farm management and organic production, focusing on diversified agricultural products and livestock that include mushroom cultivation for local markets and the international market for organic farming training programs.

Five species of mushroom are widely cultivated at a commercial scale in Nepal, which are listed below:

1. White button mushroom (*Agaricus bisporus*)
2. Oyster mushroom (*Pleurotus ostreatus*)
3. Shiitake (*Lentinula edodes*)
4. Straw mushroom (*Volvariella volvacea*)

5. Red *Ganoderma* mushroom (*Ganoderma lucidum*)

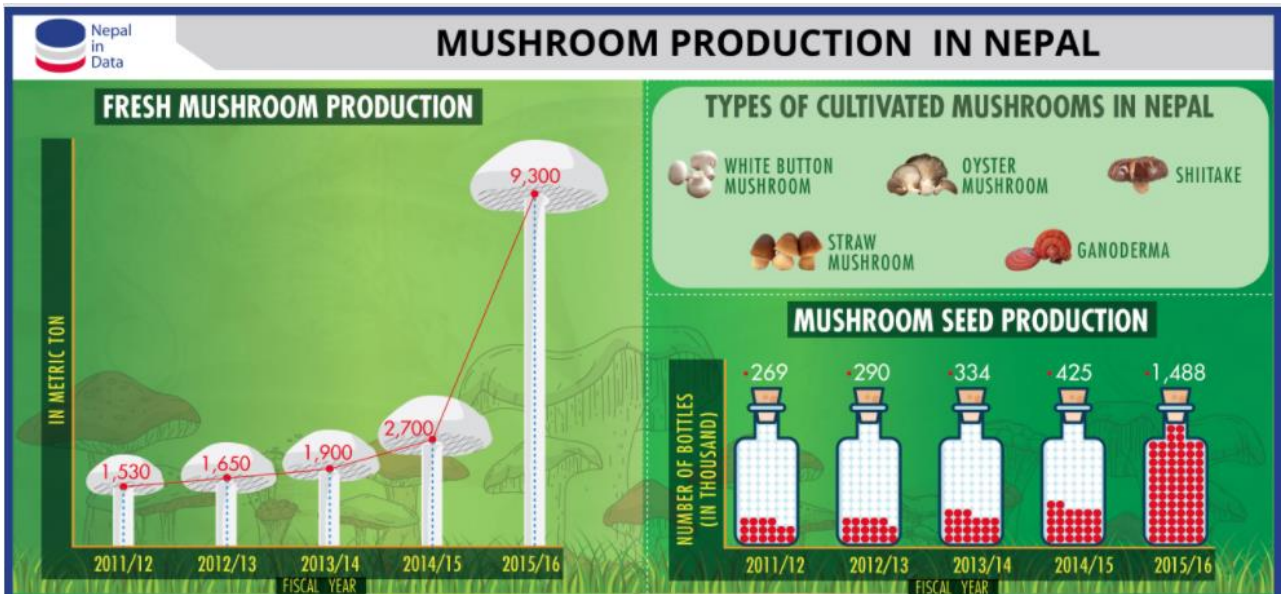

Figure 7. Mushroom production in Nepal

Among them, white button mushroom is the most popular, covering almost 80 % of the total mushroom production of the country. The international market for edible fungi is large and expanding as the demand is rising (Wang and Hall 2004) and Nepal has the ability to produce some species that are commonly traded on the world market. Information on market prices of fungi is difficult to find, and the available information varies greatly according to supply area and quality of collection. It is our estimate from information provided by buyers and sellers on the internet (e.g. www.alibaba.com; www.ec21.com; www.ectrade.com; www.chinesetruffle.com; www.auiswisscataloque.com) as well as other sources (Adhikari, 2000), that market margins to collectors in Nepal, China, Pakistan, and India for morels and other fungi exported to Europe are approximately 20% of the retail price, 25 - 35% of the selling price of the European wholesale company, and about 50% of the local export price.

Morel

In Nepal, morels are one of the wild edible fungi that are exported in larger quantities. They are mainly found in pine forest between 2000 and 3500m and are most abundant in the western part of Nepal. In Jumla, Humla, Mugu, and Dolpa Districts, commercial picking has been carried out for decades. At collection sites, middlemen pay NRP 8000/kg[5] for fresh morals and NRP 16000/kg for dried morals. In Kathmandu, it is NRP 10000 per kg. Near the boarder to India, cost are higher because ease of access to the Indian market. Beside India, morels are exported to Europe, especially France and Switzerland, and other buyers are in Germany, Belgium, and the Netherlands.

[5] Source: interview with local staff of RAP (Rural Access Program) at Jumla

Case study from Mustang:

'Kunjo Village' situated at 3200 m asl altitude in the mountainous district of Nepal is rich in biodiversity, including wild edible mushroom diversity. Over 40 different species of mushroom can be just found around the periphery[6]. Black morel (*Morchella escluenta*) is a highly valued, nutritious and medicinal mushroom, commercially exploited from 'Kunjo' for two decades. Morals are collected during early June (early collection) and usually grow along the edges of maize or barley field. The second collection season is during July in blue pine (*Pinus wallichina*) forest floor. According to local collectors, if the floor is burnt then production will be high next year. However, due to unsustainable over-extraction, this mushroom was listed as endangered in the year 2009. According to local residents of Kunjo village, mushroom cultivation scientists supported a project with the aim to develop a protocol on spawn production technology. An attempt made in 2009 failed mainly due to immature and infected spores. Later, in the 'mini-lab' set at the village, scientists were able to purify the culture for spawn production. Even after 9 years of successful purifying of the culture, though, there are no reports of successful cultivation of moral in the village or any other place in Nepal.

Ganoderma

In Nepal, *Ganoderma lucidum* was cultivated in 2004 at the Nepal Agricultural Research Council. Research was conducted for developing cultivation technique of *Ganoderma* using locally available resources in Nepal. Different types of substrate were used in the research such as (a) sawdust 90%, rice bran 10%, (b) sawdust 72%, corn meal 20%, rice bran 7.8 %, CaCO3 0.2%, (c) sawdust 90%, wheat bran 12% and (d) sawdust 90%, wheat bran 10%. Saw dust of *Alnus nepalensis*, *Shorea robusta*

Figure 8. Ganoderma cultivation in Pokhara, Nepal

[6] Source: interview with local residents.

and *Dalbergia sisoo* were also used in different experiments. Suitable substrates were selected, and cultivation was successfully carried out. At present, several farmers and entrepreneurs are engaged in the cultivation and production of *Ganoderma* in Nepal.

At present, *Ganoderma* production is done in several districts of Nepal that include major cities, such as Kathmandu and Pokhara. Cost of fresh mushrooms varied according to market and city between NRP 10/gm to NRP 20/gm. On the other hand, dried mushrooms cost NRP 20/gm to NRP 70/gm based on percentage of moisture content and place. Entrepreneurs in Kathmandu have been able to evaporate more than 80% of total moisture from fresh mushrooms. Because of medicinal properties and good publicity about the health benefits of the *Ganoderma*, it is used in town areas while remaining product is exported.

Mushrooms for nutrition, livelihoods and forest-fungi systems in Nepal

There are a number of the ongoing programs in SE Asia currently implementing training and demonstration practices for the cultivation of mushrooms at the village level that include developing tree-fungi agroforestry system. Given the rich ecological and biological diversity in Nepal, there is ample opportunity for including economic mushrooms in community-owned and -managed forests, given that trees provide a wide range of underneath production.

