HUNGARIAN AGRICULTURAL ENGINEERING
N° 29/2016 5-10
Published online: http://hae-journals.org/
HU ISSN 0864-7410 (Print) / HU ISSN 2415-9751(Online)
DOI: 10.17676/HAE.2016.29.5

PERIODICAL OF THE COMITTEE OF AGRICULTURAL AND BIOSYSTEM ENGINEERING OF
THE HUNGARIAN ACADEMY OF SCIENCES
and
SZENT ISTVÁN UNIVERSITY
Faculty of Mechanical Engineering

TECHNOLOGY INNOVATION IN SUSTAINABLE GROWING AND DISTRIBUTION OF KING OYSTER MUSHROOM

Author(s):
B. Gyenge[1] – T. Kozma[1] – B. Almádi[1] – J. Szarvas[2] – G. Villás[2] – M. Urvölgyi[2]

Affiliation:
[1]Szent István University Faculty of Economics and Social Sciences Department of Operations Managament and Logistics, Páter Károly u. 1. H-2100, Gödöllő, Hungary
[2]Mushroom Spawn Plant and Strain Research Laboratory, Biokékes Nonprofit Ltd., H-3395 Demjén, Top. Nr. 0287/8.

Email address:
gyenge.balazs@gtk.szie.hu, kozma.timea@gtk.szie.hu, bernadett.almadi@gmail.com, szarvasjozsef@hotmail.com, koronalab@gmail.com

Abstract

Mushrooms are great food for humans with low energy content but high nutritional values. While in most Asian countries growing, eating exotic mushrooms as well as their medical use have a long tradition, unfortunately we do not make use of their potential hidden value here in Europe.

The aim of our current work is to work out growing king oyster mushroom [Pleurotus eryngii (DC.:Fr.) Quél.] adapted to Hungarian resources and Far Eastern polypropylene bottled technology while the efficiency of investment and growing was examined how to meet the expectations of sustainable farming.

To grow this species, the growing organic substrate was based on using mainly agricultural, industrial and forestry by-products and formed by considering Hungarian opportunities since this species is capable of degrading and utilising different lignocellulose materials.

In the course of the work polypropylene bottled technology in line with an automated system was first used in growing this excellent edible mushroom species in the Carpathian Basin. In the future this technology can mean the base for growing not only P. eryngii but also other mushroom species (e.g. Flammulina velutipes, Hericium erinaceus, Hypsizygus marmoreus etc.) at plant-level sustainable production.

Keywords

mushroom growing, sustainable farming, supply chain, sustainable production, polypropylene bottled technology

1. Introduction

From nutritional and physiological aspect mushrooms are really valuable foods having low energy, containing various minerals, fibres, essential amino acids and important vitamins.

Several varieties have healing effects but traditional ones are also delicious and cheap food for many of us. More and more people recognize mushroom as a kind of gastronomic delicacy. Mushroom is the best friend of those who are on a diet or living with diabetes because it does not contain fat (0 g), it has only traces of carbohydrates and calories. It is a real "vitamin bomb" because it contains a high amount of vitamins B1, B2, C and D, magnesium, iron, phosphorus, zinc, potassium, copper, selenium, manganese, niacin, pantothenic acid, folic acid, especially in case of oyster mushroom which at the same time reduces cholesterol and has healing effects. Its economic importance is great since it can be grown based on plants, established several times a year meanwhile it provides growers with economic income in a sustainable way.

The unique significance of mushroom growing is that by its nature it can be grown in a sustainable way because it does not have any negative effects on the landscape, does not cause unwanted pollution, is very income intensive and the participants can earn a good living from it, too. It cannot be neglected that it utilises several by-products and supplies the energy sector or agriculture with them.

The success of mushroom growing depends on whether we find a unique growing technology version and an effective cooperation strategy by which the success of the whole supply chain can be maintained.

In the past years several innovative technological developments were made which markedly change mushroom growing and farming method as well as its sustainability aspects.

For some people mushroom growing seems to be difficult and risky while it can bring huge profit to others. The explanation for this substantial difference can be often found in innovation or its lack. Maybe it is accidental that both in the biggest competitor countries (like Poland) and in Hungary several innovative development experiments concerning technology and reaching customers were and are being carried out these days.

Originally in the home country of mushroom growing, so in France growing was taking place is stone mines and cellars [1], however, today completely new technologies appear.

It is a key question that we should learn and evaluate the possibilities, expectations of the new technologies as soon as possible.

