frontiers | Frontiers in Sustainable Food Systems

TYPE Perspective
PUBLISHED 16 August 2023
DOI 10.3389/fsufs.2023.1232830

OPEN ACCESS

EDITED BY
B. Mohan Kumar,
Arunachal University of Studies, India

REVIEWED BY
Erlyna Riptanti,
Sebelas Maret University, Indonesia

*CORRESPONDENCE
Yasuhito Okuda
✉ kin-yoku@infosakyu.ne.jp

RECEIVED 01 June 2023
ACCEPTED 28 July 2023
PUBLISHED 16 August 2023

CITATION
Okuda Y (2023) Enhancement of rural agriculture in Japan through industry-academia collaboration: a case of cloud ear mushroom production in Tottori Prefecture. *Front. Sustain. Food Syst.* 7:1232830. doi: 10.3389/fsufs.2023.1232830

Enhancement of rural agriculture in Japan through industry-academia collaboration: a case of cloud ear mushroom production in Tottori Prefecture

Yasuhito Okuda*

Basic Mycology Division II, Tottori Mycological Institute, Tottori, Japan

Rural agriculture is a crucial component of social infrastructure owing to its functionalities including domestic food production, securing income sources, and cultural transmission, which are all essential for local communities. Densifying urban settlements including in Japan has resulted in population outflow from rural areas, undermining rural agriculture. Therefore, to prevent population decline in rural areas, it is effective to create innovative and attractive businesses through industry-academia collaboration. Although mushroom production can be a promising option as a model of sustainable, circular agriculture with low environmental impact, there are very few examples of collaboration. In Tottori Prefecture, Japan, among the major domestically cultivated mushrooms, attempts were made to produce cloud ear mushroom (*Auricularia polytricha*), which was heavily dependent on imports, through industry-academia collaboration. Along with the development of new cultivars suitable for the climate, research was conducted on optimal cultivation conditions, pest control, and post-harvest treatment. As a result, the Tottori Prefecture has achieved the highest production volume of cloud ear mushroom in Japan. This project not only supplies food but also contributes to securing an income source and social welfare because everyone can participate regardless of age or disability. In addition, because no special land or facilities are required for mushroom production, this project can be initiated at a low cost. The characteristics of this project, developed through cooperation between mushroom producers and academic institute, indicate that it is a useful model that contributes to community revitalization as well as mushroom production.

KEYWORDS

agricultural promotion, community revitalization, domestic production, mushroom cultivation, wood ear mushroom

Introduction

Provincial agriculture contributes to the revitalization of local communities by creating jobs, which leads to the security of income sources for residents and the provision of food and cultural inheritance. Globally, urbanization has resulted in farmland fragmentation and soil erosion, which has a significant impact on agricultural sustainability (Caldwell et al., 2022). In Japan, the overabundance of the population in cities tends to deprive rural areas of workers needed for agriculture, thus weakening rural communities. This is due to the scarcity of jobs in rural areas,

as well as the high cost of starting an agricultural business. In addition, as Japan is mountainous, flat-lands suitable for farming are generally scarce. Therefore, it is difficult to expand farmland, which is a disadvantage compared to countries with vast flatlands. Japan's food self-sufficiency rates in terms of production value and calories are 38 and 63%, respectively, which are low compared with other countries (MAFF, 2021). These factors result in low agricultural productivity, making it difficult to maintain the quantity and quality demanded by consumers, and the agricultural processing and marketing supply chains. The key to overcoming this situation is the promotion of agricultural enterprises that satisfy the conditions of job generation and that are also low risk.

Mushroom cultivation methods include log, bag, and bed cultivation (Okuda, 2022). In particular, production using culture bags (bag cultivation) does not require farmland, and some mushroom species, including shiitake mushroom (*Lentinula edodes*) and cloud ear mushroom (*Auricularia polytricha*), can be cultivated in simple facilities. Because the work is light, mushroom cultivation is an ideal agricultural enterprise, which can be an income source for men and women of all ages, including those who have disabilities. In Japan, mushrooms are recognized as important food ingredients because they account for 44% of the forestry industry's production value from forests that occupy nearly 70% of the country's land (Forestry Agency, 2020). In addition and based on available knowledge, no pesticides or chemical fertilizers are used for mushroom cultivation in Japan. Because of these characteristics, mushroom cultivation is regarded as a model of sustainable, circular agriculture with a low environmental impact (Okuda, 2022).