Field trip in Nepal

Dr. Sailesh Ranjitkar from the CMF, and collaborator from Nepal Shailendra Karki and Sanjog Thakali led and visited different part of Nepal to observe and understand the existing cultivation/production of *Ganoderma* and *Morchella*. In addition to this,

Figure 9. Dinner-meeting to discuss mushroom training program and its implication in Nepal. Participants Dr Sailesh Ranjitkar, Mr Bikram Pun, Dr Krishna Chandra Paudel and Mr Shailendra Karki

various organization and person promoting and involved in mushroom cultivation were contacted for obtaining information on mushroom cultivation and promotion in a community forest. The aim was to assess the current status, challenges, and practices of mushroom cultivation in the country. This knowledge will help guide any future activities to further improve and develop the mushroom industry in the region by providing technical support, quality materials, and assist in market development. A team of experts on agroforestry systems, a trainer experienced in working with community-based agricultural programs and a mushroom entrepreneur discussed the cultivation and marketing of various mushroom in Nepal during a dinner-meeting, followed by visiting a mushroom cultivation site. Dr Sailesh Ranjitkar (agroforestry) from the Kunming Institute of Botany, Dr Krishna Chandra Paudel (agroforestry) Former Secretary of the Ministry of Science and Technology, Shailendra Karki (development worker and trainer) and Mr Bikram Pun (mushroom technologist and entrepreneur) joined the meeting. Mr Pun had successfully developed a technique to cultivate *Ganoderma* besides other mushrooms.

Major points discussed during meeting:

1. *Only fresh consumption* - Most of the mushroom consumed in Nepalese market are fresh, and if fresh mushrooms are not consumed, production is wasted as there is no good technique of drying the mushroom. Therefore, partners from Nepal are seeking to understand new mushroom drying technologies borrowing from the Chinese experience.
2. *Seed selection and spawn development* - sustaining good production, implementing proper selection and cultivating spawn development are all vital components. Most farmers complain spawn problems. There is a need to understand proper techniques behind seed selection.
3. *Complex techniques* - most of the techniques used are complicated for small farmers to learn and implement. Entrepreneur such as Mr Pun, although very successful in mushroom cultivation, use techniques that are unaffordable for small-farmers. Mr Pun has better super facilities, including one for addressing issues as they arise, and cultivation is therefore successful and faster compared to normal production at other sites. But small-farmers need techniques that are simple, affordable and free of contamination.
4. *Market* - Current production is limited, and the main market is limited to major town areas where the cost is higher. Many Nepalese cannot afford nutritious mushrooms because of low production numbers and high prices. If proper techniques are introduced that enable high production, enable long-term storage of the production, and proper drying of mushroom, it would become affordable to the majority of the population and consumption could be increased. If high production costs lower, it will become affordable to the population at-large. This will expand the edible mushroom market, even for a mushroom like *Ganoderma*. Therefore, there is an urgent need to develop

proper strategies for bolstering local markets and improving international trade links, which are currently dominated by a few entrepreneurs.

5. *Site* - Location close to Kathmandu is ideal for implementing mushroom cultivation and developing forest-fungi systems. It is the center for dispersion of knowledge, technology and access to market. Therefore, the community forest at Godavari has been selected as an ideal site for implementation. While at the developmental stage, learning from entrepreneurs and their experiences could be beneficial.

Partners from Nepal expect to learn the following from the Chinese experience -

- Seed selection and spawn development
- Organic treatment of soil for soil grown mushroom
- Mushroom nursery management
- Insect and cross-contamination management
- Drying techniques
- Forest-fungi system which can be introduced to community forest in Nepal
- Farm business planning (observation based on Chinese marketing strategy)

3.3 History of mycological work and role of mushroom in Myanmar

Although the project funded by SSDC Project was focused on India and Nepal, based on a previous study and the connections forged therein, we invited two more participants from Myanmar to attend the mushroom cultivation training in Kunming in 2018 with an aim to increase the local capacity and extend the project impacts and benefits to local communities in yet another South Asian country.

The following represents preliminary research and consultations with Myanmar.

Introduction to mycological knowledge in Myanmar

Mycological work in Burma began in 1923 with resident mycologists viz. Rhind (1924), Seth (1945), and Su (1931) in the Department of Agriculture carrying out subsequent collections and investigations until World War II broke out in 1942 (Rhind & Seth 1945). Wilhelm Sulpiz Kurz (1833-1878), Curator of the Herbarium at Royal Botanic Gardens, Calcutta, India (Banglapedia 2006) made the first collections of Burman fungi from the Pegu Yoma Range in Lower Burma from 1864-1866. His collections contained a significant number of forest macrofungi. Mycologist Frederick Currey of England reported on the Kurz collections in 1876 (Butler & Bisby 1931). Imperial Mycologist Edwin J. Butler from India made further collections in 1908 (BPI 693022, 693351 & 52, HCIO 1037) and 1912 (BPI 694423, 694428, 696630). In the context of time, territory, political reality, and work identity present days, it is assumed that most of the collections from Burma were deposited at Herb. HCIO and/or K, Burma then being a colony of British Empire. Specimens and records on file in Burma were lost during World War II. As of 1945, macrofungi reckoned from among the fungi on the country

lists of Butler & Bisby (1931) and Rhind & Seth (1945) totaled 105 species in 70 genera in Ascomycota and Basidiomycota.

Since these historical mycological discoveries, very few studies have been done specially on the taxonomy of macrofungi in Myanmar (Thaung 2007; Poinar et al. 2014; Lockwood 2013), and almost no studies have been done on molecular phylogenetics of mushrooms and cultivation of new edible mushrooms in Myanmar. The edible and poisonous mushroom identification knowledge of the locals in Myanmar is very limited.

As part of our research studies, Shangri-La, Baoshan, Lijiang, Mengla, and Mengsong in Yunnan Province, China and Chiang Rai, Thailand are being investigated, resulting in many new species, new records, a record containing remarkable mushroom biodiversity (Karunarathna et al. 2011a, b, 2014; Zhao et al. 2012a, b, 2013; Wisitrassameewong et al. 2012; Guzman et al. 2012; Li et al. 2014, 2016; Ye et al. 2014, 2016; Liu et al. 2015; Bandara et al. 2016) and several field guides of Chinese mushrooms (Mortimer et al. 2014, 2016; Xu et al. 2016). We have also been focusing mostly on potentially cultivatable and edible genera (Karunarathna et al., 2011a, b; 2016; Bandara et al. 2016). Since Myanmar borders Thailand and tropical/ subtropical parts of China with similar vegetation types to Thailand and tropical/ subtropical parts of China, we expect high fungal diversity. As Myanmar is rich in good forests and lots of macrofungi have been collected according to the historical mycological reports, there is an exciting research opportunity to survey macrofungi of Myanmar.

Roles of edible mushrooms for improving local livelihoods

Local mycological knowledge including the use of mushroom for food, medicinal purposes, recreational objects, in beliefs and myths, as well as income-generating activity to poor households is well documented in different parts of the world (Buyck and Nzigidahera 1995; Pilz and Molina 2002; Guissou et al. 2008; Zsigmond 2010; Tibuhwa 2012; Garibay-Orijel et al. 2012). Mycological identification is explicably linked to culture, religion and as food sources in several Southeast Asian cultures. The information on how to identify and differentiate between edible and non-edible/ poisonous mushrooms depends largely on traditional knowledge on taxonomy. Vernacular naming and description systems are often deeply embedded in traditional taxonomy (Tibuhwa 2012). These vernacular systems transfer information from one generation to another while transmitting the cultural significant of specific mushroom species. Wild edible mushrooms are among the non-timber forest products (NTFP) not well documented in many countries including Myanmar. In fact, mushroom forming

fungi are poorly collected, understudied and comparatively underutilized in the country.

