Slutrapport

Denna slutrapport har i huvudsak två syften. Det ena är att möjliggöra synlighet och extern kommunikation kring de projekt och resultat som BioInnovation finansierar. Det andra är att samla sådan information som behövs för att möjliggöra en långsiktig analys av BioInnovations projektportfölj. Slutrapporten ska kunna spridas och publiceras fritt och får inte innehålla konfidentiella eller på annat sätt känsliga uppgifter.

Slutrapporten ska skickas in till BioInnovations programkontor: info@bioinnovation.se. Observera att slutrapporten är ett eget dokument, även om informationen delvis kan vara densamma som anges i Vinnovas slutrapport.

Detta inledande instruktionsavsnitt ska vara kvar i dokumentet. Text i grå kursiv stil i resten av dokumentet är vägledande för förväntat innehåll och bör tas bort ur slutrapporten innan den skickas in.

Allmänt om projektet

Fyll i tabellerna

Projekttitel på svenska	Skogsrester för kombinerad produktion av ätlig svamp och biobränsle (comush)
Projekttitel på engelska	Forest residues for combined edible mushroom and biofuel production (comush)
Vinnovas diarienummer	2017-02705
Volym (kr) – BioInnovations bidrag och totalt	4 130 000 SEK från BioInnovation, totalt: 8 983 000 SEK
Tidpunkt för start och slut	2017-09-01 - 2021-02-28
Projektledare (person)	Shaojun Xiong
Projektledare (organisation)	Sveriges Lantbruksuniversitet, Institutionen för skogens biomaterial och teknologi
Deltagande organisationer	Umeå University, ProcessIT Innovations, Biosteam AB, Valutec AB, SCA Obbola AB, SCA Munksund AB, Svampkungen AB, Swedfungi AB, Umeå Energi AB, Hällnäs Handelsträdgård AB, Cathaya Co Sweden AB

	Andel män respektive kvinnor som arbetat i projektet	**Andel av arbetet (timmar) som utförts av män respektive kvinnor**
Män	90%	90%
Kvinnor	10%	<10%
Totalt	100 %	100 %

Short summary

Max 1000 tecken, på engelska

This project was to develop technologies for integrating mushroom and biofuel production. Four white-rot edible fungi and a few wood residues were studied for mushroom yields, substrate delignification and recycling spent substrates for processing ethanol. It showed that *Lentinula edodes* is one of the best species. Birch and alder wood are good growing sources. One important finding is that optimal ratios of nitrogen and bark in the substrates reduce glucan degradation by 20-30%, and thus more glucan is available for enzymatic hydrolysis and fermentation to bioethanol. The studies succeeded in determining key parameters for hot-air pasteurisation of mushroom substrates that can reduce 60% energy use and 65% CO_2 emission than conventional steam autoclavation. Further, new devices and processes were developed

to facilitate robotization of mushroom production, which may save >30% labour costs and 25% cultivation time. Five academic publications and 2 patents are among the major results.

Projektets bidrag till en biobaserad samhällsekonomi

Beskriv – ur ett behovsägarperspektiv – de huvudsakliga samhällsutmaningar som adresserats och hur projektet bidrar till att lösa dessa

Beskriv på vilket sätt projektet bidrar till och drar nytta av omställningen till en biobaserad samhällsekonomi och FNs mål för hållbar utveckling

One of the core issues of bioeconomy strategy is to develop climate smart holistic solutions and to increase resource and energy efficiency in society. This project has proved that a process-integrated edible fungi (food) and energy production using local woody residues can be a potential and promising approach.

The results from this project indicate that the new system we developed will make the edible fungus production more cost effective, energy efficient and environmentally friendly than ever before. It can save up to 60% energy, >30% labour costs and ~25% cultivation time compared with conventional production of mushrooms such as shiitake. This suggests that it is more realistic to novelise/revive Swedish mushroom industry that has suffered from high labour and energy costs associated with low-tech processes. Edible mushrooms are rich in protein and can be an alternative to meat products. Today, the annual consumption of meat products in Sweden is approximately 55 kg meat per capita, which is 30 kg more than human dietary requirements (Svenska Jordbruksverket 2013), while meat production and related transportation have a large climate impact (FAO 2013). Mushrooms can grow on forest residues that are plentiful but largely underused in Sweden and the growing process does not need extra land, fertilizer and pesticides.

Advantages of growing edible fungi can be extended to more efficient production of cellulosic ethanol as an alternative to fossil fuels. Our results show that the cultivation of shiitake can function as an effective process of delignification resulting in > 70% degradation of lignin. This suggests that the cultivation of edible mushroom can be an alternative to existing physical and chemical pretreatment that requires high inputs of energy and chemicals that costs about 30% of all expenses from wood resource to ethanol product. Without further pretreatment and addition of chemicals, the spent mushroom substrates (SMS) after a harvest of mushroom fruit bodies are a feedstock good enough for a direct enzymatic saccharification and subsequent fermentation of hydrolysate sugars to bioethanol fuel. In addition, the solid leftovers after the hydrolysis, which is about 30% of initial substrate, can be used as combustible biofuels for heating. Thus, a circular biobased economic model is demonstrated.

