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Sustainable carbon solutions by the aid of wood decay fungi

LIGNOCELLULOSE WASTE BIOCONVERSIONS OPENED WITH COMPARATIVE GENOMICS AND ECOPHYSIOLOGY

Taina Lundell

University of Helsinki, Finland

Background: terms and facts

- **Sustainability** = capacity for the biosphere and human civilization to coexist on Earth (Wikipedia)
- Climate change = atmospheric warming and its consequences
- Global warming = human caused, release of excess
- Greenhouse gases GHG: CO_2, CH_4, N_2O
- Circular economy = re-use of wastes as raw materials
- Biomass = plant and animal materials for energy and use
- **Renewable natural resources** = plant, animal and microbial biomasses and products, carbon capturing and re-cyclable
- -> alternatives for fossil fuels and resources

Climate change & global warming effects

The University of Manchester, UK, 2016, report
https://www.manchester.ac.uk/discover/news/severe-future-effects-of-climate-change/

Fossil CO_2 and GHG emissions of the world, 2019

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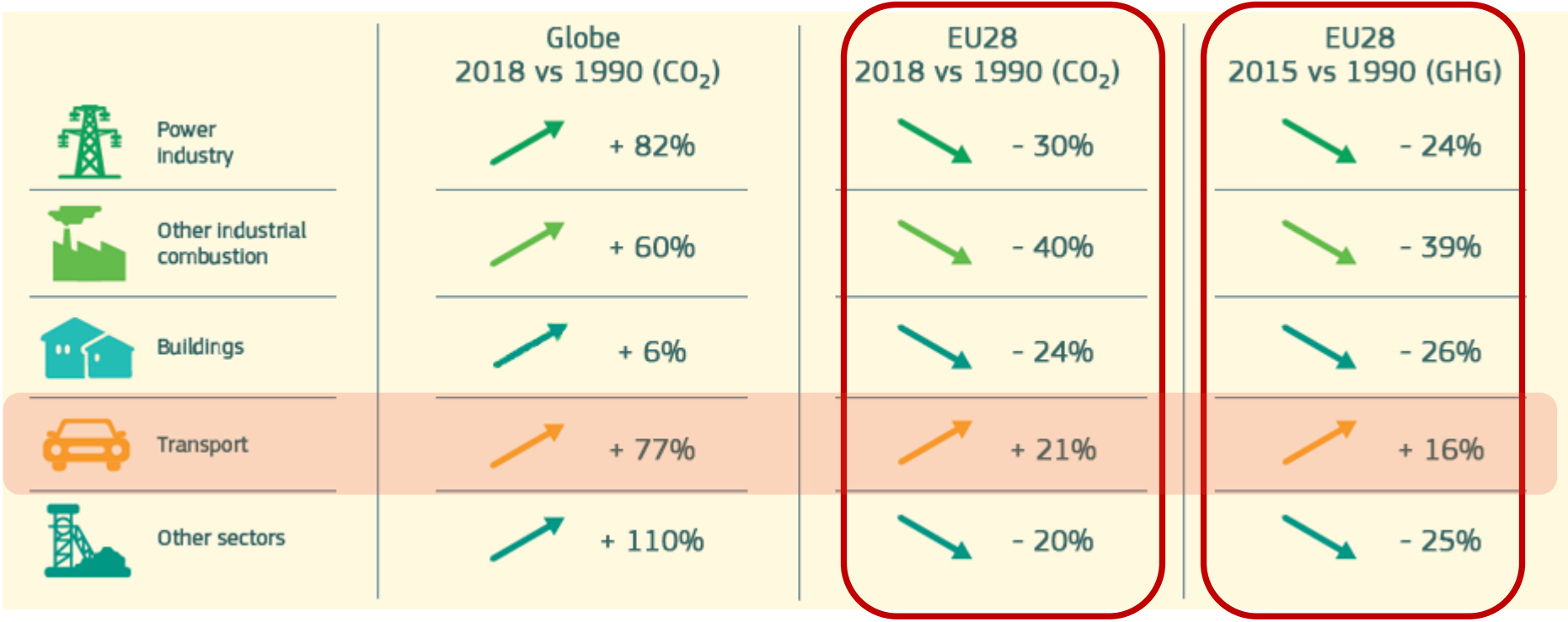
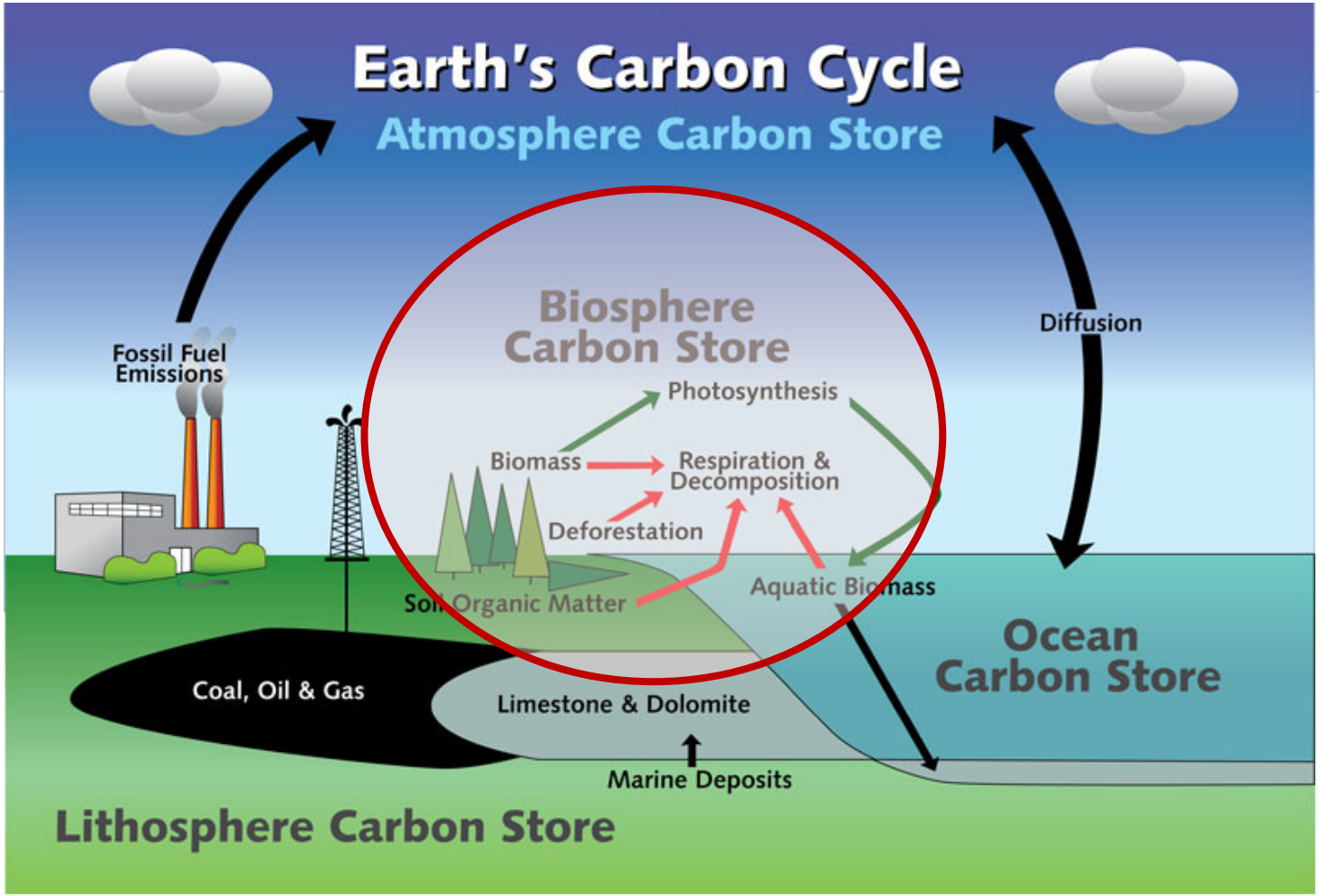