Recently, there has been increasing interest in mushroom utilization worldwide. Mushrooms are used in foods because of unique biochemical compositions, contents of antioxidant compounds, proteins, carbohydrates, lipids, enzymes, minerals, vitamins and water. However, there is no reliable information on how much is harvested; there are also no market orders or well-defined value chains. In addition, general awareness regarding the income generation potential and its contribution to rural food security is new in areas of Myanmar.

In general, knowledge of identification techniques and overall utilization of wild edible mushrooms were both poor among local community members. As previously stated, wild mushrooms can be an important source of nutrition and household income, previously underutilized in Myanmar. Therefore, the project team has carried out mushroom identification training in Chin and Shan States. In addition to community-level training, a lecture on edible and poisonous wild mushrooms in Myanmar was given at the Yezin Forestry University in 2016.

Figure 10. A. Wild mushroom collection in Myanmar; B. Detailed discussion of the collected mushrooms

3.4 Training programme on the selected mushrooms cultivated in Kunming

Supported by SSDC Project, representatives from India, Nepal, and Myanmar who had been visited by our staff at the first phase of the project were invited to the Kunming Institute of Botany to spend five days training intensively in the cultivation and production of mushrooms that were deemed viable for growing in their country of origin.

Figure 11. Dr. Peter Mortimer fields questions from the visitors after a presentation on *Ganoderma* cultivation.

In order to aid in the tangible mushroom cultivation initiatives in the host countries of the visitors, it was essential to conduct hands-on training in our laboratory and greenhouses. During the week 22- 26 October 2018, representatives from Nepal, India, and Myanmar visited CMF/KIB and witnessed first-hand the methods and procedures that are proven to work at the Kunming Institute of Botany and its partner mushroom cultivation institutions. The training workshop was led by Dr. Peter Mortimer, Dr. Samantha Karunarathna, Dr. Zhao Qi, and Dr. Asanka Bandara. The training covered both solid state cultivation (e.g. bag cultivation method) and liquid state cultivation, with a particular emphasis on the cultivation of *Ganoderma lucidum* and *Morchella* sp.

The training in these two high-demand species was meant to serve as a foundation for the cultivation of countless other mushroom varieties whose cultivation methods are consonant with those featured during the training sessions. As such, the visitors are now trained in a variety of mushroom cultivation techniques. In addition, a video was recorded of the entire training and will be made available for public, thus enhancing the capacity of rural development through mushroom cultivation across the world.

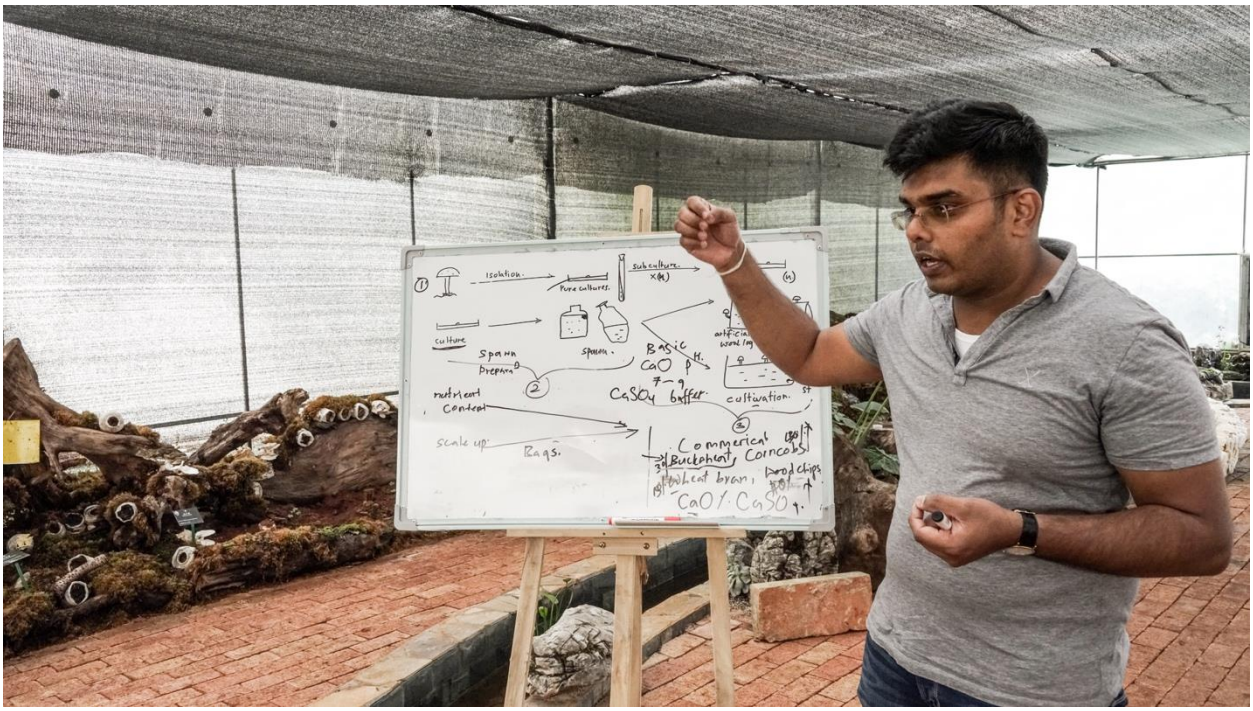

Figure 12. Dr. Asanka Bandara introduces visitors the complete life cycle of *Ganoderma* cultivation, from isolation to harvest.

Ganoderma species have long been used as medicinal mushrooms in Asia. *Ganoderma lucidum* has been widely used in the commercialized "Lingzhi" products found in the world market, since it has been shown to possess numerous medical properties (Lai et al.2004). As *G. lucidum* is rare in nature, wild mushrooms are not sufficient for commercial exploitation. Accordingly, *Ganoderma* cultivation has become essential to meeting the increasing demands in the international markets (Yang et al., 2003).

Morchella esculenta are one of the four most famous edible fungi in the world. They are favored in western countries and considered a high-grade edible fungus. The wholesale price of dried mushrooms is 200-250 USD/kg. At present, the total production of *Morchella* cultivated in China accounts for more than 99% of its global production. The products are mainly sold in China and some are exported to western countries. Morels can benefit human immunity and detoxify the kidneys. Researchers at the Kunming Institute of Botany have conducted demonstration studies on species diversity, agronomic traits and the industrialization of morels, and made important breakthroughs in the fields of resource discovery, improved breeding and large-scale planting, and made contributions to its diversity, sustainable use, and industrial development. As such, KIB possesses some of the most high-quality and cutting-edge morel cultivation techniques in the world.

Figure 13. Nepalese visitor Shailendra Karki poses a question at the *Morchella* facility jointly operated by Dr. Zhao Qi, Kunming Institute of Botany (KIB), Chinese Academy of Science, and private sector investors.

