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Hydrothermal Carbonization of Human Excreta:

Effect of process severity on hydrochar properties

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9th International Conference on Sustainable Solid Waste

2.4 billion people lack access to basic sanitation services

0.5 billion people still practice open defecation

izzso.com,

Energy Scarcity

Current decentralized sanitation practices are problematic

- Human pathogen contamination (water and soil) - outbreaks of diseases
- Environmental – greenhouse gas emissions, nutrient contamination
- Water based sanitation is not feasible (flushing toilet)
- Often not economical
- Waste of resource (C, N, P, K)

We need alternative solutions

Hydrothermal Carbonization (HTC)

- Thermo-chemical conversion of **wet** biomass into hydrochar (char like material)
- Temperature range of 180-250°C and self-generated **pressure**
- Reaction time from minutes to several hours

- Main Chemical reaction : dehydration & decarboxylation

Severity factor

Simplified kinetic model that takes into account the relative contribution of both

Temperature and Time combined into one parameter

$$Severity = 50 * t^{0.2} * e^{\frac{-3500}{T}}$$

t-time, T-temp

Ruyter H.P

Objectives-

Does same process severity, result in similar hydrochar properties?

Corelation between process sevirity and hydrochar properties

Specifically:

- hydrochar characteristics
- combustion behavior of hydrochar and gas emissions

Experimental design

SF	0.13			0.21			0.24			0.32		0.41
Temp (°C)	180	210	240	180	210	240	180	210	240	210	240	240
Time (min)	120	11	1.3	1319	120	14	2727	248	30	997	120	395

$$Severity = 50 * t^{0.2} * e^{\frac{-3500}{T}}$$

t-time, T-temp

Collection campaign

Autoclave

Dried 65^{0}C

Ground

Methodology

\+

Water ratio1:4

HTC

Temp:
180, 210, 240 ºC

Time:
1min- 48 hr.