Crippa, M., Oreggioni, G., Guizzardi, D., Muntean, M., Schaaf, E., Lo Vullo, E., Solazzo, E., Monforti-Ferrario, F., Olivier, J.G.J., Vignati, E., Fossil CO2 and GHG emissions of all world countries - 2019 Report, EUR 29849 EN, Publications Office of the European Union, Luxembourg, 2019, ISBN 978-92-76-11100-9, doi:10.2760/687800, JRC117610.


Earth's Carbon Cycle
Atmosphere Carbon Store
Biosphere Carbon Store
Photosynthesis
Biomass
Respiration & Decomposition
Deforestation
Soil Organic Matter
Aquatic Biomass
Fossil Fuel Emissions
Diffusion
Ocean Carbon Store
Coal, Oil & Gas
Limestone & Dolomite
Marine Deposits
Lithosphere Carbon Store

How fungi may help us?

- CO_2 level in the atmosphere has increased >40% since anno 1750
- Global CO_2 emissions from fossil fuels combustion and processes: **40 Gtn/year** (37.9 Gtn in 2018)
- Annual increase: 1.9 %
- China, US, India, E28, Japan: 2/3 of total global fossil CO_2 emissions
- To mitigate accumulation of CO_2
- -> replace fossil fuels with renewable biomasses and energy sources
- -> process recycled organic wastes by microbes and fungi
- -> fungal biotechnology and bioconversions for
- -> renewable biofuels, novel bio-based and biodegradable materials for industry and consumers

Solution 1: Fungal genomics

- New CAZYmes and genes from white rot fungi for lignocellulose conversion and valorization of biomasses, wastes and lignins

Mäkinen *et al. BMC Genomics* (2019) 20:430
https://doi.org/10.1186/s12864-019-5817-8