Mushrooms are well-known healthy foods that are high in dietary fiber, vitamin D, and beneficial bioactive ingredients, such as antioxidants and polysaccharides (El-Ramady et al., 2022). Mushroom constituents are also essential for individuals with religious or philosophical dietary restrictions (Okuda, 2022). Cloud ear mushroom (Figure 1A; Supplementary Video S1) is nutritionally characterized by higher levels of dietary fiber, calcium, and vitamin D than other mushroom species (MEXT, 2015). The demand for wood ear mushrooms (*Auricularia* spp.), including cloud ear mushroom, has increased, especially in Asia, and their production volume is ranked third in the world after that of shiitake and oyster mushrooms (*Pleurotus* spp.; Royse et al., 2017). As the second largest mushroom producer after China (FAOSTAT, 2022), Japan predominantly cultivates the following mushroom species (Forestry Agency, 2022): enokitake (*Flammulina velutipes*), bunashimeji (*Hypsizygus marmoreus*), shiitake, maitake (*Grifola frondosa*), eryngii (*Pleurotus eryngii*), wood ear mushrooms (called "kikurage group" in Japanese; mainly cloud ear mushroom, *A. polytricha*, and black ear mushroom, *A. auricula-judae*), and nameko (*Pholiota nameko*). Wood ear mushrooms are distributed as fresh and dried products, and their domestic consumption is ranked 6th (fresh weight: 25,025 tons; Forestry Agency, 2022). Thus, although there is a high demand for wood ear mushrooms in Japan, but 87.9% of the country's consumption relies on imports from China, creating dependency on foreign products (Forestry Agency, 2022). However, in recent years, risks such as misrepresentation of the origin of imported agricultural products, and the negative impact of residual pesticides have become apparent in imported agricultural products, and there is a growing demand for domestically produced mushrooms, especially wood ear mushrooms.

Academic achievements remain at the basic research level, requiring time and money to commercialize. Industry-academia collaborations make it possible to establish innovative businesses that can adopt the findings of valuable agricultural research. However, there are very few examples of industry-academia collaboration related to mushroom production worldwide (Zhang et al., 2014; Febrianda and Tokuda, 2017), and countries and producers considering food production need a report of successful examples. Tottori Prefecture has the smallest population and is a local government with the smallest gross prefectural domestic product in Japan (Statistics Japan, 2023). Considering the demand for domestically produced mushrooms, the Tottori Mycological Institute (TMI; Tottori, Japan), a research institute specializing in mushrooms, and the mushroom producers in Tottori Prefecture launched a cloud ear mushroom production project in 2015. At that time, the tendency to rely on imported products resulted in the vulnerabilities of the technologies related to cloud ear mushroom cultivation in Japan, such as cultivars, cultivation conditions, and post-harvest processing. By clearing these issues and establishing a business base, this project has achieved the highest production volume in Japan and has revitalized the entire domestic production of cloud ear mushroom (Forestry Agency, 2022). In this study, the author provide a case study and a perspective of a cloud ear mushroom production project utilizing industry-academia collaboration within a small local government area, the Tottori Prefecture.

Area data

The Tottori Prefecture is located in the Chugoku region of western Japan and consists of 19 municipalities (Figure 2A). The coordinates are lat. 35°20′N and long. 133°49′E, and extends 125.4 km east to west and 61.8 km north to south, with a geographical area of 3,507 km^2. The annual average temperature from 1991 to 2020 was 15.7°C, and the annual sunshine hours totaled 1793.1 h (JMA, 2022). In summer, the highest temperature in Japan is recorded (39.2°C in 2021), while in winter, the lowest temperature is 5°C or less, and it is recognized an area with drastic temperature changes depending on the season. Specialty products include crabs, watermelon and Japanese pear. In addition, 10 hot spring resorts serve as tourism resources. Tottori Prefecture has the smallest population in Japan (less than 550,000). According to a survey by the Cabinet Office, Tottori's gross prefectural domestic product was the lowest of all 47 prefectures at 1.908 trillion yen (approximately $15 billion in 2023; Statistics Japan, 2023). It was imperative to develop agricultural business models that overcome these geographical, climatic and economic characteristics that are unfavorable for cloud ear production and related commercial activities.

