Implementation of Small-Scale Mushroom Production Systems in Rural Cambodia

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***Abstract*— Cambodia has a largely agrarian economy, with roughly 75 percent of the population working in agriculture, chiefly cultivating rice. Since rice can only be grown eight months of the year, the other months farmers are forced to migrate to cities to find employment to support their families. Mushroom cultivation is an attractive source of alternative work and supplemental income in Cambodia because it is not labor intensive and it produces a high-value crop. Thera Metrey is a venture making mushroom cultivation accessible to farmers in rural areas around the town of Kampong Cham in central Cambodia. Initial introduction of the technology was successful in involving farmers and aligned with socio-cultural traditions. As the venture grew to include over 80 mushroom houses, opportunities to improve the technology as well as the business model became evident. This article discusses the early stages and growth of Thera Metrey in order to highlight the successes and obstacles faced in its implementation.**

Keywords—mushroom production, Cambodia, agricultural ecosystems, implementation

I. Introduction

Rice accounts for 75% of Cambodia's agriculture, and is a crop that is grown in the wet season from May to October [1]. In the off-season, rice farmers lack a steady source of income and rely on small-scale poultry farming, vegetable farming, or migration to urban centers to support themselves and their families [2]. Migration causes much of the adult male population to leave rural areas and can trigger social challenges in urban areas like pressure on limited infrastructure and negative health effects due to increased population density [3]. Mushroom farming is a source of supplemental income with great potential that allows farmers to remain in rural areas during the off-season and has already been utilized in Cambodia [4].

Straw mushrooms (Volvariella Volvacea) have been cultivated in Southeast Asia for nearly two centuries [5]. Over the last two years over 80 mushroom production systems (MPSs) have been built by farmers in the Kampong Cham region of Cambodia. These structures consist of a wooden frame covered with plastic or cloth to retain heat and humidity and a thatched or metal roof. Inside are wooden racks that hold beds of rice husks on which straw mushrooms grow. Farmers can generally make about $200 per month farming mushrooms, but due to variation in the materials and design not all MPSs work as well as others.

This paper describes the successes and roadblocks in the early stage use of MPSs within a particular village. The insights gained from initial iterations of the technology, system of end-to-end support for farmers, and business model will all be outlined. Although difficulties emerged with temperature control and durability of MPS structures, lack of structure standardization, post-harvest practices, and consistent mushroom supply for buyers, the introduction of mushroom farming in this village was successful overall as many farmers adopted the technology and were able to increase their income. While examining the growth of the specific venture and innovation discussed here, this work also serves as a case study of the process of introducing a technology and means of income generation in a low-resource setting.

II. Supplemental Income Streams for Rice Farmers

As mentioned above, most people in Cambodia farm rice and lack sufficient income, making just over $3 a day on average [6]. This poverty is especially felt in the times between rice harvests, known as "hunger months." Farmers seeking additional means of income often travel to urban areas where they work in garment factories (add other occupations). Urban migration places stress on cities as they receive large influxes of people who are only there temporarily and on rural areas that lose much of their adult male population [6, 7].

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Leaving their homes to work factory jobs also requires farmers to be away from their families, deal with the stress of traveling to and from cities, and perform menial tasks that lack the cyclical nature of farming. People who do not travel to cities for work still need to generate supplemental income to feed their families, educate their children, and make other necessary purchases. Currently, farmers add to their income from rice farming with small-scale poultry farming, pig farming, vegetable farming, and the operation of small shops.

This hardworking, entrepreneurial mindset is well-suited to mushroom production. Cultivating straw mushrooms is an option for farmers that allows them to remain in their homes and produce a lucrative crop (~$3.50/kg) with minimal labor. The added revenue stream from farming mushrooms can stabilize a family's finances so that they can afford not only the essentials but also save up for larger investments. It is also well suited for women entrepreneurs, who have other responsibilities like children and household tasks, because it does not require migration or as much time as rice farming [8].

An MPS design that can be disseminated across Cambodia creates a dependable option for generating income; farmers can avoid "hunger months" and tumultuous moves to cities by farming mushrooms with well-designed, well-tested MPSs.

Figure 1. A mushroom house in rural Cambodia

III. Mushroom Production

The mushroom production cycle includes five major steps: composting, spawning, casing, pinning, and cropping. The entire production cycle takes about 15 weeks, 2-3 weeks of which is the mushroom growth that takes place in an MPS. Mushroom production systems can produce up to 20 kg of mushrooms per square meter, or 120-150 kg per MPS per harvest. The yield is dependent on temperature, humidity, prevention of contamination, and light exchange. Failure to monitor and control each of these factors can result in pests or mold, unprofitable farming, or the failure of mushroom growth [5, 9].