2019

BMC Genomics

RESEARCH ARTICLE Open Access

Genome description of *Phlebia radiata* 79 with comparative genomics analysis on lignocellulose decomposition machinery of phlebioid fungi

Mari Mäkinen[1,4], Jaana Kuuskeri[1], Pia Laine[2], Olli-Pekka Smolander[2,5], Andriy Kovalchuk[3], Zhen Zeng[3], Fred O. Asiegbu[3], Lars Paulin[2], Petri Auvinen[2] and Taina Lundell[1*]

Applied Microbiology and Biotechnology (2018) 102:5657–5672
https://doi.org/10.1007/s00253-018-9045-y

2018

GENOMICS, TRANSCRIPTOMICS, PROTEOMICS

Transcription of lignocellulose-decomposition associated genes, enzyme activities and production of ethanol upon bioconversion of waste substrate by *Phlebia radiata*

Mari A. Mäkinen[1] · Netta Risulainen[1] · Hans Mattila[1] · Taina K. Lundell[1]

Kuuskeri *et al. Biotechnol Biofuels (2016) 9:192*
DOI 10.1186/s13068-016-0608-9

2016

Biotechnology for Biofuels

RESEARCH Open Access

CrossMark

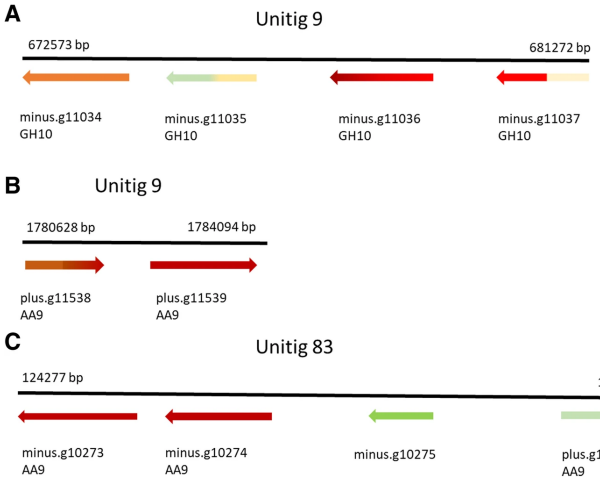
Time-scale dynamics of proteome and transcriptome of the white-rot fungus *Phlebia radiata*: growth on spruce wood and decay effect on lignocellulose

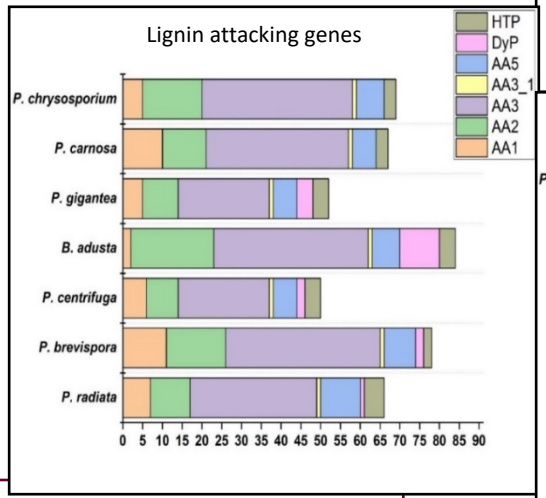
Jaana Kuuskeri[1], Mari Häkkinen[1], Pia Laine[2], Olli-Pekka Smolander[2], Fitsum Tamene[3], Sini Miettinen[3], Paula Nousiainen[4], Marianna Kemell[5], Petri Auvinen[2] and Taina Lundell[1*]