The training program on selected mushrooms cultivation was successfully completed on October 26, 2018. The details of the training are as follows:
Venue: Kunming Institute of Botany, Chinese Academy of Science
Laboratory facilities: Jinning Phosphate Mining Company
Mushroom factory: Luxi
Date: 22-26 October 2018 (5 days)

Figure 14. Dr. Asanka Bandara demonstrates proper spawn production in the KIB Greenhouse

Table 2. Tentative schedule:
Cultivation of *Ganoderma* – *G. lingzhi* and *G. lucocontextum*

Date	Time	Activity	Place	Demonstrator
Day 1	9:00-10:00 am	General Introduction to edible, medicinal mushrooms and their cultivation - PowerPoint slides	Meeting room - KIB	Dr. Sam
	10:30-11:00 am	Movie - *Ganoderma*	Meeting room - KIB	
	11:00-12:00 am	*Ganoderma*: Cultivation of *Ganoderma* species - PowerPoint slides	Meeting room - KIB	Dr. Asanka
	1:30 pm	Demonstrate spawn preparation and field cultivation of *Ganoderma*	Greenhouse No. 10 - KIB	Dr. Asanka, Gig
Day 2	7:30 am from KIB	Demonstrate lab technique	Laboratory - Jinning	Dr. Asanka
Day 3	7:30 am from KIB	On-site visit to Luxi mushroom factory	Luxi	Dr. Asanka

Table 3. Cultivation of *Morchella*

Date	Time	Activity	Place	Demonstrator
Day 4	Morning	1. Key technology for annual cultivation of Morel (*Morchella esculenta*) - PowerPoint slides 2. The Chinese Morel Market- PowerPoint slides	Meeting room - KIB	Dr. Zhao Qi
	Afternoon	Laboratory visit	Southwest lab - room 325	Dr. Zhao Qi
Day 5	Morning	Visit to *Morchella* factory		Dr. Zhao Qi
	Afternoon	Free time		

Figure 15. Dr. Zhao Qi walks the guests through his laboratory, detailing the spore sequencing process of *Morchella*.

Cultivation Methods

Solid-state cultivation

Five steps of the bag cultivation method of *Ganoderma*

- Selection, isolation and subculture of *Ganoderma* strain
- Preparation of spawns on grain medium
- Inoculation spawns to bags with woody substrate
- Burying bags with completely grown mycelium of *Ganoderma* under the soil
- Harvesting of *Ganoderma* production

Selection, isolation and subculture of *Ganoderma* strain:

This step was demonstrated in the laboratory of the Jinning Phosphate Mining Company on day 2 of the workshop. In this process, we discussed the characteristics necessary to observe when selecting wild *Ganoderma* fruiting bodies for isolation. In addition, the technique of isolation was demonstrated using the tissue culture method. After the successful isolation of *Ganoderma*, the mother culture was sub-cultured and multiplied by the total number of cultures under a sterile environment. These cultures will be used for the spawn preparation which is the next step of mushroom cultivation.

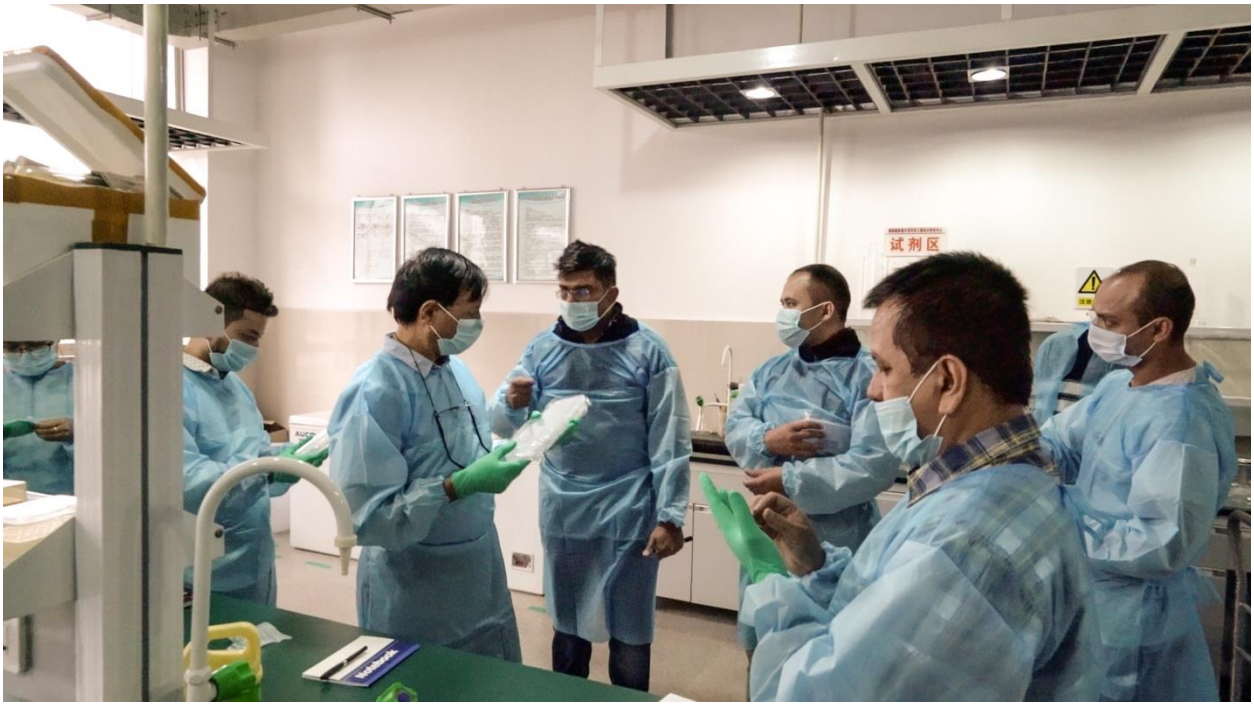

Figure 16. Dr. Asanka Bandara prepares to demonstrate the process of isolating wild *Ganoderma* fruiting bodies in the laboratory of the Jinning Phosphate Mining Company.

Preparation of spawns on grain medium and inoculation spawns to bags with woody substrate:

These two steps were demonstrated in Greenhouse 10 at KIB on day 1 of the workshop. Spawn preparation and bag preparation of *Ganoderma* were demonstrated using available grains and agriculture waste. Next, spawn bottles and cultivation bags were inoculated under sterile conditions, and optimum conditions were provided during the mycelium colonization period.

Figure 17. *Ganoderma lucidum* grows in the KIB greenhouse.

Burying bags with completely grown mycelium of *Ganoderma* under the soil and harvesting of *Ganoderma* production:

We demonstrated the method of planting fully colonized mycelium bags in the field and how to manage the field until they develop mature fruiting bodies in the greenhouse. Finally, the correct way of harvesting *Ganoderma* and processing for marketing were demonstrated.