Historical background to the cloud ear mushroom market in Japan

Japanese statistics on the production, import, and consumption volumes of wood ear mushrooms are customarily summarized as the "kikurage group" (mainly cloud ear and black ear mushroom), which are commercially distributed to the domestic market. The exact import and consumption volumes of cloud ear mushroom alone are unknown. However, it is clear that cloud ear mushroom make up the

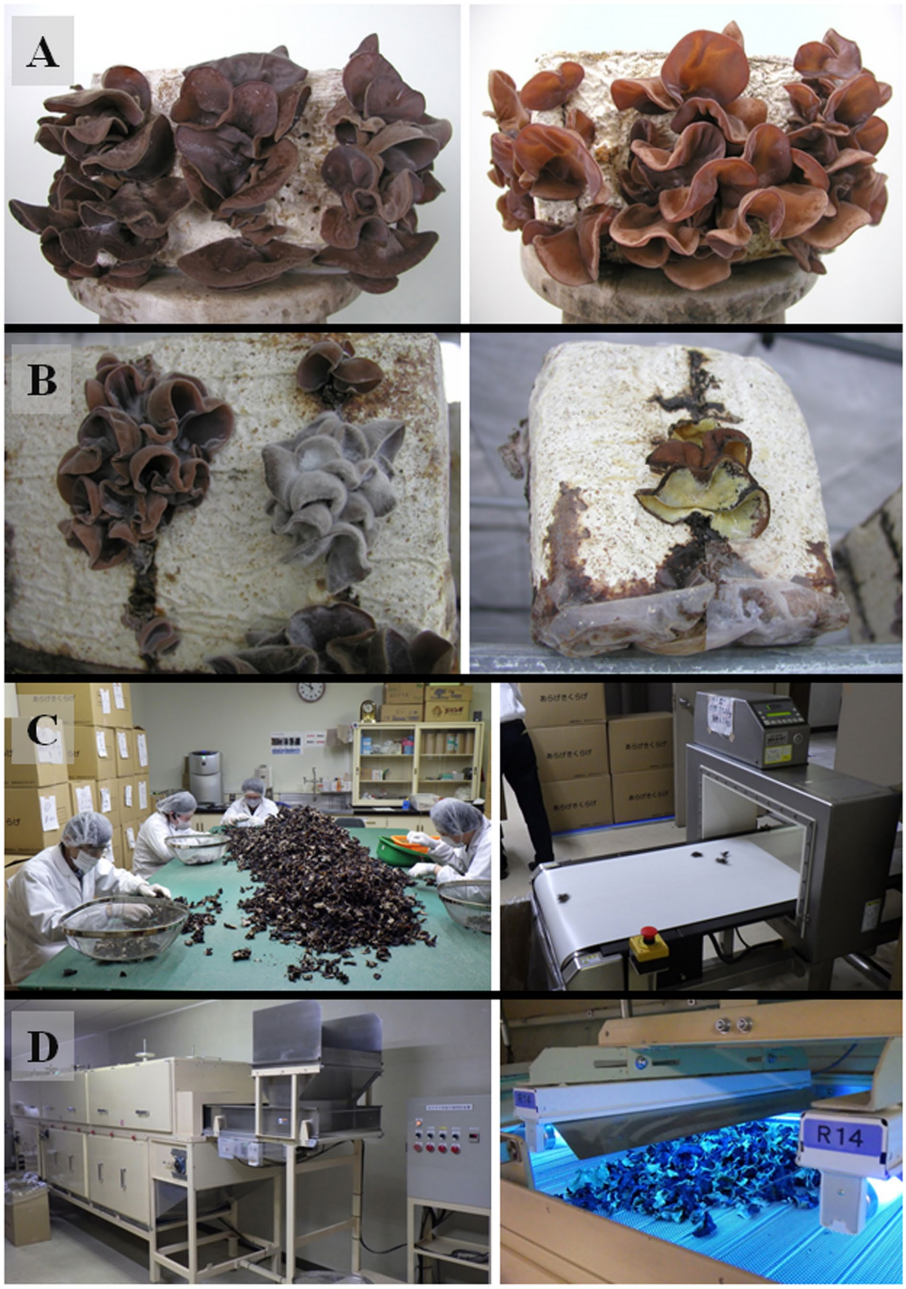

FIGURE 1
Processes from cultivation to post-harvest treatment in cloud ear mushroom production project in Tottori Prefecture. **(A)** Left: "Kinko AP1 go"; Right: common cultivar. The color of "Kinko AP1 go" does not fade in any environment or condition. **(B)** Cottony leak disease by *H. pseudocorticiicola*. Left: right side cloud ear mushroom fruiting bodies are covered by symptoms thickening of cotton-like hyphae. Right: A late symptom that turned into a yellow symptom and formed numerous asci. **(C)** Double-check of sorting by human and metal detector. Left: sorting to remove faded colored mushrooms and foreign substances. Right: sorting to remove metal substances. **(D)** Left: ultraviolet irradiator for vitamin D enhancement. Right: the lid was opened to confirm UV irradiation.

majority of the domestic production volume in the "kikurage group." According to statistics in 1985, domestic production was 230 tons, with imports of 1,542 tons, indicating that dependence on imported products continues to this day (Forestry Agency, 2022).

Long-term dependence on imported products has stagnated the development of domestic cloud ear mushroom cultivars. The production capacity of cloud ear mushroom with only five officially registered cultivars was clearly vulnerable to shiitake mushroom, *F. velutipes*, and *H. marmoreus*, which have 215, 51, and 61 cultivars, respectively (MAFF, 2023a). Therefore, there was an urgent need to develop cultivars that would meet the demands of both domestic producers and consumers. Cloud ear mushroom has similar culture characteristics to shiitake mushroom and is cultivated using culture bags containing medium composition based on broad-leaved trees

FIGURE 2
Location and the producers of Tottori Prefecture in Japan. **(A)** Location of the cloud ear mushroom producers in Tottori Prefecture. **(B)** Left: simple cultivation facility without air conditioning equipment. Right: cultivation facility with air conditioning equipment. Cold and warm air from the air conditioner comes out from the hose (yellow arrow) at the center of the room.

(Fagaceae family) sawdust (Figure 1A; Supplementary Video S1). The production of cloud ear mushroom was low at the time; hence, consideration of the specialized medium composition was neglected, and that of shiitake mushroom was diverted to cloud ear mushroom cultivation. Therefore, further research and development were required to find a specialized medium to support cloud ear mushroom production. In this way, the establishment of a production base required resolving issues, such as practical breeding and improvement of cultivation technology.