Based on our results, one ton dry mass (DM) of birch-based substrates may product 600 kg fresh shiitake fruit bodies (90% w/w moisture) and recover 600 – 700 kg DM of SMS that may be converted to about 130 litre bioethanol fuel and 300 kg solid biofuels for combustion.

Konkreta resultat och leverabler

Beskriv tekniska problem som har lösts och innovationer som uppstått, samt lista leverabler som demonstratorer, patent och annan IP, rapporter och vetenskapliga publikationer etc.

Major concrete results are summarised as follows:

- Two Swedish patents have been granted. One is about new pasteurisation method (SE1651575A1) and the other is about the mushroom growing device and process for automatic cultivation of

mushroom (SE542577C2 (SE1850883-A1). Compared with conventional methods, the new way of pasteurisation can save up to 60% energy and considerable costs for mushroom production; the new growing device and process can potentially save considerable labour costs.

- The parameters such as temperature and duration of pasteurisation have been verified for at least three edible mushrooms, and even regarding differences in substrate particle size, density and block dimension. These data will be delivered as instructions for industrial uses.
- Substrate formulations ("recipes") composed of different wood species are developed. Underused forest thinning residues from birch, alder and aspen are major ingredients resource for production of protein-rich edible mushroom and biofuels. Major results have been included in academic publications but can be also used for industries.
- Academical publications on the cultivation and utilisation of edible mushrooms such as *Lentinula edodes*, *Pleurotus pulmonarius, P. ostreatus,* and *Auricularia auricular-judae*.
  Major academic publications
  - Chen F, Grimm A, Eilertsen L, Martín C, Arshadi M, Xiong SJ (2021) Integrated production of edible mushroom (*Auricularia auricular-judae*), fermentable sugar and solid biofuel. Renewable Energy. Doi: 10.1016/j.renene.2021.01.124.
  - Chen F, Martin C, Finell M, Xiong SJ (2020). Enabling efficient bioconversion of birch biomass by *Lentinula edodes*: regulatory roles of nitrogen and bark additions on mushroom production and cellulose saccharification. Biomass Conversion and Biorefinery. Doi: 10.1007/s13399-020-00794-y.
  - Chen F, Xiong SJ, Sundelin J, Martin C, Hultberg M (2020). Potential for combined production of food and biofuel: cultivation of *Pleurotus pulmonarius* on soft- and hardwood sawdusts Journal of Cleaner Production, 266, 122011. Doi: 10.1016/j.jclepro.2020.122011.
  - Wei M, Xiong SJ, Chen F, Geladi P, Eilertsen L, Myronycheva O, Lestander TA, Thyrel M (2020). Energy smart hot-air pasteurisation as effective as energy intense autoclaving for fungal preprocessing of lignocellulose feedstock for bioethanol fuel production. Renewable Energy, 155:237-247. Doi: 10.1016/j.renene.2020.03.154.
  - Xiong SJ, Martín C, Eilertsen L, Wei MG, Myronycheva O, Larsson S, Lestander T, Atterhem L, Jönsson LJ. 2019. Energy-efficient substrate pasteurisation for combined production of shiitake mushroom (*Lentinula edodes*) and bioethanol. Bioresource Technology 274:65-72.Doi: 10.1016/j.biortech.2018.11.071

Utveckling enligt TRL, MRL och SRL

Ange TRL, MRL och SRL[1] för projektets startpunkt och slutpunkt, samt beskriv den förflyttning i TRL, MRL och SRL som projektet medfört

Fyll i tabellen	Start	Slut
TRL of key technologies: For mushroom production (hot-air pasteurisation) For ethanol production (enzymatic hydrolysis of spent substrates and fermentation)	 4 2	 6 4
MRL For mushroom production (hot-air pasteurisation)	1	1,5
SRL For mushroom production (hot-air pasteurisation)	0	1

[1] Se BioInnovations Ansökningsguide

Resultatens effekter och potential

Redogör för förändringar i värdekedjan (tekniklösningar, samverkan, råvaror, kundbeteenden etc.), samt redogör för eventuella nya företag, material/produkter/tjänster, anställningar, affärer och värdekedjor

One of the most important impact is: an industrial development project (SvampHäll) is initiated by several partners of this project. SvampHäll is co-financed by EIP-agri program through Jordbruksverket and has the aim at developing automation/robot processes, based on our patents, for a production of edible fungi and mushroom substrates for domestic and international markets. Several SME in Västerbotten are preparing to form a new company working on a new industrial chain.

The global production of cultivated mushrooms is about 34 million tons in 2015, and market demand is increasing (Royse et al. 2017). Europe has about 24% of the world production, second after Asia. Annual production of shiitake is about 7,5 million tons, which generates about 7,5 – 12.5 million tons of SMS DM that can be converted to 2-3 million m3 of ethanol fuels (Wei et al. 2020). These figures show a great potential of our development.