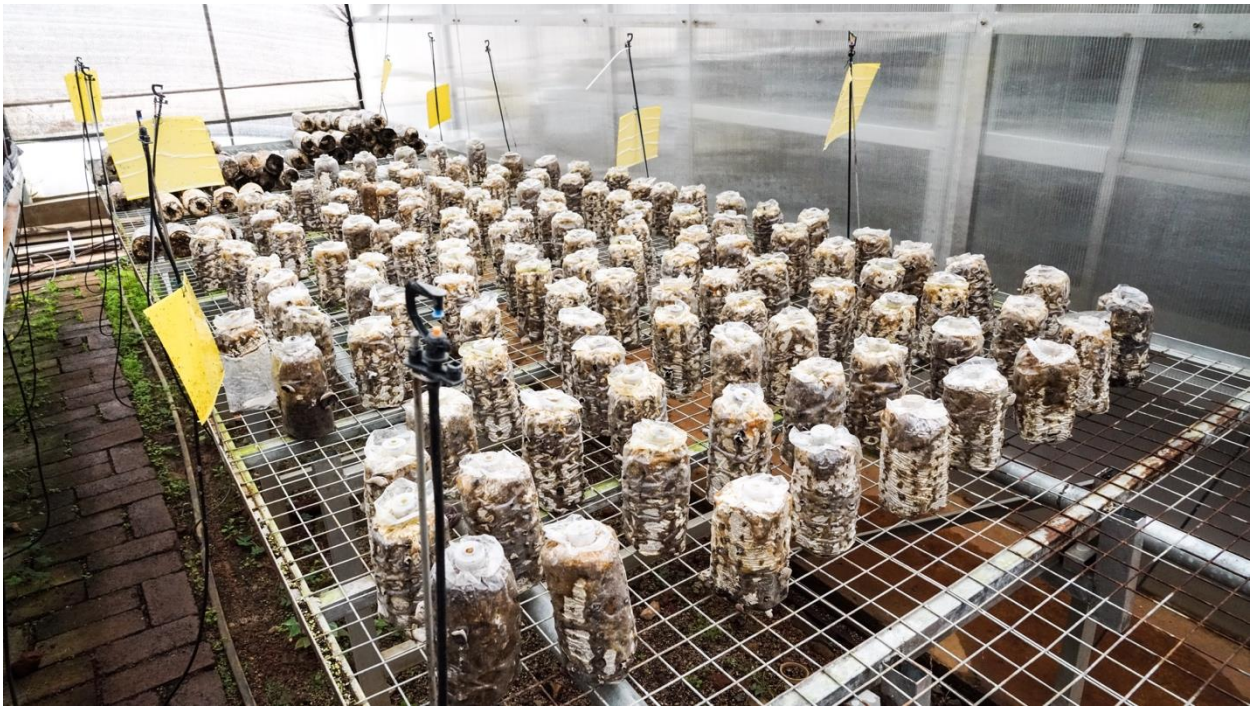

Figure 18. Bags of infused substrate grow white *Auricularia* (muer) in the KIB greenhouse.

On the 2nd day, Dr. Asanka Bandara demonstrated the lab techniques necessary for sequencing and proper spawn production under sterilized conditions. The entire sequence, which is complex and must be followed precisely so as to avoid mycelial infection, was filmed and will be made available online.

On the 4th day there were presentations about the key technologies used for annual cultivation of Morels (*Morchella esculenta*). The process of selecting stable and high-yield morel species, as well as the cultivation method of morels and best management practices were discussed in this presentation. The PowerPoint and relevant information have been distributed to the visitors.

On the 3rd and 5th day of the workshop, participants visited the large-scale *Ganoderma* and *Morchella* production facilities in Luxi and Songming, respectively. During these visits, participants got an opportunity to discuss scaling-up production of mushrooms, the problems therein, and how to minimize those problems in large-scale mushroom production.

Figure 19. Visitors from Myanmar and Nepal look closely at a cluster of *Morchella* while visiting Dr. Zhao Qi's mushroom farm outside of Kunming.

Figure 20. Cin Khan Lian of Myanmar is presented his certificate of completion by Dr Peter Mortimer of KIB.

Outputs:

- **Knowledge on forest-fungi agroforestry**: Understanding potential forest-fungi agroforestry System
- **Capacity building**: Local agro-technicians trained during the project have mastered technologies necessary in edible and medicinal mushroom cultivation. They will be able to set benchmarks for the cultivation of economic mushrooms and train small-holder farmers, especially women, in their local communities.
- **Training video**: A full mushroom cultivation training video was recorded during the training workshop, uploaded onto the ICRAF website and available for public access. The video will enhance the ability of the visitors to apply what they learned during the visit by serving as a reference when mushroom cultivation is undertaken.
- **Training manual**: A handbook on economic mushroom cultivation will be finalized and published.

The capacities of visiting delegates from Nepal, India, and Myanmar and, by extension, community forest members, to utilize high-value mushroom growing technologies have been enhanced, and they will be able to train farmers in their respective communities. There are already some post-project impacts. For instance, after receiving training at KIB, two significant development has been achieved in Nepal. Spawn received from KIB was handed over to one entrepreneur and the national laboratory of Nepal and successfully grown. It is currently being provided to several mushroom farmers in Kathmandu and preparing for potential integration into the market. After training, the Nepalese team made a survey around the Kathmandu

Valley among mushroom farmers to understand issues during various phase of production. Realizing the need for high-quality spawn and substrate to germinate mushrooms, the team proposed a national bank to invest and government of Nepal to support to develop spawn and substrate production unit, which has been approved in early 2020.

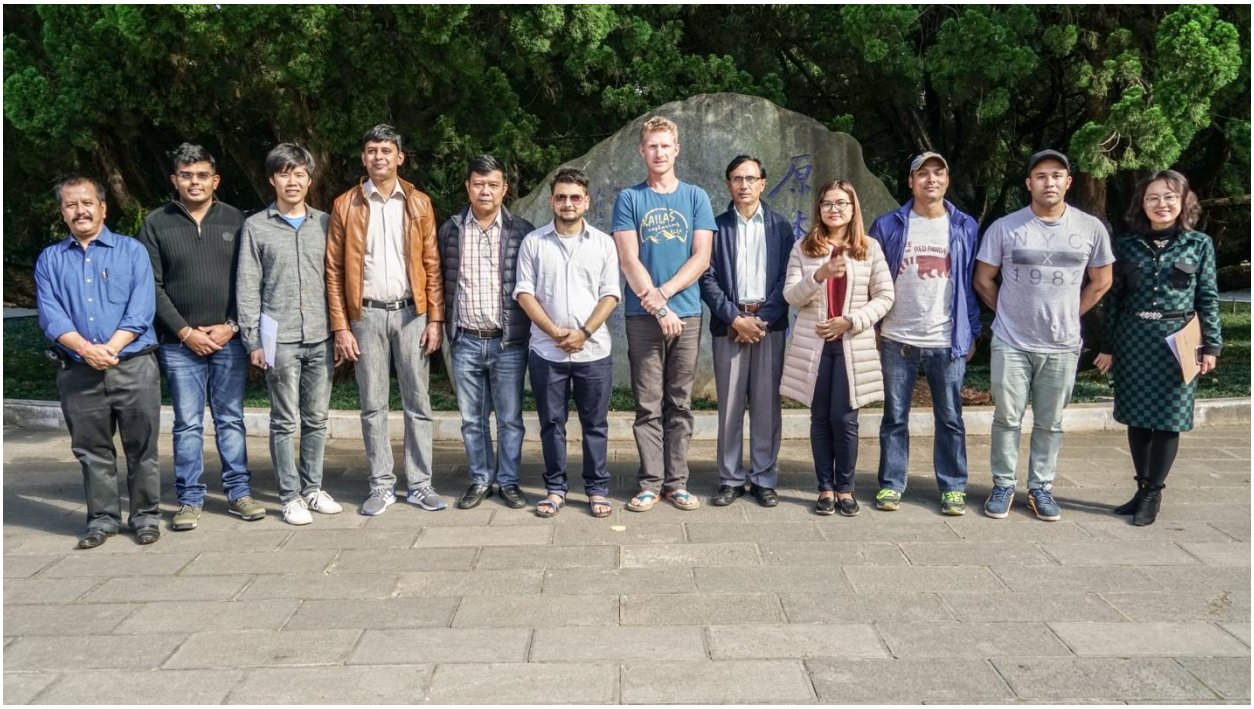

Figure 21. Staff from the Kunming Institute of Botany pose for a group photograph with visitors from India, Nepal, and Myanmar.