2. Methodological background

In our study we intend to evaluate and analyse the latest technological development possibilities by comparative analysis. By a detailed analysis of the technology selected in the experiment we wish to state what advantages and disadvantages the new technology has, and whether the advantages exceed the disadvantages.

During the analysis we do not only want to concentrate on growing technology questions but also judge the real added values of the development alternatives and long-term

sustainability at the level of the whole supply chain. The final decision is made from the aspect of the customer, the end point of consumption. It is a proved fact that nowadays neither products nor rival enterprises but whole supply chains are competing in the market [2, 3]. In this fierce situation those companies and participants will be the winners who can satisfy customers' dynamically changing needs faster and more exactly, or can provide the customers with their needs regularly and in a reliable way.

With our method we would like to make inductive conclusions based on our experiences in our growing experiment which is still an ongoing research today. We want to reveal and summarize the preliminary results of these experiments in a scientific way.

Besides these we wish to compare certain technological alternatives in the comparative analysis carried out in the study, and on the basis of the experiences we want to use the method of giving recommendations to make them improve.

3. Discussion

Introducing the king oyster mushroom:

The king oyster mushroom [Pleurotus eryngii (DC.:Fr.) Quél.] is the king of the oyster mushrooms, less known among the consumers but delicious and nutritious mushroom variety.

Like the examined mushroom varieties, those of "higher value" have the following characters Szarvas [4]:

- consuming mushrooms can meet the protein need for those who do not eat animal source food or for countries which lack animal proteins;
- we can regard mushrooms as dietetic foods;
- as supplementary foods and products containing healing substances, mushrooms offer unexploited treasures for natural therapies;
- they can well match vegetarian meals.

In many parts of Hungary and Europe the king oyster mushroom grows outdoors, unlike other oyster mushrooms they do not live on wood parts but on the dead taproot of the tumbleweed which gives the Hungarian name, too [5]. The intensive growing of the king oyster mushroom began in Hungary in 1950 for the first time in the world [6].

At present the biggest countries of growing king oyster mushrooms are Japan, China, Korea and Italy. Regarding quantity, its growing in China increased from 21,000 tons to 114,000 tons between 2001 and 2003 [7], and the Italian demand also exceeds the 2,000 tons per year [8]. Wild varieties of this mushroom are collected and sold freshly at the local markets both in Italy and Spain. In the United States of America its growing for sales began in 2000 and 85 tons were grown until 2004 [9, 10]. Its favourable character is that it can be stored for a long time and its market price is high [11]. The mushroom belonging to the oyster mushroom family is the most delicious grown variety, both fresh (packed on trays) and processed (mushroom slices, dried mushroom, mushroom powder, mushroom cans, Chinese growers put them in salty juice and pack them in metal cans or plastic bags then sell them). The price of the mushroom can be really high if the product comes from organic farms free from chemicals and pesticides, and the consumers should know this information as well.

The significance and varieties of growing king oyster mushrooms:

Growing mushrooms is important because it can match the value network of other agricultural activities because they can utilise (practically recycle) various agricultural by-products and wastes and this way they provide new valuable food for mankind.

Regarding the king oyster mushroom four growing methods are known as usual:

- plastic bag,
- cover,
- bottled,
- outdoor method [12].

Plastic bag method: The essence of this method is that the mushroom compost is put into different (0.5-5.0 kg of weight) polypropylene sometimes polyethylene bags; after sterilizing the material the bags are inoculated and homogenized.

The permeating and ripening of the mushroom threads take 15-25 days on average at 23-25°C then the temperature is reduced to 10-18 °C so as the spawns (primordia) should grow. After that the bags are opened in order to make the fruit bodies grow. After the first growing cycle the wasted compost is usually thrown away [13, 14].

Cover method: This method is usually used when concerning the climate there is a less controlled growing environment available. In this case there is a need to prevent the water loss of the compost. Interestingly, the mushroom does not tolerate posterior water replacement. The cover layer (peat, sand, soil etc.) is loaded up to 1.5-3 cm after permeating the compost. With this method three growing cycles can be reached [10]. Győrfi and his colleagues [15] pointed out the positive effect of the cover on the harvest.

Bottled method: As for the method applied in Japan, Korea, China and slightly in the USA the soil is put into recycled polypropylene bottles (of 850-1050 ml), and after sterilization and inoculation the upper part of the bottles are foiled and after the removal of the foil the first fruit bodies can be expected to grow. With this method a growing cycle can be achieved but it is up to the way of inoculation (liquid, side cut etc.) and the clever placement of the bottles [10, 11, 13].