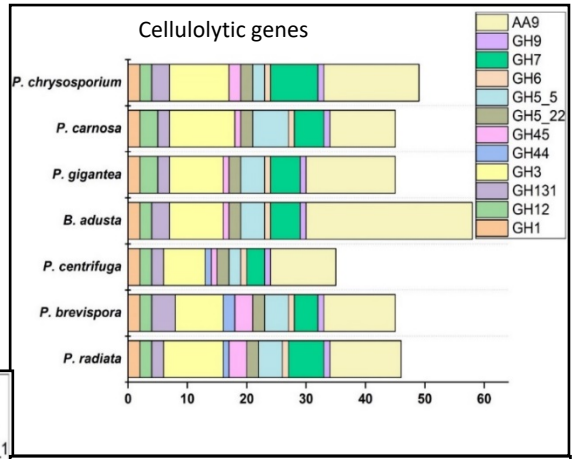
Phlebia radiata 79 comparative genomics

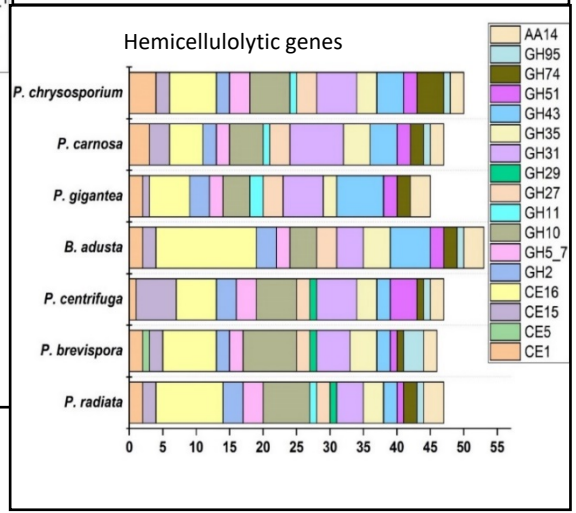
- 7 phlebioid fungal species
- comparative genomics on CAZy genes
- phlebioid white-rot decay specific set of CAZy genes against wood lignocelluloses
- genomic clustering of AA9 and GH10 genes

Mäkinen, Kuuskeri et al. 2019 BMC Genomics 20: 430









Clustered localization of CAZy genes
-> co-regulation?
-> transcriptome RNA-Seq meta-analysis, *Mattila HK et al. 2020 Biotechnol Biofuels*

Solution 1: Fungal genomics

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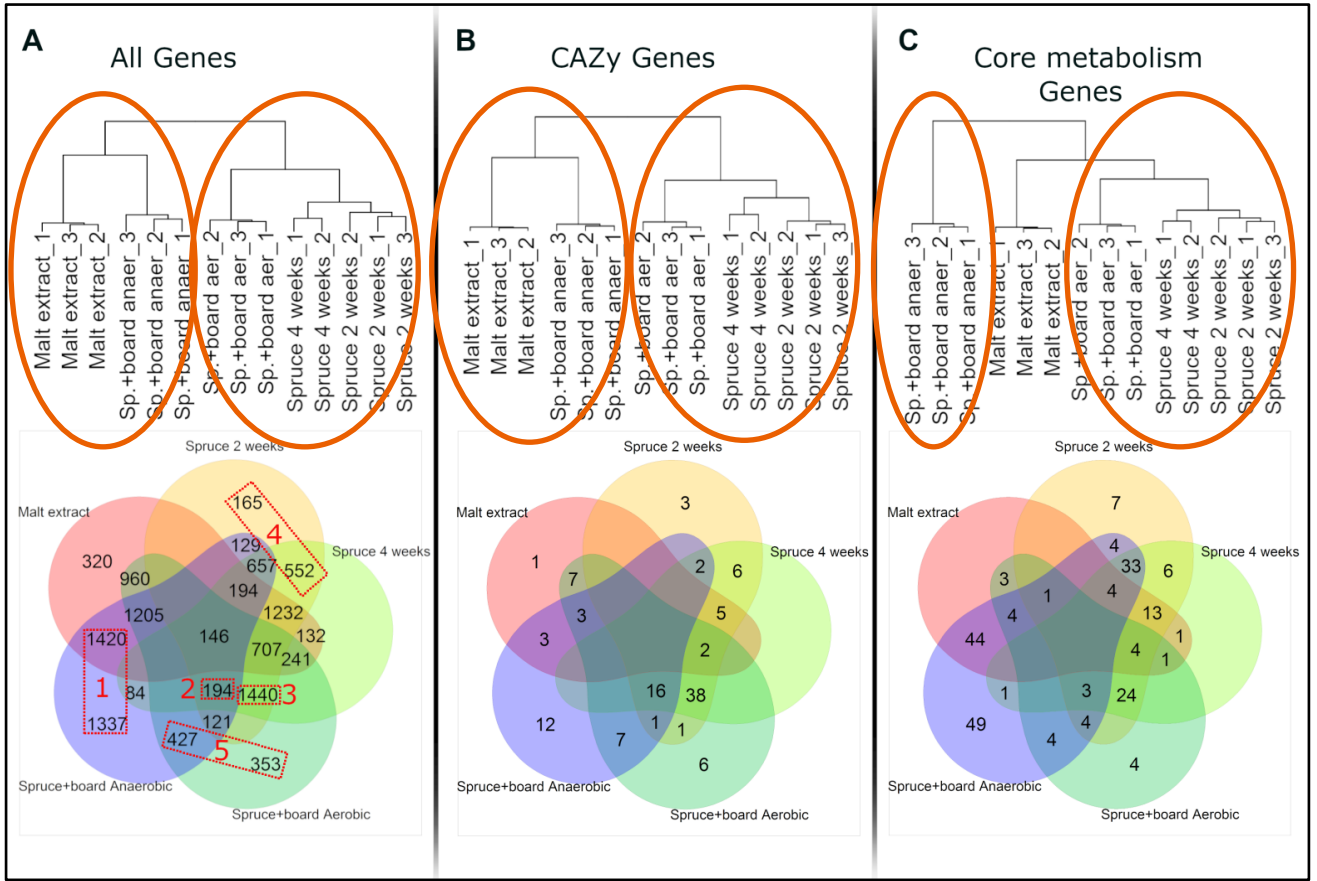
Towards understanding wood decay fungal metabolism and regulation to allow systems biology approaches for bioconversions