Farmers in Cambodia grow mushrooms in rice straw, as it is widely available. The rice straw is composted in chicken manure, water, clay, and moss. The damp straw is gathered into bundles and laid on the shelves in the MPS. Firewood is used to heat water in metal drums, creating steam that travels through pipes into the MPS, raising the temperature to pasteurize the straw. Once the temperature drops slightly, spores that the farmer has purchased are combined with the straw.

Mycelium – which is like the root system of mushrooms – will begin to form. "Pinheads" or mushrooms in very early stages of growth will appear within a week [9]. At this point, some ventilation and light is necessary for proper growth. 4-5 days after that, they will have progressed to the desired egg and button stages and are harvested before they reach the mature stage, during which the cap fully opens [9].

Figure 2. Straw mushrooms grow from substrate in a mushroom house.

Straw mushrooms are a practical choice for farmers, particularly rice farmers, in Cambodia who are supplementing their income by producing mushrooms. As compared to other mushroom varieties, straw mushrooms are relatively easy to grow and go from spawning to harvest in under 2 weeks [2, 20], so they don't require extensive training or technology and provide a consistent income flow. Since they grow on rice straw, rice farmers don't need to purchase additional material for substrate to grow straw mushrooms and mushroom farming repurposes waste [20]. Mushrooms are also a valuable addition to people's diets, providing protein and essential nutrients/vitamins [20, 5]. Like many mushroom varieties, straw mushrooms are increasing in popularity and are used in traditional foods, restaurants serving primarily the tourism industry, and exports to North America and Europe.

Figure 3. Straw mushrooms for sale at a market in Cambodia.

IV. Technology

The basic design of the MPS structure comes from similar technologies used in Thailand and Vietnam to grow straw mushrooms. It is also dependent on the materials readily available in the village where mushroom farming was first introduced. This village in the Kampong Cham province had access to sources of wood and bamboo for the structure frame

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as well as larger markets where fabric, plastic sheeting, and corrugated metal could be purchased.

World Hope International works with local farmers to design MPSs that have the critical elements for mushrooms cultivation. These elements include racks to hold the substrate, a concrete floor, a structurally sound frame, and a covering to keep steam and heat in the structure. Although farmers receive some guidance during construction there is relatively little information about the structure specifications that optimize mushroom production. For this reason, there is variation in MPSs as farmers iterate to identify the best design. This variation causes productivity to be higher in some MPSs than others. Design, construction, and production data was gathered from 60 MPSs in summer 2017 to analyze what elements are needed for optimal production. The elements identified as drivers of productivity (in terms of kilograms of mushroom yield per area of substrate) are roof type and temperature control, ease of maintenance, and efficiency of input use.

A. Roof Type & Temperature Control

Mushrooms require a specific temperature at different stages of growth, which farmers attempt to attain by opening and closing the plastic and cloth coverings of the MPSs to ventilate the growing crop. However, design decisions, particularly roof material, affect temperature and the farmer's ability to control it.

The most common roof type is aluminum, accounting for 45% of observed house roofs. Corrugated aluminum is a fairly easy material to obtain, but it does a significantly worse job of moderating temperature than most other roof types. Because of this, famers have to adjust, by building overhangs or putting palm leaves on the roof to moderate the temperature. Putting leaves on the roof alone accounts for enough to bring the temperature back down to a usable range. Before putting palm leaves on the roof the interior temperature was reported to be 37-38 degrees Celsius, but after, the temperature dropped to only 33 degrees. This is within the acceptable range of 28 – 34 degrees.

Figure 4. Mushroom house with a metal roof. The farmer has placed palm fronds on top in an attempt to regulate the temperature inside the house

Other roof types include thatched (30% of observed MPSs), palm leaf (8%), and plastic (5%). Thatched roofs have good temperature moderating properties, so these mushroom houses do not require modifications to maintain the optimal growing temperature, but access to a sufficient quantity of raw material prevented some farmers from utilizing this roof type. Palm leaf is about as good at mediating temperature as grass thatched houses. This palm leaf thatch is more readily available than grass thatch, but it is also significantly less durable. Many palm leaf thatched houses had to use plastic to cover holes in the roof, which decreases the insulation ability of the roof. The least desirable roof type is the plastic roof. The plastic typically used for roofs is usually taken from the bags used to store rice straw or mung bean shell, and crudely sewn together to form a roof. This plastic lacks durability, provides poor insulation, and allows a significant amount of sunlight to hit the racks, which is bad for mushroom growth.