Insecticides, including methamidophos and chlorpyrifos, in imported wood ear mushrooms have been detected in excess of the national Japanese standards (Tanaka and Utsumi, 2007). These risks have heightened consumer demand for domestic production of wood ear mushrooms, including cloud ear mushroom, which have been imported in large quantities. The restaurant chain Ringer Hut Co., Ltd. (Tokyo, Japan), which has been using only domestically grown vegetables since 2009, responded quickly.[1] To meet consumer demand for domestic cloud ear mushroom products, the company partnered with the Tottori Mycological Institute (TMI), starting a production project in 2015. This has transformed and revitalized the domestic market for cloud ear mushroom into a "blue ocean," which means an attractive untapped market. The domestic production of major mushrooms in Japan is almost stagnant, with a 0.3% decrease in production between 2012 and 2021 (Forestry Agency, 2012, 2022). In contrast, the domestic production of cloud ear mushroom increased by 370% from 819.2 tons to 3031.1 tons over the past 10 years. Riding this wave, cloud ear mushroom production in Tottori Prefecture has grown rapidly from 54.3 tons to 268.6 tons in 7 years since 2015, resulting in the Prefecture becoming the primary producer in Japan (Forestry Agency, 2015, 2022).

Input by the mushroom production industry

In 2015, a few producers initiated cloud ear mushroom production project. The required quantity and quality improved,

1 https://www.ringerhut.jp/

and the scale of production expanded to one individual and seven corporations, making it a corporation-based project by 2023 (Figure 2A). The production of cloud ear mushroom consists of three processes: (1) culture bag preparation, which includes medium composition, sterilization, inoculation, and incubation; (2) cultivation, which includes growing and harvesting mushrooms after providing a stimulus for fruiting; and (3) post-harvesting, which includes the excision of the mushroom base, washing, and drying. The sterilization apparatus for the production of culture bags requires a relatively high initial investment. Therefore, only a few mushroom producers installed the apparatus, prepared culture bags, and distributed them to other producers. Cultivation using culture bags, including cloud ear mushroom, has an advantage over other agricultural methods in that no farmland is required, and only a simple facility is necessary for the bag cultivation process. In particular, cloud ear mushroom needs to be maintained in a warm and humid environment at a temperature of 20°C or higher and a humidity of 70% or higher. This method is simple because it does not require the precise cultivation controls such as air conditioning used for other cultivated mushroom species. In simple facilities, mushroom producers cultivate cloud ear mushroom during the warm season from spring to fall, and shiitake mushroom during the cold season from autumn to spring (Figure 2B). Therefore, initial investments in the cultivation of cloud ear mushroom are low. Larger producers can extend year-round cultivation in air-conditioned facilities (Figure 2B).