- Clustering of 14 transcriptomes of *Phlebia radiata* on
- Different substrates and lignocelluloses
- Under aerobic and anaerobic (fermentative) atmospheres
- *Mattila H, et al. (2020) Biotechnology for Biofuels*
- Poster A2-27



Solution 2: Fungal ecology & physiology

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-> to understand fungal interactions

- Wood decay Basidiomycota species
- *Polyporales*
- *Hymenochaetales*
- Natural and specific co-cultures
- Enzyme activities
- VOCs & gases
- Dissolved degradation products
- Interactomes

PLOS ONE

2017

RESEARCH ARTICLE

Interactions affect hyphal growth and enzyme profiles in combinations of coniferous wood-decaying fungi of Agaricomycetes

Tuulia Mali, Jaana Kuuskeri, Firoz Shah, Taina Kristina Lundell*

Microbiology and Biotechnology, Department of Food and Environmental Sciences, Viikki Campus, University of Helsinki, Helsinki, Finland

OXFORD FEMS JOURNALS investing in science

FEMS Microbiology Ecology, 95, 2019, fiz135

doi: 10.1093/femsec/fiz135
Advance Access Publication Date: 23 August 2019
Research Article

2019

RESEARCH ARTICLE

Decomposition of spruce wood and release of volatile organic compounds depend on decay type, fungal interactions and enzyme production patterns

Tuulia Mali[1], Mari Mäki[2,3], Heidi Hellén[4], Jussi Heinonsalo[1,3,4], Jaana Bäck[2,3] and Taina Lundell[1,*,†]

Solution 2: Fungal ecology & physiology

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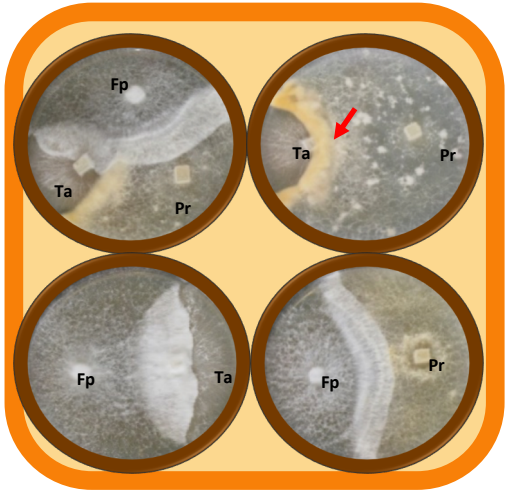
- *Interactions of wood-decay Agaricomycetes, enzyme activities and decomposition events*
- Tuulia Mali PhD project



- 3 species of *Basidiomycota Agaricomycetes*
- isolated in Finland on decaying wood
- colonize Norway spruce (*Picea abies*) dead wood

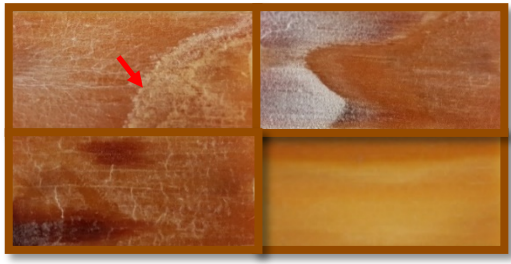
F. pinicola
BR

T. abietinum
WR

P. radiata
WR

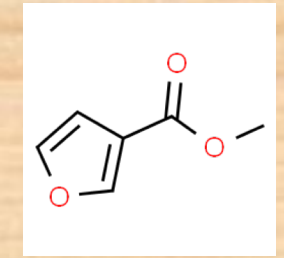
- BR fungus Fp supreme colonizer
- WR fungus Pr forms dense yellow mycelial front
- against the second WR fungus Tr

9 months on spruce wood



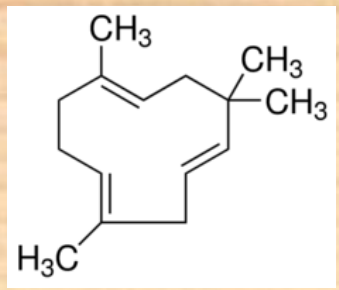
Mali T, et al. 2017 PLoS ONE 12(9): e0185171
Mali T, et al. 2019 FEMS Microbiology Ecology 95:
Mali T, Mäki M, Hellén H, Bäck J, Lundell T, 2020