Visioning on future development towards bioeconomy, SLU Forestry Faculty has decided to finance a new laboratory (Svamplabb) to facilitate future research on “mushroom + biofuel”.

Samhälleliga förutsättningar

Beskriv samhälleliga (politiska, regulatoriska, marknadsmässiga) förutsättningar för innovationen och värdekedjan i ett bredare perspektiv, särskilt samhälleliga hinder för bioekonomin

The rural areas in Sweden has under a long time experienced deindustrialisation and depopulation. To break this trend, we need new and innovative solutions that make rural areas more attractive to the industry. Today's farmers are to a large extent dependent on income from the forest, but due to long rotation period in forests the farmers have to endure long periods of hard work that do not generate any income. Between harvests (clearing and thinning) and during harvests, large amounts of biomass are left in the forests due to low profitability. Our new concept of “edible mushroom + biofuel” will provide a considerable market value and a clear bio-economic potential for this biomass. The edible mushrooms grows well on forest residues, require small land areas, and no fertilizers or pesticides are needed. There are also great opportunities to establish the actual in-house and vertical cultivation in rural areas, as well in the north as in the inland as most fungi requires neither sun nor high temperatures during the cultivation process.

Extern synlighet

Beskriv projektets synlighet i media, framträdande vid konferenser och liknande – nationellt och internationellt

- The project was considered as one of “Yearly best research and technology in Sweden 2019” (“Årets bästa – forskning och teknik i Sverige 2019”, IVA Aktuellt Nr 6 2019 (https://issuu.com/iva-publikationer/docs/iva_nr_6_2019_hogupplost), or Tuula Teeri:s Årets framsteg inom forskning och teknik. IVAs årliga tekniktal 2019. (https://youtu.be/Q7L585G6mCw, från min 10:39)).

- Skogsindustrierna Forum för bioekonomi #1-2020. Svampen har ersatt en dry process för att göra biodrimedel. Sidan 8-9. (https://www.skogsindustrierna.se/bioekonomi/hur-vi-reser-och-transporterar/)
- Swedish National Program Bioinnovation: Inhemsk odling av delikata matsvampar i sikte – och biodrivmedel på köpet. 2019-12-20. (https://www.bioinnovation.se/nyheter/inhemsk-odling-av-delikata-matsvampar-i-sikte-och-biodrivmedel-pa-kopet/)
- Sveriges vetenskapsradio 2019-02-18: Svensk innovation kan ge billigare matsvampar (https://sverigesradio.se/sida/artikel.aspx?programid=406&artikel=7154503)
- Forskning.se 2019-02-11: Fördelen med att odla läckra svampar på björkved (https://www.forskning.se/2019/02/11/fordelen-med-att-odla-lackra-svampar-pa-bjorkved/

Nästa steg

Beskriv resultatens fortsatta väg till marknad, följdprojekt och liknande

Industrial demonstration is at the top of the list. For doing it, industrial and mechanical processes and devices shall be materialised.

Digitalisation of the processing shall be one of the central technologies to be developed, which is crucial for level up Swedish competitiveness in the world.

Further research and development are suggested upgrading mushrooms to edible protein and bio-medicinal/healthy-improving products, as they are important parts of bioeconomy.

Cultivation of edible fungi on softwood residues is especially interesting in Sweden where 83% of forests are composed of scot pine and Norway spruce, but it is a global challenge today. Fundamental research to understand the poor susceptibility of conifer biomass to edible white-rot fungi are needed, so as to develop methods to tackle the problems.

Bilder

Om det finns bilder tillgängliga som kan illustrera projektet, t.ex. för presentation på BioInnovations webb, får dessa gärna skickas till BioInnovation samtidigt som slutrapporten

Uppgifter för statistik

Fyll i tabellen	**Nej** (kryssa)	**Ja** (ange antal/värde)	**Inom 5 år** (gissa antal/värde)
Har projektet lett till publikationer?		5	15
Har projektet lett till patentansökningar?		2	5
Har projektet lett till nya eller väsentligt förbättrade produkter?			x
Har projektet lett till nya eller väsentligt förbättrade processer?		x	x
Har projektet lett till nya eller väsentligt förbättrade värdekedjor?		x	x
Har projektet lett till nya eller väsentligt förbättrade affärsmodeller?	x		
Har projektet lett till nya intäkter?	x		
Har projektet lett till utveckling av policy och regelverk?	x		
Har projektet lett till nya nätverk?		x	x
Har projektet lett till följdprojekt? Finansierat av vem?		X (Jordbruksverket)	

Med stöd från VINNOVA Sveriges innovationsmyndighet, Energimyndigheten, FORMAS, Strategiska innovationsprogram
Initierat av: Skogs Industrierna, IKEM, TEKO Sveriges Textil- & Modeföretag, BIOINNOVATION