4. Conclusion

Wild mushrooms can be an important source of nutrition and household income, but identification techniques and overall rate of utilization of wild edible mushrooms were very poor among local communities in many developing countries. Moreover, due to limited knowledge on mushroom consumption, people suffer from mushroom poisoning and are admitted to hospitals every year, especially during the summer.

Information on how to identify and differentiate between edible and non-edible/ poisonous mushrooms depends largely on traditional knowledge on taxonomy. Wild edible mushrooms are not well documented in many developing countries, and mushroom forming fungi are poorly collected, understudied and comparatively underutilized.

There has been increasing interest in mushroom utilization worldwide, but there is no streamlined information regarding how much is harvested, as well as no market orders or well-defined value chains. In addition, general awareness regarding the income

generation potential and its contribution to rural food security is a novel introduction in many developing countries.

Even if there are some constraints and issues, the project and other relevant cases have shown great potentials for mushroom cultivation and production for smallholder farmers and women and would directly and indirectly contribute to the following UN Sustainable Goals (SDGs):

1) It would help poor smallholder famers increase their income and promote economic growth, employment and decent work to reduce poverty (SDG 1 & 8).

2) It can provide nutritious food for all and generate decent incomes, while supporting people-centered rural development and protecting the environment (SDG2).

3) It would provide equal access for men and women to affordable, high-quality technical and vocational education, and increase the relevant skills for employment and decent work (SDG4).

4) It would provide women and girls including the ones from poor families with equal access to training, decent work and economic decision-making processes at household and community levels (SDG5).

5) It would provide economic opportunities for the least developed countries in mountain areas with large numbers of impoverished populations, ethnic minorities, and disadvantaged and marginalized populations to reduce income inequality between and within countries (SDG10).

6) It can make use of agricultural waste products, further adding to the sustainability of the production line, as the spent substrates from growing mushrooms can in turn used as a fertilizer for crop plants, closing the cycle of production. It is a green and sustainable agricultural development mode and an efficient utilization of natural resources, which would contribute to build inclusive, safe, resilient and sustainable cities and communities (SDG11, 12).

7) Mushrooms can be cultivated in a sustainable, low cost fashion, or simply harvested from the wild without additional costs, which would contribute to protect biodiversity, strengthen natural resource management and increase land productivity (SDG15).

8) It is replicable, and can be promoted to the development, transfer, dissemination and promotion of environmentally friendly technologies for developing countries

and strengthen international support for effective and targeted capacity-building activities in developing countries (SDG 17).

5. Follow-up works

5.1 Joint Academic Research

The academic research can provide insight into the mushroom biogeography of the target areas, including new knowledge relating to mushroom species distribution, discovery of new mushroom species, and furthering scientific knowledge surrounding the drivers of mushroom distribution (factors including forest type, soil type, climatic variables). Mushrooms suggested for consumption need to be screened for toxins and nutrient profiles compiled, as none of this research has previously been performed at a large scale in most Asian countries.

5.2 Demand-driven Need Assessment

Assessment of local knowledge relating to the use and trade of mushrooms in target countries also needs to be done. Household interviews and targeted group discussions need to be conducted to assess the extent of knowledge relating to the use and trade of mushrooms by the relevant communities. Edible, medicinal and poisonous mushrooms need to be highlighted for further study and awareness within the target communities/areas.

5.3 Forest-Fungi Agroforestry System Project Phase Ⅱ

More importantly, training program must be continued. Mushroom identification and cultivation training at community-level are needed in developing countries. It is necessary to provide technical knowledge and further demonstrations about other mushroom species with higher market value. More attention and opportunities should be given to women for trainings, as they engage more in this kind of work at the household level. Continuous support from the SSDC Project will be essential for doing this. The practical experiences from the previous SSDC project has shown great potential for demonstration, popularization and replicable across other regions. We should consider carrying out more training for partner countries on the basis of actual needs and try to promote similar practices in other countries outside South Asia.

5.4 Develop value chain for mushroom

Value chains for the mushroom trade needs to be developed, starting with product development (wild harvested or cultivated mushrooms), product processing, and

market access for trade. Mushrooms of economic value need be used for the development of trade and income generation. Deep processing and high value-added production need to be developed and promoted, allowing households to have increased income based on the trade of mushrooms.

5.5 Public Awareness

Lastly, social development for the members of rural households in the target areas with increased capacity to identify mushrooms from the wild and cultivate mushrooms at the village level is needed. This knowledge can be used to enhance the livelihoods and nutritional intake of households within targeted villages. Additionally, social development can be implemented beyond the village level, and provide capacity building for students, technicians, and more, including technical laboratory skills and the ability to establish field plots and conduct field monitoring of mushroom species throughout the season.

6. Recommendations

Despite rising popularity and active promotion, forest-fungi agroforestry systems in developing countries have been restrained by varied factors:

(1) Social and cultural impacts

Traditionally, in many developing countries, mushroom consumption is not common, due to limited knowledge and practices. For instance, in Nepal, mushrooms are only accepted for eating socially and culturally among certain ethnic groups. Mycological identification is explicably linked to culture, religion and as food sources in several Southeast Asian cultures. The information on how to identify and differentiate between edible and non-edible/ poisonous mushrooms depends largely on traditional knowledge on taxonomy. Local knowledge of wild edible mushrooms in areas is so limited that people are often afraid to eat wild mushrooms.

In fact, mushroom consumption and production have a long history, the entwinemnet of the two has brought huge economic benefits and work opportunities for relevant local communities and mushroom industry stakeholders in China. For instance, in 2018, the total output of edible mushroom in China reached 37.12 million tons (over 70% of the world's total output), with an output value of 272.1 billion yuan and nearly 30 million employees[7]. Mushroom production has additionally become an important approach to poverty alleviation in the agricultural sector. In many poor areas of China,

[7] https://baijiahao.baidu.com/s?id=1635949922802363965&wfr=spider&for=pc

the cultivation of mushrooms is becoming popular as a means of rural development, poverty alleviation, providing alternative, sustainable sources of income and household nutrition for rural and impoverished communities[8].

However, male-headed households usually dominate societies in most developing countries, and men tend to have sole decision-making power; therefore, they normally have more chances and power to access different resources, to receive education, training, technologies and funds/loans, etc. However, based on our prior experiences, women are more interested and engaged in mushroom cultivation.

Recommendation: Raise awareness and understanding of the multiple benefits of mushroom production and consumption, as well as forest-fungi agroforestry systems for multi-level stakeholders. The multiple benefits should be recognized and emphasized by government, as nutrition and income comprise just two parts of its function, whereas circular production and environment protection may play increasingly important roles in long-term sustainability strategies. If there are any relevant programs, extension services, funding support or trainings, more opportunities and attentions should be provided to women.