Signature VOCs released by wood decay fungi from spruce wood

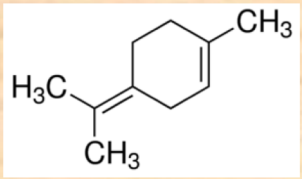


methyl 3-furoate

White Rot

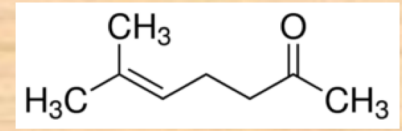


α-humulene
(sesquiterpene)



terpinolene

Brown Rot

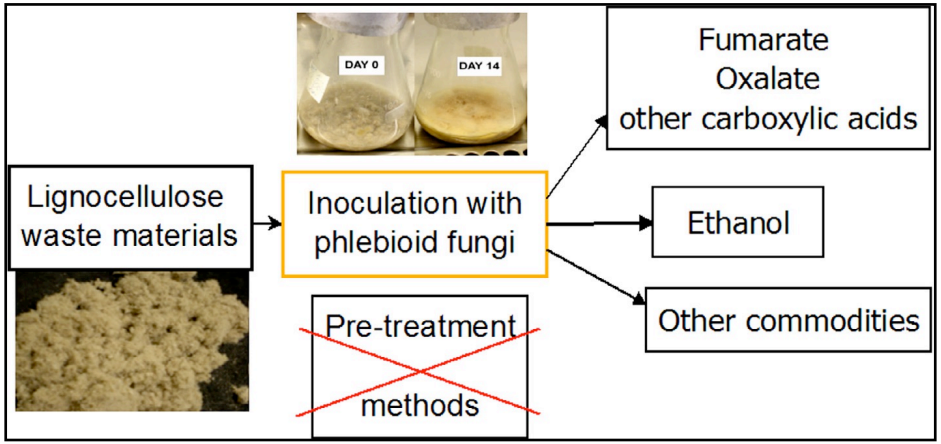


6-methyl-5-hepten-2-one

Mali T, et al. 2019 FEMS Microbiology Ecology 95: fiz135

Solution 3: Fungal bioconversions

- Biofuels by wood decay fungi: low cost, single-step bioprocessing and fermentation to ethanol



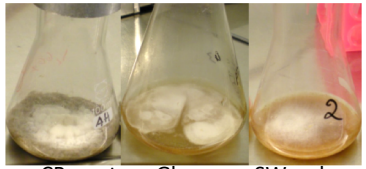
- Sustainability: lignocellulose instead of food plant biomasses
- Circular economy: waste as raw material
- CO_2 mitigation: wood fibers and products are biotransformed, not burned
- 2nd generation biofuels, metabolites, natural products

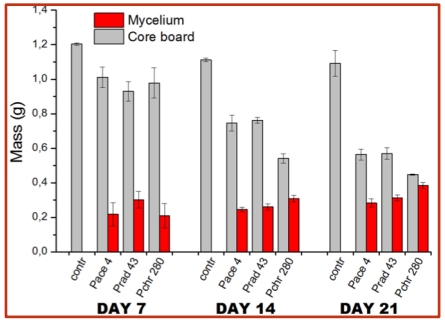
Mattila H, Kuuskeri J, Lundell T (2017) Bioresource Technology 225: 254-261

Ethanol, organic acids and sugars by fungi from lignocelluloses and wastes

Ethanol production by Phlebia species on lignocellulose wastes

Hans Mattila PhD project, poster A2-27





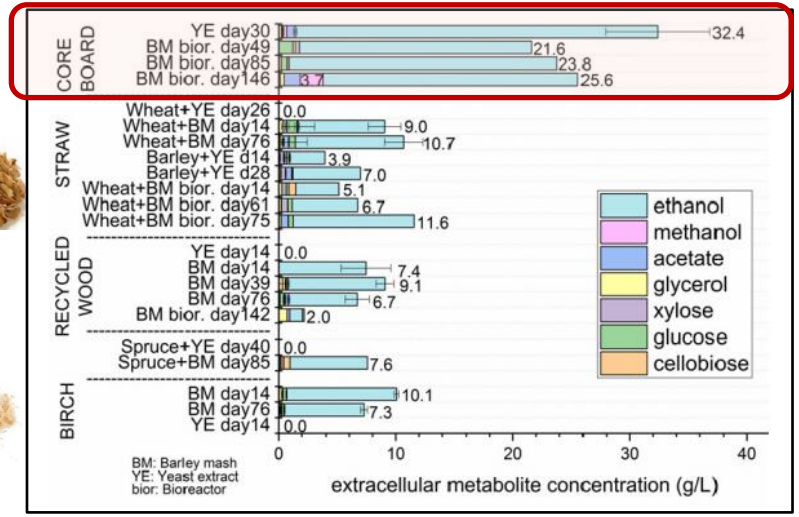
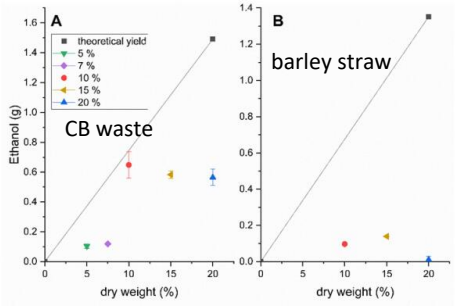


Table 2
Yield of ethanol production in white rot fungal single-organism and combined organisms using fermentations on various lignocelluloses, extrapolated to 100 g of the solid substrate.