The population of Tottori Prefecture continues to decline owing to depopulation and aging, and the closure rate of elementary schools is high compared to the rest of the other prefecture. An unexpected benefit of such closures is the possibility of using an abandoned school site as a workshop for cultivation and post-harvest processes. In Tottori Prefecture, restaurants, cafés, lodging facilities, and shared offices use abandoned school buildings.[2] A mushroom cultivation facility that uses heat from hot springs is an example of the utilization of Tottori's unique local resources. Hot water can be sprayed throughout the facility to maintain the correct temperature and humidity even during winter. The cultivation of cloud ear mushroom requires relatively less hard work, and individuals of all ages can participate regardless of their age or disability. This fits well with the care farming approach, which is the therapeutic use of farming practices. Particularly in European countries, care farming is a promising example of multifunctional agriculture (Hassink et al., 2020). Tottori Prefecture has a high percentage of people aged 65 and over in the total population and ranks 14th among the 47 prefectures (MIC, 2022). Several elderly and disabled people are currently participating in this project; Cooperation between agriculture and welfare is an initiative to realize their social participation and, moreover, to add valuable workers to the agricultural industry. Thus, the production of cloud ear mushroom contributes not only to the food supply but also to social revitalization by securing income sources and promoting social welfare.

Although still expensive compared with imported products, the domestic price of cloud ear mushroom is gradually declining. Consumers welcome the drop in prices of domestic products. Mushroom producers need to strengthen their competitiveness by considering conversion to organic farming. However, conversion to organic farming generally carries the risk of lower productivity, higher labor costs, and higher prices in exchange for added value (Crowder and Reganold, 2015; Reddy et al., 2022). Mushroom production typically does not use pesticides or chemical fertilizers (Okuda, 2022), and conversion does not reduce productivity or increase personnel costs. However, there is a slight increase in costs associated with adopting the materials required to obtain organic certification. Although organic agricultural products are common in Japan, there are few certified organic mushroom producers.[3] In this project, to add rarity to the Tottori Prefecture's cloud ear mushroom and strengthen its competitiveness, all producers obtained organic certification with the support of the Tottori prefectural government. The acquisition of organic certification not only improves the price by upgrading quality but is also an effective means of strengthening competitiveness in terms of raising awareness of hygiene among producers, such as preventing contamination.

Input from academia: the Tottori mycological institute

The Tottori Mycological Institute (TMI) played an academic role in the cloud ear mushroom production project. To match the requirements of producers and consumers, the author at TMI developed a cultivar that suits the materials and conditions for mushroom cultivation in Japan as well as the morphology, yield, and color of breeding targets. Because the color of cloud ear mushroom fades under poor cultivation conditions, resulting in a decline in market value, it was important to impart a trait that stabilizes the color under all cultivation conditions (Figure 1A). Considering these points, a new cultivar, Kinko AP1 go, was developed (Figure 1A; Supplementary Video S1; MAFF, 2023a). Typically, cloud ear mushroom requires 60 days of incubation in the culture bags for initiation of the development process. The author enabled the shortening of the incubation period from 60 days to 30–50 days by adding materials such as shell fossil powder (the main component being calcium carbonate) and dried soybean curd residue to the medium (Okuda et al., 2021, 2022). This cultivar, which has gained competitiveness by acquiring specific traits and optimized cultivation conditions, has contributed to the successful production of cloud ear mushroom in the Tottori Prefecture. Furthermore, this cultivar has become a catalyst to the expansion of domestic production of cloud ear mushroom generally, but more particularly in western Japan.