B. Ease of Maintenance

When part of a MPS fails, most commonly the bamboo slats on the racks or the plastic, a farmer must find and install an appropriate replacement. Due to the disparities between mushroom houses, there is no standard solution or replaceable part. This means that the farmer must take a significant amount of his or her time to solve a simple issue that could be easily resolved if there was a standard part to buy. Profits for the farmer and supply of mushrooms to the market are both halted while the repair is made. An example of this would be if a section of the roof of an MPS fails. With the wide variety of roof types, fixes are typically improvised, such as covering a hole with plastic bags. Plastic is a poor roofing material, and this haphazard replacement is likely to cost the farmer in production volume.

A similar problem involves adapting the MPS to the specific sun, wind, and weather conditions where it is located. Farmers often try to insulate the side of their MPS that gets sunlight during the hottest part of the day, as mushrooms on the top racks in that side do not grow as well due to high temperatures. Farmers use a few different tactics, including putting cardboard on the bottom of the roof or hanging fabric between the plastic and roof. These are design decisions that should be calculated, rather than improvised. By giving a design recommendation, farmers would not have to spend their time conceiving of and implementing a solution themselves and could use an established process that is engineered to work well.

Figure 5. A mushroom house roof that was damaged in a storm.

C. Efficiency of Input Use

Without a standard structure, there could be no standardized cultivation process fitted to the size, rack configuration, ability to ventilate, or other specifics of the structure. This resulted in some farmers purchasing and using more spores, rice straw, or other inputs without the benefit of higher yields to justify the extra cost. For example, although mushroom house growing areas varies significantly, 82% of mushroom houses where the number of spawn bags used were recorded, used the exact same number of bags: 140. Clearly this is not the most efficient method, as larger houses should use more spawn, and smaller should use less. This would be easily remedied by using a standard size mushroom house, so the optimal ingredient portions could be more rigidly defined.

While farmers' innovations offered insights as to the best design for MPSs, to expand at a large scale MPSs need a proven, standardized design that can be efficiently built and maintained to ensure farmers consistent results.

V. Business Model

Work throughout the last three years has demonstrated both rice farmers' demand for MPSs, with nearly 100 built as of June 2017, and the market's demand for the resultant mushrooms, with over 1500 kg purchased weekly. Thera Metrey's business model involves both purchasing mushrooms from farmers and selling mushrooms at larger urban markets. While Thera Metrey helps farmers to construct their mushroom house at no cost, the farmers purchase the construction materials. Thera Metrey uses carpenters already on staff at World Hope International, minimizing labors costs. These cost are then offset by bulk mushroom sales as explained below.

Thera Metrey buys mushrooms from farmers at a stable price of about $2.80 per kilogram. Although other buyers pass through the area, farmers sell most of their mushrooms to Thera Metrey because of the price stability and competitiveness with these other middlemen. Thera Metrey then transports the mushrooms to Phnom Penh and sells them wholesale for roughly $3.50/kg. This resale is where Thera Metrey makes money, so a consistent supply of mushrooms to resell is tantamount to the venture's success. As the mushroom house structure and growing process becomes more standardized, the daily yield of mushrooms will stabilize. A Kia 1.4-ton cool storage truck was recently acquired to increase the accessibility of Phnom Penh markets for larger sales and profit margins. As one farmer said, "It is a 'Money Truck.' You see truck. I see money." Again, the truck is most profitable when it is at full capacity each night when it travels to Phnom Penh, requiring consistent production from farmers who sell to Thera Metrey.

An additional limit on profits in Thera Metrey's initial model is that lower grade mushrooms sell for half as much as good quality straw mushrooms. A cost-effective way of adding value to these mushrooms is a key opportunity for future development. Another opportunity is expansion to hotels in tourist areas like Siem Reap that want to grow their own food as well as to bordering areas in neighboring countries like Vietnam and Thailand. In addition, there is a growing demand for mushrooms in Cambodia as tourism has increased by over 4 million annual visitors since 2000 [10]. This demand is currently met by imports from Vietnam, but could shift to local farmers if production was made cheaper and more efficient.

An additional revenue stream could come from selling a productized, standardized mushroom house in other areas of Cambodia, instead of having farmers build their own. After refining our design based on the results of field-testing, Thera Metrey will be able to commercialize the standardized MPSs as a product for profit. Farmers will purchase an MPS for $800 and have additional costs per growth cycle of $50-60 for spores and $5-10 for other inputs (firewood, urea, etc.). One cycle from one MPS yields 120-150 kg of mushrooms, which the farmer sells to Thera Metrey for approximately $2.80/kg. Farmers thus conservatively profit $200 per 30-day cycle, or $2400 per year, with an expected ROI of 4 months.