Ethanol/substrate (g/100 g)	Substrate	White rot fungus	Duration (days)	Reference
Single organism				
10.4	Core board	*Phlebia radiata* 79	9	Present study
20	Newspaper	*Phlebia* sp. MG-60	9	Kamei et al. (2012)
42	UHKP[a]	*Phlebia* sp. MG-60	7	Kamei et al. (2012)
9.9	Rice straw	*P. chrysosporium*	19	Bak et al. (2009)
Combined organisms				
1.7 (3)	Corn stover	*P. chrysosporium* (with yeast)	7 (9)	Shrestha et al. (2008)
6.6	Corn stover[b]	*P. chrysosporium*	>9	Vincent et al. (2014)
		Co-culture with a brown rot fungus and yeast		

[a] Unbleached hardwood kraft pulp.
[b] Sodium hydroxide pre-treatment.

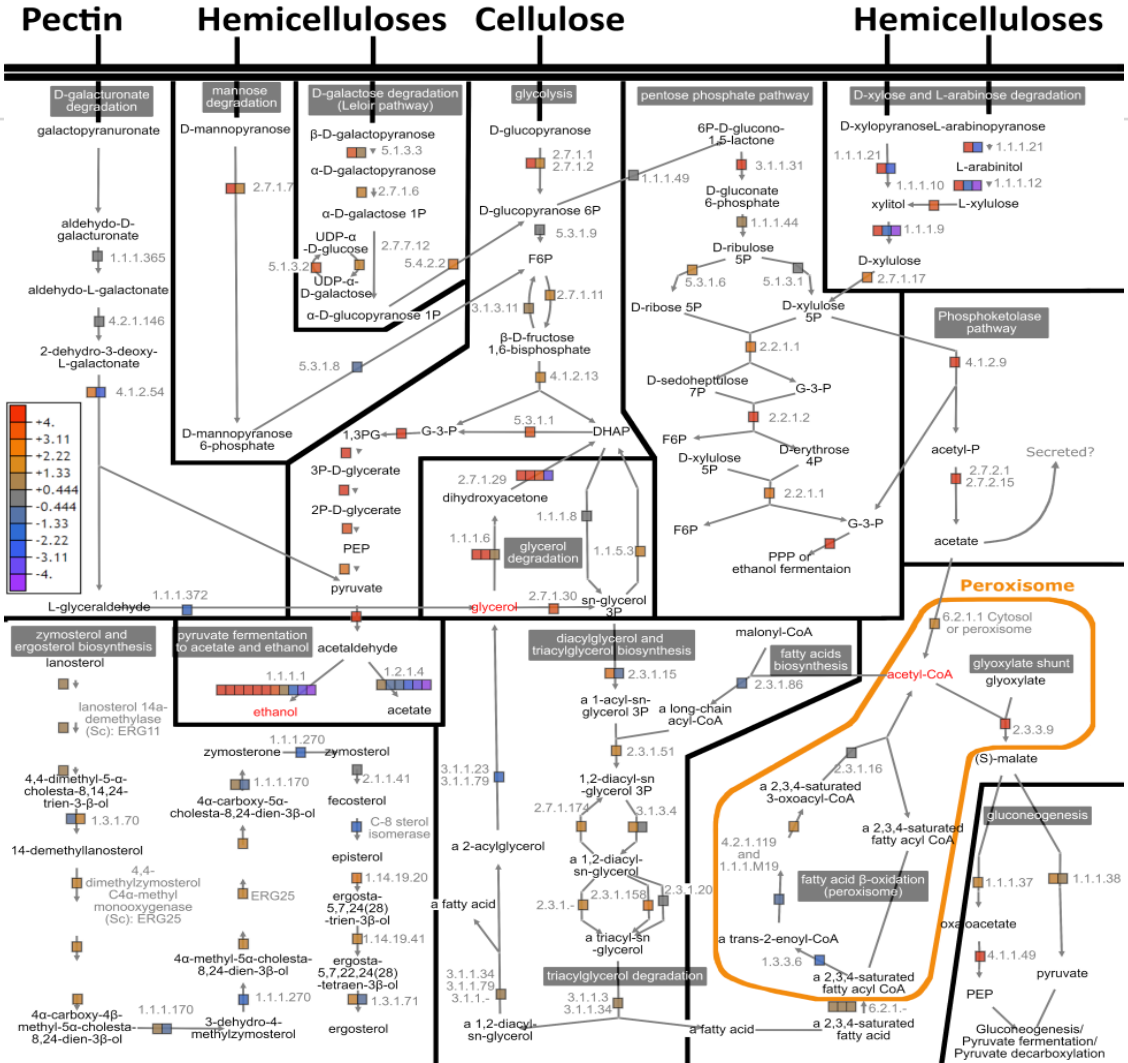


Mattila H, Kuuskeri J, Lundell T (2017) Bioresource Technology 225: 254-261
Mattila H, Kacar D, Mali T, Lundell T (2018) AIMS Energy 6(5): 866-879