Outdoor growing: The cover method mentioned above can be used for outdoor growing as well. This method is mainly applied in Italy. The plastic bags containing the soil are pasteurized, inoculated and incubated indoors. After permeating is completely over, the plastic bags are removed and the soil is placed into a ditch outdoors and covered by the soil found there. A metallic structure is built with the purpose of shielding and protecting then covered by cloth. Watering is carried out periodically [16]. The disadvantage of the method is that it has to be adjusted to the seasonal period, however, the growing period can be extended with appropriate placement [10]. In growing experiments the most common measurement and quality parameter is Biological Efficiency, BE(%). Defining BE is as follows:

$$BE(\%) = \text{mushroom fresh weight} / \text{compost dry weight} \times 100$$

Formula 1. The definition of Biological Efficiency, BE% [17]

Another useful parameter is Productivity (P%), which was defined by this formula:

$$P(\%) = \text{mushroom fresh weight} / \text{compost fresh weight} \times 100$$

Formula 2. The definition of Productivity, P% [18]

4. Results

98 percent of the whole growing of the mushroom industry plant in Demjén and the National Crown Mushroom Grown Union is growing agaricus, and the remaining 2 percent is oyster and exotic mushroom species (shiitake, king oyster etc.). Growing king oyster mushroom is small in quantity, however, its significance is far beyond that. It has many points of contact, development possibilities and strategy options for the future which can substantially be built into the structure of the whole supply chain in value creation. The importance of growing oyster mushrooms exceeds the Hungarian needs; it reaches international dimensions

and often steps out of the agricultural frames. There has not been a new oyster mushroom variety in the market for a long time, the utilisation areas of the current varieties are just being unfold from large scale waste utilisation to energy industry. There are many experiments ongoing in the world with a focus on the unique cellulose degrading capacity of oyster mushrooms and their nutritional values.

Furthermore using the extended map of mushroom supply chain [19], looking at the individual value creating points of the supply chain we introduce the determining elements, possible development options of the "new technology" and their versions known from international sources. We do not only mean growing technology simply as technology but rather the value creating solutions and sustainability criteria lying inside the complex relation system of the whole supply chain from the grower to the customer.

An important criterion for sustainability is that we should list the factors (hazard analysis) threatening the value of the end product [20, 21] and the value creating ability of the whole supply chain. In the following we are presenting these criteria.

The basic questions of a successful and value creating strategy are as follows: 1. How can this activity be profitable? 2. How can this profitability be sustainable, repeatable persistently? 3. How can this activity be different from others, having individual advantages?

Growing step:

In creating modern mushroom farms traditional and new types of growing concepts and methods are competing. Growing can take place in cellars, areas, tents, rooms created for this reason, and in the so-called Dutch type of growing houses etc. Thanks to the bigger yields per cubic metres the growing tunnel and the multi-level technology seems to better and more modern than other solutions but there can be other combinations as well. It is important that the grant system to support growers should be synchronized with the new technologies continuously.

Considering mushroom growing as a whole last year the main areas of research were 1. elaborating professional growing 2. modernization and mechanization of the individual growing phases, technological development 3. cost reduction and 4. reaching special goals. These developments help reduce the energy costs and improve the quality of the mushroom grown.