(2) Gap in technical capacity and services

There are some gaps in technical capacity and services related to the cultivation of mushrooms. For instance, we found some problems during our visit in India in August 2018: 1) Spawn supply is sporadic, and quality is variable. There are a limited number of species/strains available to local growers. Based on feedback we received, production and supply of quality spawn is a major bottleneck for all mushroom producers in the region. 2) The bagging process is slow and inefficient, with an inconsistent quality of grown bags; ultimately yields will vary and an increase in infection is likely to result as well. At the same time, among observed farms, no mushroom producers use mechanized equipment for producing bags. 3) Introducing new edible and medicinal mushroom species can be a time-consuming process. However, most of the currently used technique are complicated and unaffordable for small farmers.

Recommendation:

a) Specialized institutions responsible for forest-fungi agroforestry system development and management should be established with multiple sectors,

[8] http://www.ntv.cn/z/352731/

empowered with specialized outreach and technical personnel.

b) To ensure a high level of quality for the mushrooms being produced, and to maintain high yielding crops, it is necessary to provide scientific/technical knowledge and more in-depth training about mushroom cultivation to growers. Trainings for professionals and technicians also need to be held. The exchange of information and popular science education should be enhanced among resource institutions to the establishment of a peer-to-peer partnership.

c) Equally important, simple, affordable and contaminant-free techniques should be developed for small-farmers, and a certain degree of extension work would make an impactful difference to the quality and yields of the mushroom growers. Proper techniques need to be introduced to enable high production, enable long-term storage of the production, and proper drying of mushroom. Increased production will make mushrooms more affordable to the public, increasing consumption.

(3) Market information and access

There is no streamlined information on how much is harvested nor on market orders or well-defined value chains. In addition, general awareness regarding the income generation potential and its contribution to rural food security is new to many developing countries. Information on market prices of fungi is difficult to find, and the available information varies greatly according to supply area and quality of collection.

Recommendation:

Value chains for the mushroom trade need to be studied and developed, starting with product development (wild harvested or cultivated mushrooms), product processing, and market access for trade. Mushrooms of economic value need be used for the development of trade and income generation. Deep processing and high value-added production need to be developed and promoted, allowing households to have increased income based on the trade of mushroom. A mushroom network for sharing relevant information, including prices, technique, networking, etc., needs to be established. There is a need to develop proper strategies for increasing local markets and improve international markets, which is currently dominated by several entrepreneurs.

(4) Policy support

As there is limited knowledge and information about forest-fungi agroforestry systems, it has often been overlooked in being involved in the top-level policy by most

governments in developing countries. Specific promotion programs were rare to be found in annual government plans.

Recommendation: Government sectors including agriculture, environment and forestry should be integrated to identify the deficit gap in forest-fungi agroforestry systems and consider the feasibility in applying mushroom cultivation technologies.

(5) Financial issue

Affordability is one of the primary consideration of farmers without relying entirely on the assistance of governments and international organizations at the onset. High costs of self-funded technology and required materials under non-governmental projects have discouraged farmers, who require sustainable capital investment on building materials, labor, equipment and so on.

Recommendation: Technology financing mechanisms (subsidy, loans and grants) could be a solution. Public - private joint venture modes for technical promotion remains to be explored. Additionally, land may be mortgaged to apply for bank loans to fund construction.

Sustainable Development Goal Targets:

References

Adhikari MK. (2000). Mushrooms of Nepal. P. U. Printers, Kathmandu, 236 pp.

Bandara A.R., Samantha Karunarathna, Jie Chen, Kevin D. Hyde, Pattana Kakumyan: Auricularia thailandica sp. nov. (Auriculariaceae, Auriculariales) a widely distributed species from Southeastern Asia. Phytotaxa 05/(2015); 208(2):147–156.

Banglapedia (2006). Calcutta Botanic Garden (http://banglapedia.search.com.bd/HT/index _c.html).

Butler, E.J. & Bisby, G.R. (1931). The Fungi of India. Scientific Monograph No. 1. The Imperial Council of Agricultural Research. Government of India Central Publication Branch, Calcutta, India.

Buyck B, Nzigidahera B: Ethnomycological notes from western Burundi. Belg J Bot (1995), 128:131–138.

Christensen M and Larsen HO. (2005). How can Collection of Wild Edible Fungi Contribute to Livelihoods in Rural Areas of Nepal? Journal of Forest and Livelihood 4(2): 50-55.

Doyle, J. J., Doyle, J. L. (1987). A rapid DNA isolation procedure for small quantities of 464 fresh leaf tissue. Phytochem. Bull. 19:11–15.

Felsenstein, J. (1985). Confidence limits on phylogenies: an approach using the bootstrap. Evolution. 39:783–791.

Garibay-Orijel RG, Ramirez-Terrazo A, Ordaz-Velazquez M: Women care about local knowledge, experiences from ethnomycology. J Ethnobiol Ethnomed (2012), 8:25. doi:10.1186/1746-4269-8-25.

Guissou KML, Lykke AM, Sankara P, Guinko S: Declining wild mushroom recognition and usage in Burkina Faso. Econ Bot (2008), 62:530–539. doi:10.1007/s12231-008-9028-5.

Guo J., Karunarathna S.C., Mortimer P.E., Xu J.C. and Hyde K.D. (2014) Phylogenetic diversity of Russula from Xiao-Zhongdian, Yunnan, China, inferred from Internal Transcribed Spacer sequence data, Chiang Mai J. Sci., 41(4):811–821.

Guzman G., Florencia Ramirez Guillen, Kevin D. Hyde & Samantha C. Karunarathna (2012) Psilocybe s.s. in Thailand: a review of known species and four new species described. 119, January-March (2012), pp. 65–81.

Heinemann, P. 1978. Essai d'une clé de determination des genres Agaricus et Micropsalliota, Sydowia 30: 6–37.

Karunarathna S. C., Yang ZL, Zhao R, Vellinga EC, Bahkali AH, Chukeatirote E, Hyde KD (2011) Three new species of Lentinus from northern Thailand. Mycological Progress 10 :389–398 (DOI 10.1007/s11557-010-0701-6)

Karunarathna S.C., Guinberteau J., Chen J., Vellinga E. C., Zhao R.L., Chukeatirote E., Yan J., Hyde K.D., Callac P. (2014) Two potentially edible species in Agaricus tropical clade I, Chiang Mai J Sci 41: 1–10.

Karunarathna S.C., Peter E. Mortimer, Jie Chen, Guo-jie Li, Mao-Qiang He, Jianchu Xu, Jaya Seelan Sathya Seelan, Bahkali Ali Hassan, Kevin D. Hyde & Ruilin Zhao

(2016) Correct names of two cultivated mushrooms from the genus Pleurotus in China, Phytotaxa 260(1):36–46.

Karunarathna, S. C.; Yang, Zhu L.; Olivier, Raspe; Ko Ko, Thida W.; Vellinga, Else C.; Zhao, Rui-Lin; Bahkali, A.H.; Chukeatirote, Ekachai; Degreef, Jerome; Callac, Philippe; Hyde, Kevin D. (2011) Lentinus giganteus revisited: new collections from Sri Lanka and Thailand. Mycotaxon 118: 57–71. http://dx.doi.org/10.5248/118.57

Lai, T., Gao, Y. and Zhou, S., (2004). Global marketing of medicinal Ling Zhi mushroom *Ganoderma lucidum* (W. Curt.: Fr.) Lloyd (Aphyllophoromycetideae) products and safety concerns. *International journal of medicinal mushrooms*, 6(2), pp.189–194.