Mattila H, Mäkinen M, Lundell T (2020) Biotechnology for Biofuels

Metabolic pathways for degradation of wood polysaccharides are regulated by atmosphere in a white rot fungus

poster A2-27 Feb-18th



Solution 3: Fungal bioconversions

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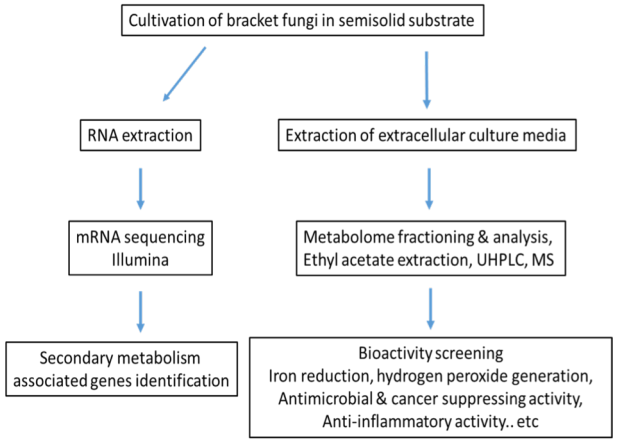
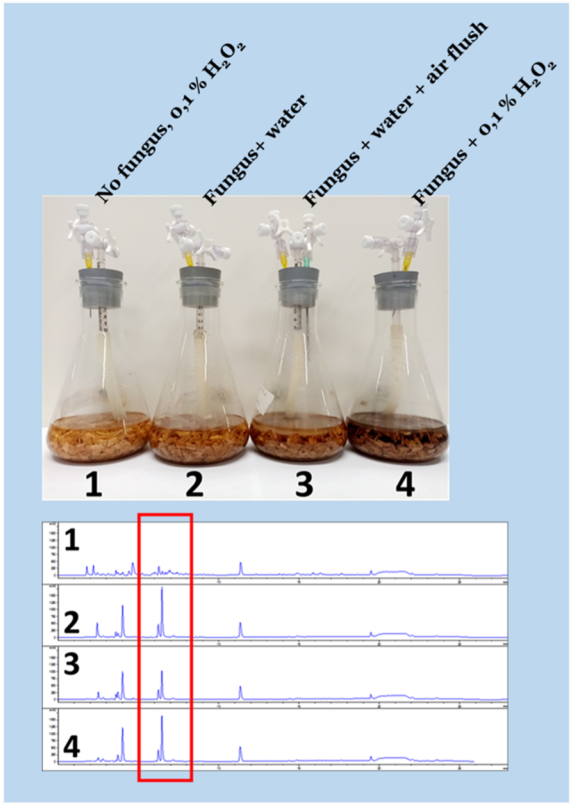
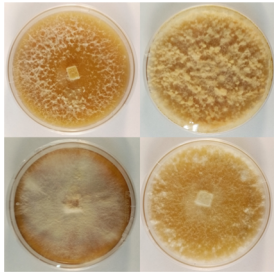
- Natural products from waste lignocelluloses by wood decay fungi
- Eero Kiviniemi, poster C1-43 Feb 20th
- Released compounds and metabolites
- Medicinal and bioactive responses tested



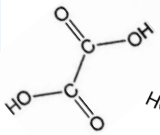


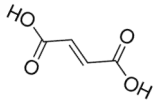


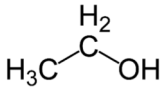
Biotechnology applications on wood-decaying fungi: conclusions

Growth on wood and waste lignocelluloses producing

- Enzymes, CAZymes, decompose and convert wood carbohydrate polymers
- Sugars from wood polysaccharides
- Secondary metabolites, bioactive compounds
- Ethanol, other alcohols, organic acids
- Fruiting bodies and mycelium for food



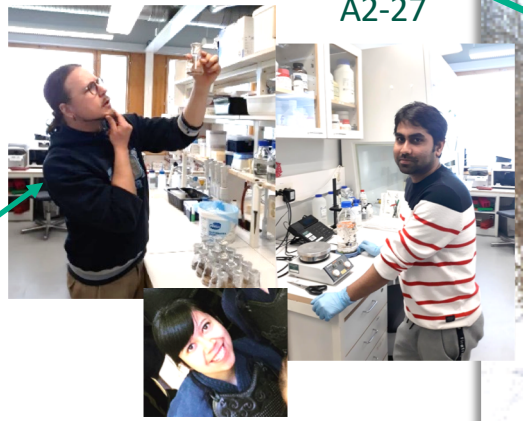




Thank you for your attention! Kiitos! Grazie!

Poster
A2-27

Poster
C1-43



More information on us:

Fungal Co-life, Omics and Ecophysiology Research Group

Fungco

https://www.helsinki.fi/en/researchgroups/fungal-co-life-omics-and-ecophysiology

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