With the increase in the production of cloud ear mushroom, the problem of pests has become more apparent. Previously, damage to cloud ear mushroom has been caused by slugs, moth larvae (Yoshimatsu et al., 2014), and fly larvae (Sueyoshi et al., 2015). In the Tottori Prefecture, cottony leak disease caused by *Hypomyces pseudocorticiicola*, an ascomycete fungus, is emerging as a new

2 https://satomono.jp/school/31329/27027/

3 https://www.maff.go.jp/j/jas/jas_kikaku/yuuki_jigyosya_list.html

disease that cause considerable problems (Figure 1B; Okuda et al., 2016). This disease manifests as a thickening of cotton-like hyphae on the cloud ear mushroom, which inhibits growth (Figure 1B). In mushroom cultivation, pest control is generally not achieved by using pesticides. Therefore, it is difficult to take measures against pests through symptomatic treatment, and it is important to establish environmental conditions that prevent pests from occurring. Preventive measures include cleaning the cultivation room and ensuring that the mushrooms are not constantly wet as cultivation management.

Post-harvest quality control is important to gain the trust of supply chains and consumers, leading to the expansion of production. Cloud ear mushroom gets easily mixed with insects and fragments of the medium during harvest; therefore, washing is essential. After washing, it is important to use a mechanical dryer instead of drying in the sun to avoid contamination by insects, gravel, and dust during outdoor drying. TMI collects the harvested products from producers, sorts them to remove faded colors and foreign substances, and prevents contamination using metal detectors to improve mushroom quality (Figure 1C). Vitamin D, which is more abundant in cloud ear mushroom than in other mushrooms, is an important nutrient that distinguishes cloud ear mushroom from other mushroom types. Although mechanical drying has the advantage of reducing foreign matter contamination, it does not involve exposure to ultraviolet rays contained in sunlight; therefore, the vitamin D content decreases. With this process at TMI, the amount of vitamin D in the mushroom increased by approximately three times or more using an ultraviolet irradiation device (Figure 1D). The implementation of these processes will contribute to meeting the strict quality demands of consumers.

TMI has promoted the production of cloud ear mushroom in Tottori Prefecture by developing a new cultivar and cultivation techniques and establishing post-harvest processes. In addition, the establishment of technology that forms the backbone of the quality and dissemination of information has earned social trust in these products. However, the differences in approaches and intentions between industry and academia in collaborative projects concerning commercial activities are sometimes fatal. Therefore, TMI not only conducts research activities as an academic institution but also participates in this project as a producer with organic certification. The flexibility of the TMI system facilitates the relationship between industry and academia and strongly contributes to business development.

Contribution of Tottori Prefecture

Tottori Prefecture has a large temperature difference between the four seasons, and the cultivation period for cloud ear mushrooms, which require a warm climate, is limited to 6 months from April to October. Tottori Prefecture is not an ideal environment for the cultivation of cloud ear mushroom compared to warmer southwestern Japan. In addition, Tottori Prefecture has the smallest population in Japan and a correspondingly limited economy. This project's success was supported by the contribution of the Tottori Prefecture government. They supported basic research, stabilized supply, and marketing to accelerate the establishment of new mushroom industries including cloud ear mushroom in the prefecture (Tottori Prefecture, 2013).

Organic agricultural products in Japan are confirmed by certification bodies to be in compliance with the Japanese Agricultural Standard (JAS). These certification bodies are third-party organizations registered with the Ministry of Agriculture, Forestry and Fisheries of Japan. In the Tottori Prefecture, the prefectural government has become a certification body (MAFF, 2023b), which has significantly reduced the fees borne by producers to 1/10. The active support of the prefectural government is important as an intermediary between industry and academia, as well as for providing a bird's-eye view, which enables partners to deepen their collaboration.

Conclusion

In terms of intellectual property utilization, academia is considered a closed innovation type. As a result, regardless of groundbreaking research and development, commercialization was often delayed due to the closed structure. In this project, through industry-academia collaboration, this has allowed knowledge from research, such as cultivars and cultivation techniques, together with the use of local resources, to be effectively transferred and used, making it a good example of open innovation. Also, in this project, labor can be performed by anyone, regardless of sex, age, or disability, which contributes to securing an income source for those who might otherwise be excluded from the rural workforce, thus enhancing social welfare in the region. In addition, this mushroom production does not require special land and uses simple cultivation facilities. This project model indicates the contribution to the mushroom production and regional revitalization regardless of province or national development stage.