VI. End to End Support

A crucial factor for the overall success of this technology implementation is the integrated approach to design, business strategy, and the implementation process. The goal was to combine existing and new practices and infrastructure to establish a complete system of support from purchase decision to farmer training to technical support, and finally, connecting growers to markets. The introduction of MPSs to this specific village began with a single farmer. He was chosen because of his willingness to learn and his well-respected status in the community. This farmer was trained in the process of growing mushrooms by a local expert. His knowledge was then passed along to other members of the village, reflective of a cultural tradition of helping neighbors and relying on others in the community.

These strong community ties are also integrated in the monthly meetings organized by World Hope. These meetings are open to all mushroom farmers and serve as time for farmers to discuss any difficulties they've been having or new practices they're trying. This is a more efficient and sustainable means of trouble-shooting than World Hope interacting individually with farmers would be.

Figure 6. Monthly farmer meeting

While World Hope ensures that the introduction of the practice of mushroom farming goes smoothly, Thera Metrey acts as a middleman and links farmers to markets in Phnom Penh, which increases people's motivation to start farming mushrooms in the first place. Thera Metrey is a reliable buyer for farmers' mushroom yields. This reduces risk to the farmer, because they know they will have a buyer at a reasonable price for their product.

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Storing and processing the mushrooms they purchase from farmers is a remaining problem for Thera Metrey. Since the mushrooms have to make it to markets in Phnom Penh, a three-hour truck ride away, by 3 or 4am, Thera Metrey can only purchase mushrooms from 7pm to midnight. Straw mushrooms grow so quickly that farmers can harvest more the next morning, but this second harvest will be bloomed and therefore worth less, by the following night's purchase. Context-appropriate storage and processing methods could increase convenience for farmers and profits for Thera Metrey.

VII. Discussion

The introduction of mushroom production as a means of supplemental income in a village in rural Cambodia has shown great promise, with over 80 mushroom houses built in the first 2 years, most of which functioned as intended and were profitable for the farmer. Development of this venture has resulted in the following insights about the technology, business, and venture creation that can be generalized to the adoption of other technologies in low resource settings.

A. *Technology*

- To optimize production, the structure should be standardized to ensure temperature control, durability, and ease of maintenance.
- The process should be standardized as well based on the uniform structure design. This avoids wasting spores and other inputs.
- Farmers made individual choices about their mushroom house design and production process. Allowing flexibility for users' innovations in early stages reveals what works best for those who interact most closely with the technology.

B. *Business Model*

- It is critical that the buying price is kept stable and competitive. This keeps farmers motivated to produce consistently and to sell to Thera Metrey, ensuring a stable profit from mushroom farming.
- A cost-effective way of adding value to low-grade mushrooms would increase profits for farmers and Thera Metrey alike. Unprocessed they sell for significantly less than high-grade mushrooms, causing a loss of profit. This could be recovered if they are used in a valuable product, like mushroom powder.
- The lack of sufficient storage and processing techniques to extend the shelf life of mushrooms led to the loss of a significant amount of product to ripening and veil opening. Development of post-harvest storage and processing processes to increase flexibility of harvest schedule and access to more distant markets.

C. *Venture Creation*

- Creating a complete system to support users from purchasing the technology through accessing markets and continued use and maintenance was critical to Thera Metrey's success. To generate a steady and sufficient supply of mushrooms, Thera Metrey had to create infrastructure for farmer training, access to spores, and ongoing technical support.
- The rapid expansion of mushroom cultivation was accomplished by understanding and incorporating existing cultural norms such as community-based learning into the mushroom farming process. Rice farmers were introduced to the technology through a familiar channel - other community members – and could learn how to farm mushrooms from trusted others.

The expansion of MPS technology as well as the introduction of other technologies for supplemental income generation in low-resource settings should be informed by the struggles and successes previous ventures to maximize their chances of positive impact.

VIII. Conclusion

To evaluate the success of Thera Metrey, we will look at the number of MPS sold, the mushroom output per MPS per harvest, and the number of MPS that recover their investment within six-month. With these metrics, we will be able to monitor farmer demand for MPS, the success of our new design of the physical structure, and the effectiveness of our venture in linking farmers to markets. Our improved design should increase the mushroom yield of each MPS. This, coupled with the development of storage and processing methods, will bring greater profit per harvest to both Thera Metrey and farmers. Higher profits coming from more durable MPS will mean that more MPS recover their investment within six months of construction.

In many developing regions around the world, people are engaged in a variety of money-making endeavors in order to support their families. In these regions, the introduction of opportunities such as straw mushroom production can play a central role in stabilizing many families' financial situations. For efforts of this type to be successful, innovators must consider not only whether or not a technology will work, but also how it will be accepted by the community, how it will fit into or alter existing lifestyles, and if it will address the true needs of the community.

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