– One of the key questions of the modern mushroom growing plants is energy cost which gives a major part of the total cost. Based on this we consider every solution aiming at energy efficiency as a value creating solution. Several experiments support how important the utilisation of renewable energy sources, geothermal energy and solar energy is in mushroom growing. Regarding by-products the utilisation of agricultural waste (trimmings, energy plants, secondary materials containing energy) can be possible with modern furnaces, energy producing and air-conditioning appliances. Cooling, air circulation and humidity regulation is as important in summer as in winter. In case of air handling unit developing modern heat recovery systems is reasonable to retrieve energy. Irrigation and ensuring the necessary humidity result in significant costs. The establishment of automatic irrigation system or the prevention of water loss can mean a possible direction to development.
– Besides energy costs manual picking of mushroom also has significant cost in mushroom growing and the greatest demand of labour force. Manual picking takes a lot of working hours and is considered as very hard work (to different extent depending on the technology), that is why it is hard to find and keep suitable labour force. Using well-known and tried methods in car industry the colleagues of Vineland Research and Innovation Center are working on developing a mushroom picking robot. Vineland's automated system allows the growers to programme different rules for individual mushrooms in order to determine which mushrooms and when to harvest. With this step growing can be optimized and the amount of mushrooms grown in one unit of compost can be increased. The technology can ensure mushrooms of equal size with a perfect shape free from damage and scratches as demanded by customers. The end product below its maximum size means potential loss for the grower.
– The essence of the computer aided technology cannot only be used in picking but in providing special conditions necessary for mushroom growing such as controlling humidity, temperature, carbon dioxide concentration which can directly influence the quantity of the yield.
– The oyster mushroom is used throughout the world for bioremediation that is degrading waste of different types. Concerning mainly by-products and wastes they are used in degrading waste of wheat and barley straw, coffee grounds or tequila production. Degrading cellulose is not easy because cellulose is an extremely durable material but the enzymes of the oyster mushrooms living on the trees as parasites can perfectly degrade it. It is not so common that it is very difficult to get rid of disposable and naturally degradable nappies, normally their degradation takes centuries in the traditional way as observations prove. According to Alethia Vázquez-Morillas [22], the researcher of the Autonomous Metropolitan University in Mexico City the process of degrading can be speeded up with the help of oyster mushroom. This species is able to degrade 90% of the nappy's material in 2 months and completely degrade it in 4 months. As opposed to the initial reluctance, "the mushrooms grown this way are cleaner than most of the vegetables you can find in the market ..."

Figure 1. King oyster mushroom and polypropylene bottled growing

The determining elements of the technology examined in the experiment:

Growing is based on polypropylene bottled technology with growing tunnels. The key issue in growing is to achieve the biggest harvest possible in a small place. In case of polypropylene bottled technology the mixture of the compost consists of beech sawdust and wheat bran mixed 80:20; 85:15 or 90:10 with humidity of 60-65 %. The pH of the material is reduced from 6-7 to 4-5 with the initial nitrogen content of 1-1.2 %.

In the experimental technology bottles of 1100 ml are used. After 30 days from the inoculation the mushrooms are ready for harvesting (after 13-16 days from scraping). As a part of the technology examined in the experiment the mushrooms are only touched in picking; after twisting the fruit body the ends of the stalk are cut back then mushrooms of 150 grams on average are put onto trays.

As a result of the examination the value of biological efficiency BE% (fresh mushroom weight related to dry compost weight) is around 70% on average.

Processing and sales step:

The success of mushroom growing does not exclusively depend on real growing. The impeccable end product must be brought, packed or processed and delivered to the customers in impeccable quality. In this area several innovations have appeared which can provide additional values to the product. The majority of developments are about 1. storing and preserving mushrooms, 2. preparing, processing and packing mushrooms, 3. logistics distribution.