Although the market for cloud ear mushroom in Japan is currently a "blue ocean" compared to other mushrooms, challenges still remain. Domestic products are still two to five times more expensive than imported products and thus lack international competitiveness. Although efficiency and scalability are necessary, there are concerns regarding the damage caused by physiological disorders resulting from the cultivation environment, such as high CO_2 and excessive humidity. Cloud ear mushroom production in Japan, including this project, is currently at a crossroad; its expansion must be achieved by continuously strengthening competitiveness of the industry through output from the academic side.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

The author confirms being the sole contributor of this work and has approved it for publication.

Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2023.1232830/full#supplementary-material

SUPPLEMENTARY VIDEO S1

Growth of cloud ear mushroom "Kinko AP1 go." Cloud ear mushroom is incubated in culture bags for 60 days, and the development process is initiated by providing a stimulus for development by linear cutting with a knife. This cloud ear mushroom was cultivated at a temperature of 23±1°C, a humidity of 96±2% and an illumination of 200lux. Usually, in the author's laboratory, it is cultivated under 8 h of light and 16 h of darkness; however, for photography, it is cultivated under constant light. This video was created by taking photographs at hourly intervals for 10 days and combining them.

References

Caldwell, W., Epp, S., Wan, X., Singer, R., Drake, E., and Sousa, E. C. (2022). Farmland preservation and urban expansion: case study of southern Ontario, Canada. *Front. Sustain. Food Syst.* 6:777816. doi: 10.3389/fsufs.2022.777816

Crowder, D. W., and Reganold, J. P. (2015). Financial competitiveness of organic agriculture on a global scale. *Proc. Natl. Acad. Sci. U. S. A.* 112, 7611–7616. doi: 10.1073/pnas.1423674112

El-Ramady, H., Abdalla, N., Badgar, K., Llanaj, X., Törős, G., Hajdú, P., et al. (2022). Edible mushrooms for sustainable and healthy human food: nutritional and medicinal attributes. *Sustainability* 14:4941. doi: 10.3390/su14094941

FAOSTAT. (2022). Food and agriculture Organization of the United Nations Statistics Database. Available at: http://www.fao.org/faostat/en/#data (accessed April, 2023).

Febrianda, R., and Tokuda, H. (2017). Strategy and innovation of mushroom business in rural area Indonesia: case study of a developed mushroom enterprise from Cianjur district, West Java, Indonesia. *Int. J. Soc. Sci. Stud.* 5, 21–29. doi: 10.11114/ijsss.v5i6.2304

Forestry Agency (2012). Special forest products production statistics survey (2012). Available at: https://www.maff.go.jp/j/tokei/kouhyou/tokuyo_rinsan/ (Accessed April, 2023).

Forestry Agency (2015). Special forest products production statistics survey (2015). Available at: https://www.maff.go.jp/j/tokei/kouhyou/tokuyo_rinsan/ (accessed April, 2023).

Forestry Agency (2020). Annual report on Forest and forestry in Japan. Available at: https://www.maff.go.jp/e/data/publish (accessed April, 2023).

Forestry Agency (2022). Special forest products production statistics survey (2021). Available at: https://www.maff.go.jp/j/tokei/kouhyou/tokuyo_rinsan/ (Accessed April, 2023).

Hassink, J., Agricola, H., Veen, E. J., Pijpker, R., de Bruin, S. R., van der Meulen, H. A. B., et al. (2020). The care farming sector in the Netherlands: a reflection on its developments and promising innovations. *Sustainability* 12:3811. doi: 10.3390/su12093811

JMA (2022). Japan meteorological Agency. *Historical Weather Data in Tottori*. Available at: https://www.data.jma.go.jp/obd/stats/etrn/view/annually_s.php?prec_no=69&block_no=47746&year=2023&month=&day=&view= (Accessed April, 2023).

MAFF (2021). Ministry of Agriculture, Forestry and Fisheries of Japan. *Food self-sufficiency rate in Japan*. Available at: https://www.maff.go.jp/j/zyukyu/zikyu_ritu/012.html (Accessed April, 2023).

MAFF (2023a) Ministry of Agriculture, Forestry and Fisheries of Japan. *Japan plant variety registration system*. Available at: http://www.hinshu2.maff.go.jp/en/en_top.html (Accessed April, 2023).