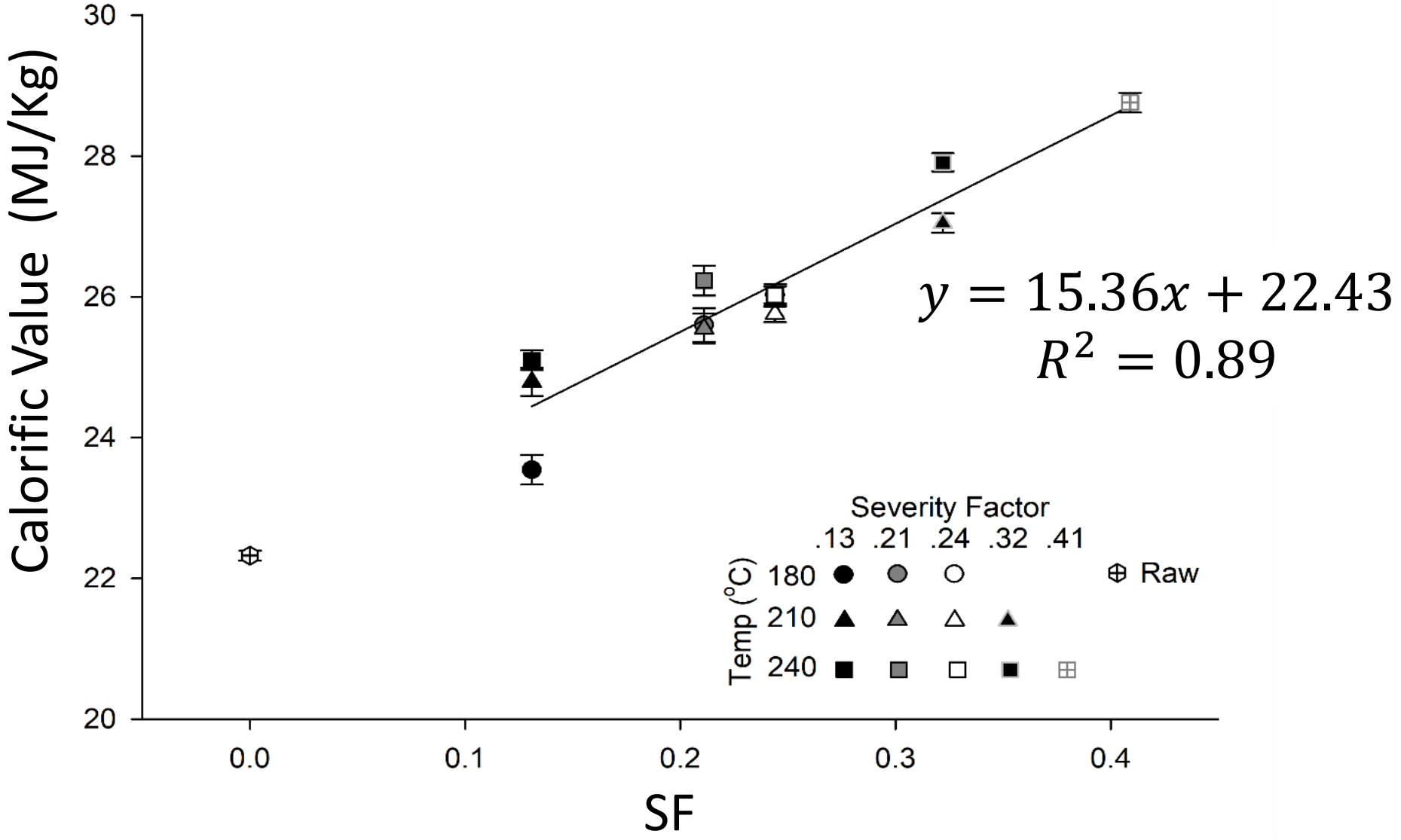
Hydrochar

C, H, N, O, S (%)
Yield
Energy content

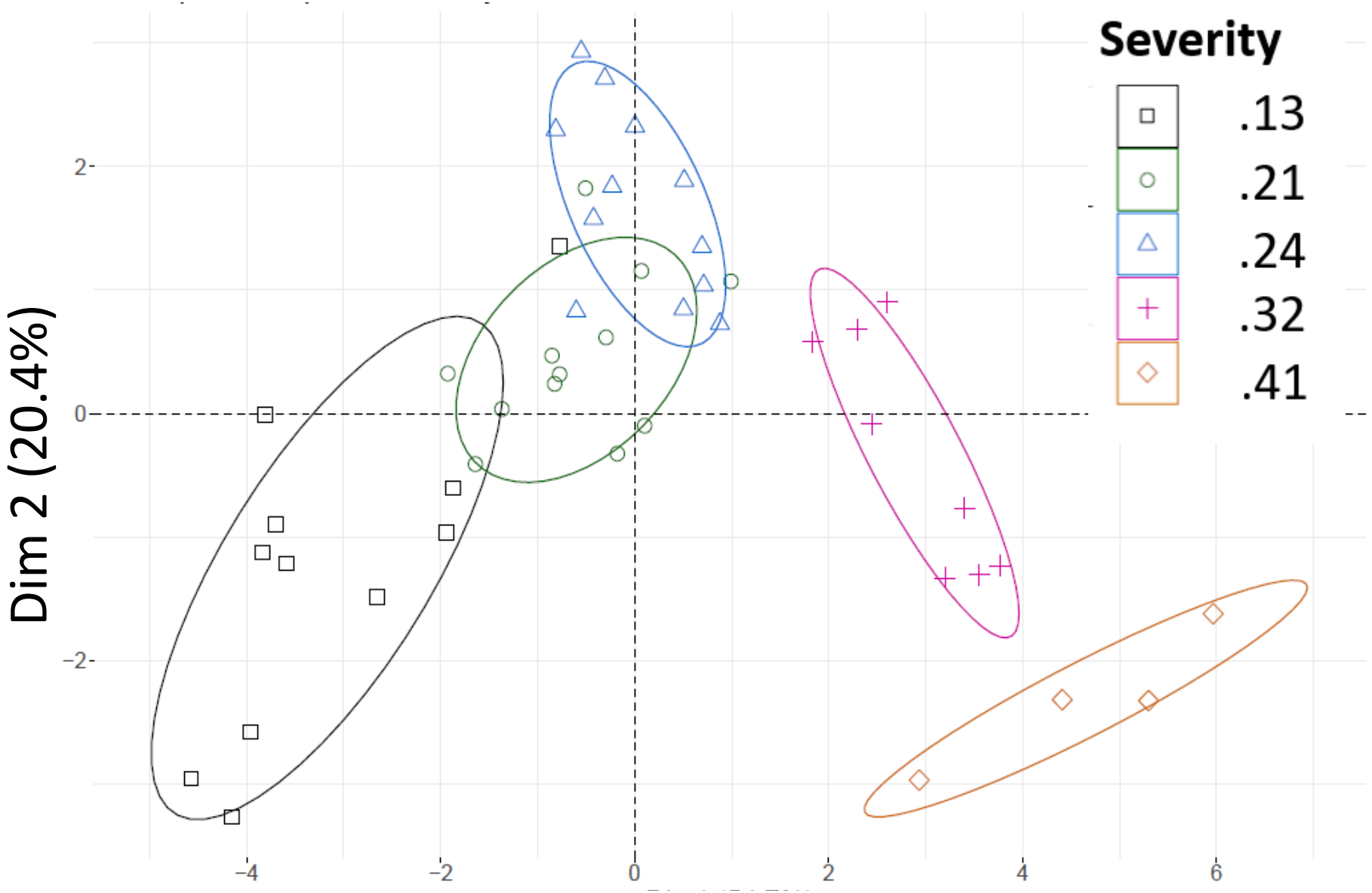
Combustion & gas emissions

Results – Hydrochar properties

High Correlation - Severity Factor vs Calorific Value