- As a result of Polish development Europe's most modern mushroom growing and distribution centre as well as cold store called Champion was established which join more than 30 Polish mushroom farms' growing (Grzybek Łosicki Cooperative). The building complex was able to significantly reduce the energy cost of the growing rooms and cooling buildings with the help of the most modern architectural innovations and technological systems. Besides growing activity Champion provides mushroom growers with complex services including planning, building, equipment and the implementation of technological systems according to local and regional needs as well as meteorological circumstances. The company's main products are mushroom growing shelf systems, picking cars, ventilation, air-conditioning, automated watering, cooling rooms, cooling water and special lighting systems, carpets and any other devices.
- In the area of packing there are many ways to develop from recyclable or recycled materials to the packages best suiting the customers' needs. For example Shine Boudreault, Earthcycle Packaging Ltd. offers vacuum foil palm fibre trays which can be disposed in a natural way. These trays are ready to be composted and on the other hand they are able to resist the wet product or sometimes higher humidity. The company paid attention to the fact that mushrooms should not touch each other and stand still with the help of spacers. In packing the customers' needs should be considered in the first place since like other animals humans are capable of determining based on various features, signs and symptoms whether the food put in front them is edible or not. This subjective judgment is made based on consistency, taste, odour, vision (shape, colour, shade, patches, threads, spots, particles, knobs, traces of pests etc.) because these innervations remained during human evolution and we are still using them during shopping in a supermarket and choosing the food we like. For example as for mushrooms we prefer tough caps free from contamination and closed sheets free from spores. It could happen in reality that a less attractive or old mushroom tastes the same but selling these mushrooms is much harder. Customers are really sensitive to colour changes and colouring due to damages or overripening or decaying (falling spores) mushrooms. It is natural when due to apoptosis (the death of cells) caused by stress genes the mushroom strives to keep certain cells alive with sacrificing other cells, and using the cap storing energy to ripen the spores. This latter is usually accompanied by cracking, browning, rarely spore scattering. After all quality care packing should be able to slow down these processes and make the beautiful mushroom shapes visible. On the one hand packing should breathe in order to avoid dampness or dehydration. The very first thing here is freshness. A widespread method is using protective gas and cooling which are good at keeping freshness and against infections but they cannot stop but slow down the processes mentioned above. Using protective gases inside packing or the intensive and fast cooling prevents considerably the spread of bacteria in the product, so the quality of the mushroom can be preserved. Many European stores use paper bags to store mushrooms to prevent dampening due to mushroom's breathing and vastly blocks the spread of bacteria situated on the cap but developing breathable packing is in progress as well. Developments preventing deterioration in quality are very complex and expensive; there are only a few of physiological researches.
- The role of packing in customer information and marketing. In the past few years the information content placed on packing becomes more and more significant. Customers are more conscious and the information about growing is relevant to them such as free from preservatives and chemicals, label "bio". In case of mushroom "offering the product" can mean added value namely information in a photo or in words can stimulate good mood to consumption since most customers are uncertain about using. Good examples are a spectacular photo, special recipes, utilisation tips, or presenting information referring to specialities. Innovations mean an area to be exploited.
- The logistic role of packing is also important because the added value shows that the products must be put into unit loads while avoiding mechanical damages. If the fine grid structure of mushroom threads cannot resist the pressure of the hand or other things, colourful patches will appear due to enzyme reaction. In this situation the tyrosinase or polyphenol oxidase enzymes as catalysts will start the oxidation of phenol compounds causing the patches. During the long lasting storage mainly at the end cut of the stalk white mushroom threads can often appear. It does not mean mould infection rather the mushroom tries to get back to its mycelium state when the mushroom is able to utilize the rest of the nutrients more efficiently. The quality deterioration appears on the product quickly after picking, overripening should be avoided.
- The most usual direction of processing is canning but there are many other possibilities such as pickled in salt or vinegar, ready-made and completely processed food. For example Highline, the biggest Canadian mushroom growing company sells stuffed Portabella mushrooms as snacks to raise the customers' interest. In other cases growers sell the grown mushrooms in the local market or to the restaurants in the region.

The determining elements of the technology examined in the experiment:

The customers' preferences can vary in the countries. In Italy the small and thin stalks with wide and dark caps are favoured. The Spanish consumers like mushrooms with lighter caps. But the customers in China prefer wider stalks and smaller caps. The king

oyster mushroom has a nice thick and white stalk with a small cap. In Hungary these stereotypes have not appeared so far, unlike agaricus almost every mushroom is new for an average consumer.

In the experiment examined the mushrooms picked freshly are first pre-cooled at 10°C after that chilled at 1-3 °C, packed and labelled. Plastic packing is used with transparent foil cover. The packed mushrooms are delivered to the hypermarkets in the areas nearby but the export is also remarkable (Table 1).

Table 1. The comparison of the experimental bottled growing and block growing

Polypropylene bottled technology	Bag (block) technology
The bottles can be recycled many times.	The bags can be used twice at the maximum, a lot of waste takes place.
A little compost is used which gives good harvest in spite of less total surface.	A lot of compost is used which gives relatively poor harvest.
The bottling process is completely automated.	The bagging process needs more manual work which means hard work.
The biological efficiency BE% is between 60 and 70 %.	The biological efficiency is very low, BE %= 35 %.
The quality of the mushrooms is more steady (depends on the environment).	The quality of mushrooms is uneven (depends not only on the environment).
Mushroom growth is synchronised (scraping and spraying water).	Mushroom growth is less synchronised (no scraping, no spraying water).

5. Conclusion

The conclusion of our research is that polypropylene bottled technology can be effectively applied in Hungary and continued with Hungarian materials. Machine lines applied for filling and moving bottles can be matched with the technology requirements and the previously created growing houses with growing tunnels. During the experiment we achieved a competitive quantity in growing. The BE value is approximately 70%.

Our further statements and recommendations are as follows:

- There is a demand for this mushroom variety and it can be increased with an extensive promotion of the mushroom.
- Growing this mushroom variety can be made more economical with further innovation particularly a bigger exploitation of renewable resources such as geothermal energy, solar energy, green energy and waste utilisation.
- Further added value can be achieved by establishing processing and logistics centres as the Polish example proves.
- In the future there are unexploited opportunities in packing developments preserving quality and further marketing value done with regard to logistic packing and end users.

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