Largent D.L. 1986. How to identify mushrooms to genus vol. 1–5. Mad River Press, CA USA.

Li H., Peter E Mortimer, Samantha C Karunarathna, Jianchu Xu, Kevin D Hyde (2014) New species of Phallus from a subtropical forest in Xishuangbanna, China. Phytotaxa; 163(2):91–103.

Liu J.K., Kevin D. Hyde, E. B. Gareth Jones, Hiran A. Ariyawansa, Samantha C. Karunarathna et al. Fungal diversity notes 1–110: taxonomic and phylogenetic contributions to fungal species. Fungal diversity 05/2015; DOI: 10.1007/s13225-015-0324-y.

Lockwood TF (2013) Cookeina tricholoma–Burma. http://www.fungiphoto.com/CTLG/pages/0851-07.html(accessed 8 October 2014).

Mortimer PM, J Xu, SC Karunarathna, KD Hyde: Mortimer, PE; Xu, J; Karunarathna, SC; Hyde, KD (eds) (2014) Mushrooms for trees and people: a field guide to useful mushrooms of the Mekong region. The World Agroforestry Centre, East Asia, Kunming, China. 125 pp.. 1st edited by Peter E Mortimer, Jianchu Xu, Karunarathna Samantha C, Kevin D Hyde, 01/2014; World Agroforestry Centre (ICRAF)., ISBN: ISBN 978-92-9059-358-4

Mortimer PM, Xu J, Karunarathna SC, Hyde KD (2016) A field guide to mushrooms in tropical and subtropical regions in Asia, The World Agroforestry Centre, East Asia, Kunming, China.

Page, R. D. M. 1996. TREEVIEW: an application to display phylogenetic trees on personal computer. Computer Applications in The Biosciences. 12: 357–358.

Pilz D, Molina R: Commercial harvests of edible mushrooms from the forests of the Pacific Northwest United States: issues, management and monitoring for sustainability. Forest Ecol Manag 2002, 155:3–16. doi:10.1007/s12231-008-9043-6.

Poinar J.G., Alfredo D.S., Baseia I.G. (2014) A gasteroid fungus, Palaeogaster Micromorpha gen. & sp. nov. (Boletales) in cretaceous Myanmar amber, Journal of the Botanical Research Institute of Texas 8(1):139.

Poinar, G.O., Jr. & Brown A.E. (2003) A non-gilled hymenomycete in cretaceous amber. Mycological Res. 107:763–768.

Rhind, D. & Seth, L.N. (1945). The Fungi of Burma. The Indian Journal of Agricultural Science 15, 142–155.

Rhind, D. (1924). Report of the Mycologist, Burma, for the period ending 30th June, 1924. Department of Agriculture, Rangoon, Burma. Superintendent, Government Printing & Stationery, Rangoon, Burma.

Saghaimaroof, M.A., Solima, K.M., Jorgenson, R.A., and Allard, R.W. 1984 – Ribosomal DNA 534 spacer-length polymorphisms in barley: Mendelian inheritance, chromosomal 535 location and population dynamics. Proc Natl Acad Sci USA 81:8014–8018.

Seth, L.N. (1945). Studies on the false smut disease of paddy caused by Ustilaginoidea virens (Cke) Tak. The Indian Journal of Agricultural Science 15, 53–55.

Stamets P. 200. Growing Gourmet and Medicinal mushrooms 3rd edition. Ten Speed Press, Berkeley Toronto, CA, The USA.

Stamets P. and Chilton JS. 1983. The mushroom cultivator: A practical guide to growing mushrooms at home. Agarikon Press, Olympia, Washington, The USA.

Su, M.T. (1931). Report of the Mycologist, Burma, Mandalay, for the year ending 31st March, 1931. Department of Agriculture, Rangoon, Burma. Superintendent, Government Printing & Stationery, Rangoon, Burma.

Swofford, D.L. 1998. PAUP and other methods. Phylogenetic Analysis Using Parsimony, version 4. Sinauer Associates: Sunderland, Massachusetts, USA.

Thaung M. M. (2007). A preliminary survey of macromycetes in Burma. Australasian Mycologist 26. (1): 16–36

Thomson, J.D., Gibson, T.J., Plewniak, F., Jeanmougin, F., Higgins, D.G., 1997. The Clustal_X windows interface: flexible strategies for multiple sequence alignment aided by quality analysis tools. Nucleic Acids Res. 25, 4875–4882.

Tibuhwa DD: Folk taxonomy and use of mushrooms in the communities around Ngorongoro and Serengeti National Park, Tanzania. J Ethnobiol Ethnomed 2012, 8:36. doi:10.1186/1746-4269-8-36.

Wang Y. and I. R. Hall. 2004. Edible Ectomycorrhizal Mushrooms: Challenges and Achievements.
Canadian Journal of Botany 82(8): 1063-1073

White, T.J., Bruns, T.L., Lee, S., Taylor, J.W., 1990. Application and direct sequencing of fungal ribosomal RNA genes for phylogenetics. In: Innis, M. A., Gefand,D. H., Sninsky,J.J., White, J.T. (Eds.), PCR Protocols: A Guide to Methods and Applications. Academic Press, San Diego, pp.315–322.

Wisitrassameewong K., Samantha C. Karunarathna, Naritsada Thongklang, Ruilin Zhao, Philippe Callac, Ekachai Chukeatirote, Ali H. Bahkali, Kevin D. Hyde (2012) Agaricus subrufescens: new to Thailand. Chiang Mai Journal of Science; 39(2):281–291.

Xu J, Guo J, Mortimer PM, Karunarathna SC: Xu J, Guo J (eds) (2016) Fantastic mushroom world: a field guide to Nabanhe Natural Nature Reserve (in Chinese). The Nabanhe Natural Nature Reserve, Xishuangbanna, Yunnan province, China.

Yang, F.C., Hsieh, C. and Chen, H.M., 2003. Use of stillage grain from a rice-spirit distillery in the solid-state fermentation of *Ganoderma lucidum*. *Process Biochemistry*, 39(1), pp.21-26.

Ye L., Peter Edward Mortimer, Jianchu Xu, Samantha C. Karunarathna, Kevin D. Hyde (2014) The genus phylloporus (Boletaceae, Boletales), from Mekong River Basin (Yunnan Province, China). Chiang Mai Journal of Science; 41:1–13.

Zhao R.L., Karunarathna, S.C., Raspé, O., Parra, L.A., Guinberteau, J., Moinard, M., De Kesel, A., Barroso, G., Desjardin, D., Courtecuisse, R. Hyde, K.D., Guelly, A.K. Callac, P. (2012a) Major clades in tropical Agaricus. Fungal Diversity (DOI 10.1007/s13225-011-0136-7)

Zhao R.L., Kevin D Hyde, Dennis E Desjardin, Olivier Raspé, Kasem Soytong, Jacques Guinberteau, Samantha C. Karunarathna, Philippe Callac. (2012b) Agaricus flocculosipes sp. nov., a new potentially cultivatable species from the palaeotropics. Mycoscience; 53:300–311.

Zsigmond G: The meanings and functions of mushrooms as food in Hungarian folk tradition. Acta Ethnographica Hungarica 2010, 55:115–138. doi:10.1556/AEthn.55.2010.1.8.