MAFF (2023b) Ministry of Agriculture, Forestry and Fisheries of Japan. *List of accredited certification bodies (domestic)*. Available at: https://www.maff.go.jp/e/policies/standard/specific/Organic_CB_domestic.pdf (Accessed April, 2023).

MEXT (2015). Ministry of education, culture, sports, science and Technology in Japan. Standards tables of food composition in Japan−2015- (seventh revised edition). Available at: https://www.mext.go.jp/en/policy/science_technology/policy/title01/detail01/sdetail01/sdetail01/1385122.htm.

MIC (2022). Ministry of internal affairs and communications. *Population estimate*. Available at: https://www.stat.go.jp/data/jinsui/2021np/index.html (announced date April 15, 2022).

Okuda, Y. (2022). Sustainability perspectives for future continuity of mushroom production: the bright and dark sides. *Front. Sustain. Food Syst.* 6:1026508. doi: 10.3389/fsufs.2022.102650

Okuda, Y., Horio, K., Tabuchi, A., and Fukushima-Sakuno, E. (2022). Shortening of the incubation period by adding dried soybean curd residue (okara) in *Auricularia polytricha* cultivation. *Mushroom Sci. Biotechnol.* 30, 155–159. Available at: https://cir.nii.ac.jp/crid/1520577215680372480

Okuda, Y., Nagasawa, E., Hase, K., Murakami, S., and Tokiwa, T. (2016). Cottony leak on cultivated *Auricularia nigricans* caused by *Hypomyces pseudocorticiicola*. *Reports of the Tottori Mycological Institute* 46, 23–29. Available at: https://agriknowledge.affrc.go.jp/RN/2010903607

Okuda, Y., Tabuchi, A., and Fukushima-Sakuno, E. (2021). Effect of adding shell fossil in *Auricularia polytricha* cultivation. *Mushroom Sci. Biotechnol.* 29, 75–78. doi: 10.24465/msb.29.2_75

Reddy, A. A., Melts, I., Mohan, G., Rani, C. R., Pawar, V., Singh, V., et al. (2022). Economic impact of organic agriculture: evidence from a Pan-India survey. *Sustainability* 14:15057. doi: 10.3390/su142215057

Royse, D. J., Baars, J., and Tan, Q. (2017). "Current overview of mushroom production in the world" in *Edible and medicinal mushrooms: Technology and applications*. eds. D. C. Zied and A. Pardo-Giménez (Hoboken, NJ: John Wiley and Sons Ltd), 5–13.

Statistics Japan (2023). "List of Japanese prefectures by GDP" in *Japan Statistical Yearbook 2023. II-3-10* Available at: https://www.stat.go.jp/data/nenkan/72nenkan/index.html

Sueyoshi, M., Murakami, Y., Kawaguchi, M., Obatake, Y., and Maeda, Y. (2015). *Neoempheria bifurcata* Sueyoshi, 2014 and *N. carinata* Sueyoshi, 2014 (Diptera, Mycetophilidae), feeding on cultivated shiitake mushroom, maitake mushroom, and cloud ear fungus. *Bull. FFPRI* 14, 43–47. Available at: https://agriknowledge.affrc.go.jp/RN/2010891500

Tanaka, M., and Utsumi, H. (2007). Food import violations after the implementation of the positive list system for agricultural chemicals. *J. Pestic. Sci.* 32, 430–434. doi: 10.1584/jpestics.32.430

Tottori Prefecture (2013). Tottori Prefecture agriculture, forestry and fisheries department. *Medicinal Mushroom Cultivation Practical Promotion Project*. Available at: http://db.pref.tottori.jp/yosan/25Yosan_Koukai.nsf/c3f59f6b9ef5cc11492574820029de35/7d14e5f2c87e7a4949257b75002347ab?OpenDocument (Accessed April 2023).

Yoshimatsu, S., Murakami, Y., and Maeda, Y. (2014). Two noctuid moths (Lepidoptera) feeding on cultivated ear fungus, *Auricularia polytricha* (Montagne) Saccardo. *Lepidoptera Sci.* 65, 26–29. doi: 10.18984/lepid.65.1_26

Zhang, Y., Geng, W., Shen, Y., Wang, Y., and Dai, Y.-C. (2014). Edible mushroom cultivation for food security and rural development in China: bio-innovation, technological dissemination and marketing. *Sustainability* 6, 2961–2973. doi: 10.3390/su6052961