Combined meta’omics reveal links among fungal community composition, gene expression, and chemical changes in decomposing leaf litter

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Introduction – Nutrient cycle in forests

Plant biosynthesis → Mineralized nutrients → Consumers → Organic matter → Decomposition

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Introduction – Decomposition as a key process in the nutrient cycle
Introduction – Controlling factors

Organic matter

\[ \downarrow \]

Decomposition

\[ \downarrow \]

Decomposition products

Litter inputs

\[ \downarrow \]

Decomposition products
Introduction – Controlling factors

Organic matter → Decomposition → Decomposition products

Litter inputs → Process rate

- CLIMATE
- LITTER QUALITY
- DECOMPOSER ACTIVITY

Decomposition products
Introduction – Climate

Parton et al. (2007), Science
Introduction – Litter quality

Berg and McClaugerty (2014), Springer
Introduction – Litter quality

Schematic view of cellulose

de Souza (2013), InTech

Berg and McClughey (2014), Springer
Introduction – Litter quality

Schematic view of hemicellulose
de Souza (2013), InTech

Berg and McClaugherty (2014), Springer
Introduction – Litter quality

Berg and McClaugherty (2014), Springer

Schematic view of lignin
Glazer and Nikaido (2007), Cambridge Univ. Press
Introduction – Litter quality

Schematic view of lignin
Glazer and Nikaido (2007), Cambridge Univ. Press

Berg and McClaugherty (2014), Springer
Introduction – Litter quality

Mass loss (%)  
Carbon content (%)  
Nitrogen content (%)  
Total phenolics  
Hemi-cellulose  
Cellulose  
Lignin  
Soil properties (pH)  
Nutrient content (K, P, NH$_4^+$, NO$_3^-$)
Introduction – Litter quality

Mass loss (%)
Carbon content (%)
Nitrogen content (%)
Total phenolics
Hemi-cellulose
Cellulose
Lignin
Soil properties (pH)
Nutrient content (K, P, NH$_4^+$, NO$_3^-$)

Berg and McClaugherty (2014), Springer
Introduction – Litter quality

Ethyl acetate

Nuclear Magnetic Resonance (NMR) spectroscopy

- Mass loss (%)
- Carbon content (%)
- Nitrogen content (%)
- Total phenolics
- Hemi-cellulose
- Cellulose
- Lignin
- Soil properties (pH)
- Nutrient content (K, P, NH₄⁺, NO₃⁻)

Bulk parameters
Introduction – Litter quality

Ethyl acetate

Nuclear Magnetic Resonance (NMR) spectroscopy

Mass loss (%)
Carbon content (%)
Nitrogen content (%)
Total phenolics
Hemi-cellulose
Cellulose
Lignin
Soil properties (pH)
Nutrient content (K, P, NH$_4$\(^+\), NO$_3^-$)

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based on Spectral Database for Organic Compounds
Introduction – Litter quality

Leaves

Litter

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Introduction – Litter quality

Litter inputs
- Decomposition products
  - Leaves
  - Litter
  - degenerated
  - synthesised
  - stable

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Introduction – Litter quality

D(+)-glucose

D(+)galactose

Original sample
Spiked sample
Introduction – Litter quality

- Litter quality

RUHR-UNIVERSITÄT BOCHUM

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Introduction – Decomposer activity

Spatial distance (m): $R^2 = 0.34^{***}$
Climate PC1: $R^2 = 0.03^{***}$
Soil Chemistry PC1: $R^2 = 0.03^{***}$

Soil fungal communities

Soil enzymatic activity

GO terms list
- Aminoacyl-tRNA ligase activity
- ATPase activity
- Cofactor binding
- DNA polymerase activity
- GTPase activity
- Hydrolase activity
- Hydrolase activity (glycosyl bonds)
- Kinase activity
- Ligase activity
- Metal ion binding
- Nucleic acid binding
- Nucleotide binding
- Oxidoreductase activity
- Peptidase activity
- RNA polymerase activity
- Transferase activity
- Transporter activity
- Other (less than 2%)

Relative abundance (%)

Talbot et al. (2014), PNAS
Material and Methods

Falling leaves
1 year-old litter

DNA  Present fungal litter communities
rRNA  Active fungal litter communities
mRNA  Eukaryotic activity in litter
NMR  Chemical composition
Material and Methods

**Falling leaves**

1 year-old litter

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>DNA</td>
<td>Present fungal litter communities</td>
<td>467 OTUs</td>
</tr>
<tr>
<td>rRNA</td>
<td>Active fungal litter communities</td>
<td>442 OTUs</td>
</tr>
<tr>
<td>mRNA</td>
<td>Eukaryotic activity in litter</td>
<td>1.3M contigs</td>
</tr>
<tr>
<td>NMR</td>
<td>Chemical composition</td>
<td>294 peaks/sample</td>
</tr>
</tbody>
</table>

6,054 contigs
69 Litter-degrading CAZymes

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Results – Communities are structured differently

Regional differences (ANOSIM R-value)

- Present
- Active

**  ns
Results – Different communities encode the same enzymes
Results – Leaves and litter are chemically distinct

Similarity among leaf and litter samples according to chemical composition ($^1$H-NMR).

2D Stress: 0.05
R=0.994, p < 0.0001

- Leaves
- Litter
Results – Chemical composition becomes more similar with ongoing decomposition
Results – Identification of correlative relationships between individuals, enzyme transcription and chemical changes

based on Spectral Database for Organic Compounds
Results – Identification of correlative relationships between individuals, enzyme transcription and chemical changes
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GH27 = α-galactosidase

Compound 1

Compound 2
Results – Identification of correlative relationships between individuals, enzyme transcription and chemical changes

GH27 = α-galactosidase

Compound 1

Compound 2

- CAZyme family transcription
- Chemical compounds (ppm)
- Glucose (ppm)
- Positive correlation
- Negative correlation
Results – Identification of correlative relationships between individuals, enzyme transcription and chemical changes

OTU27 = Species A
OTU28 = Species B
...
GH27 = $\alpha$-galactosidase

Compound 1

Compound 2
Framework for unveiling causative and mechanistic relationships
Acknowledgements

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Linking decomposer activity to decomposition

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Results – Different communities encode the same enzymes

Relative distribution (%)

CAZyme transcripts

Av. abundance

- > 0.0%
- ≥ 0.1%
- ≥ 0.2%
- ≥ 0.3%
- ≥ 0.4%

CAZyme classes and modules

- CBM
- CE
- GH
- PL
- dockerin
Results – Different communities encode the same enzymes

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CAZyme transcripts

CAZyme families

Av. abundance

CAZyme classes and modules

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- CE
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- PL
- dockerin
Discussion – Community disturbance

Microbial community composition

Different microbial composition

Performs different functions than the original community

Performs the same functions as the original community

Different process rate

Same process rate

Disturbance

RESISTANCE

RESILIENCE

FUNCTIONAL REDUNDANCY

Adapted from Allison and Martiny (2008), PNAS