Distinct differences between severities



Included parameters:

OM,

C,N,H,O

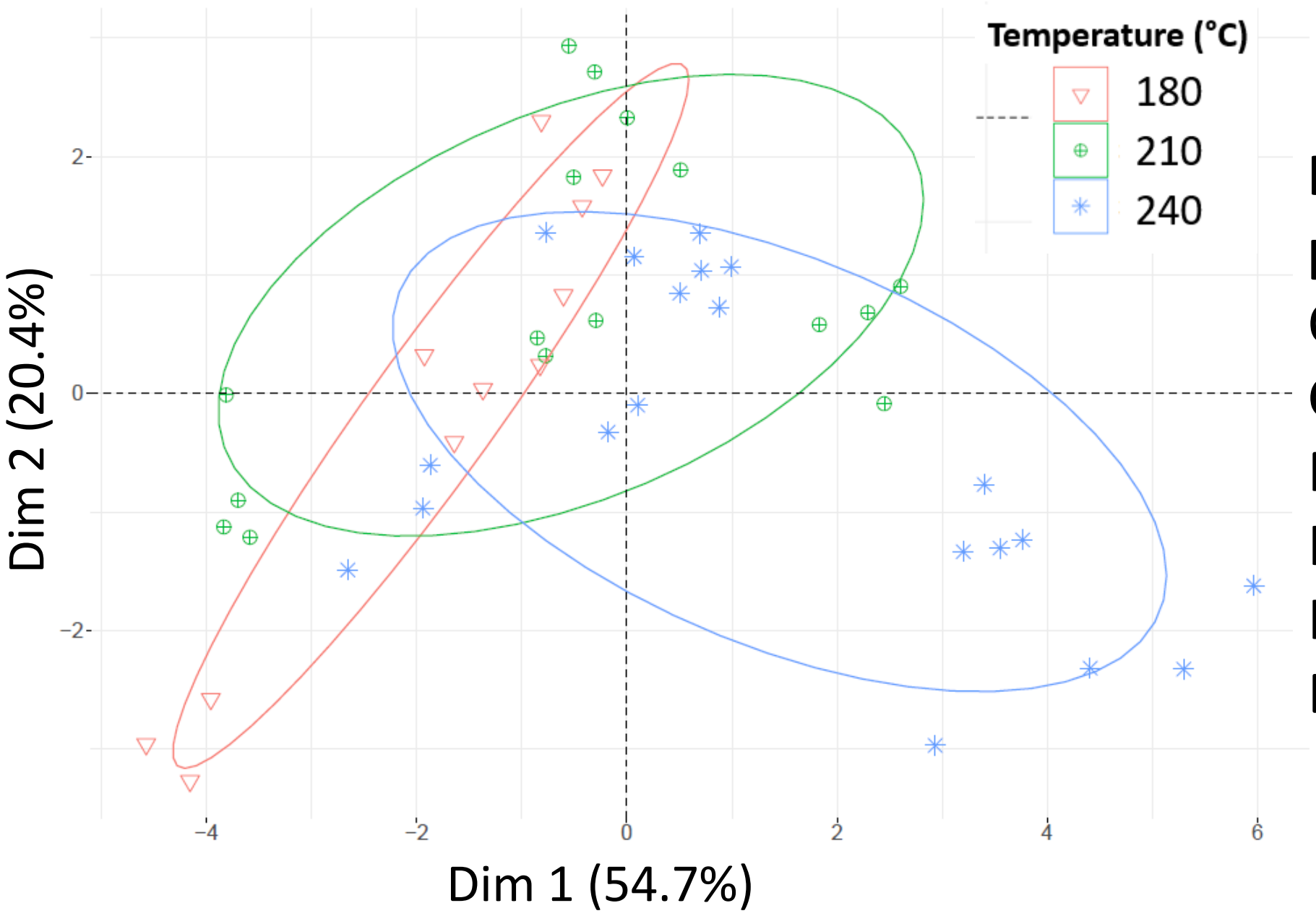
N,P,

K,Na,Mg,Ca

H:C

Energy yield

Temperature didn’t accurately categorize variables



Included parameters:

OM,

C,N,H,O

N,P,

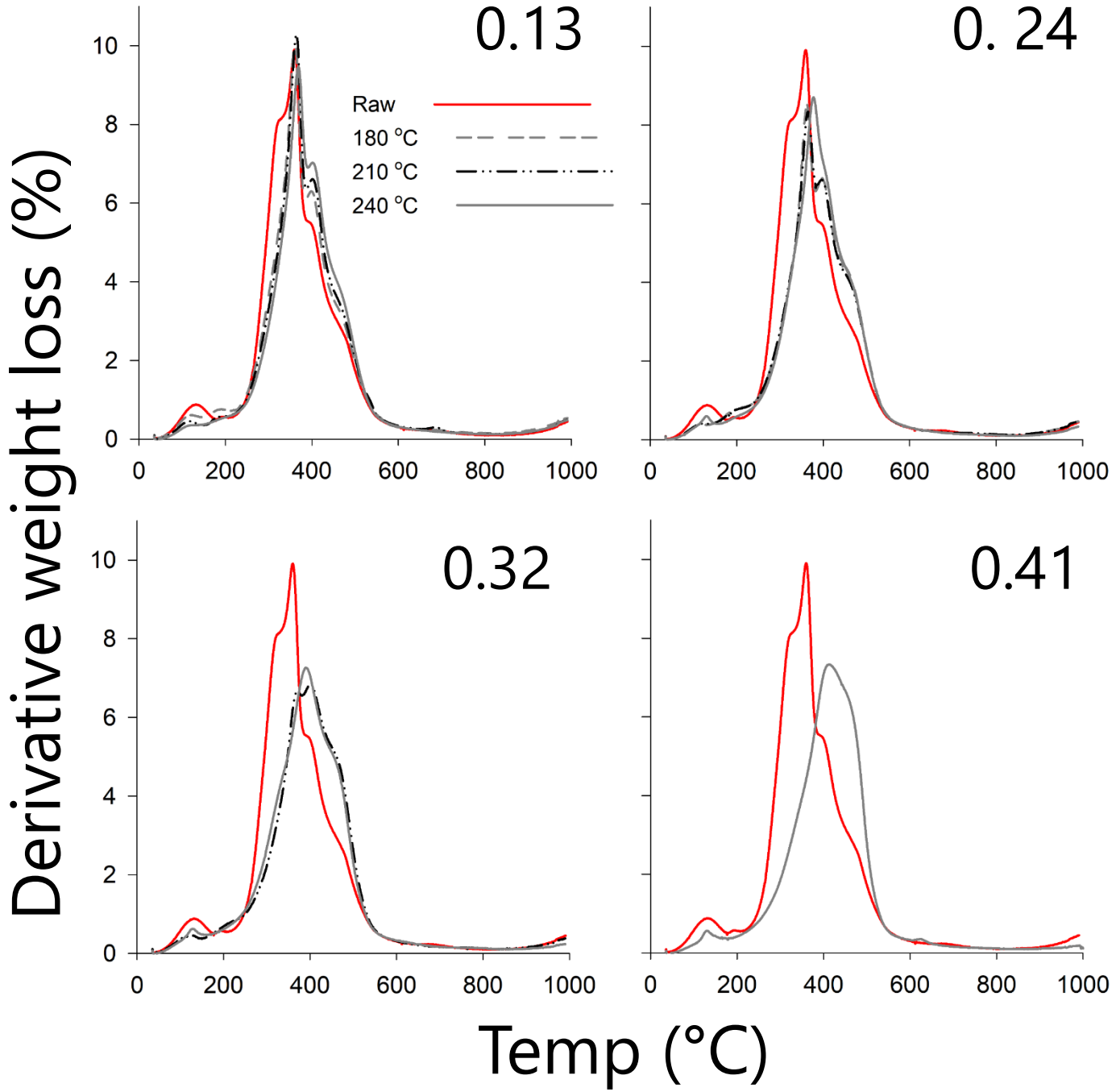
K,Na,Mg,Ca

H:C

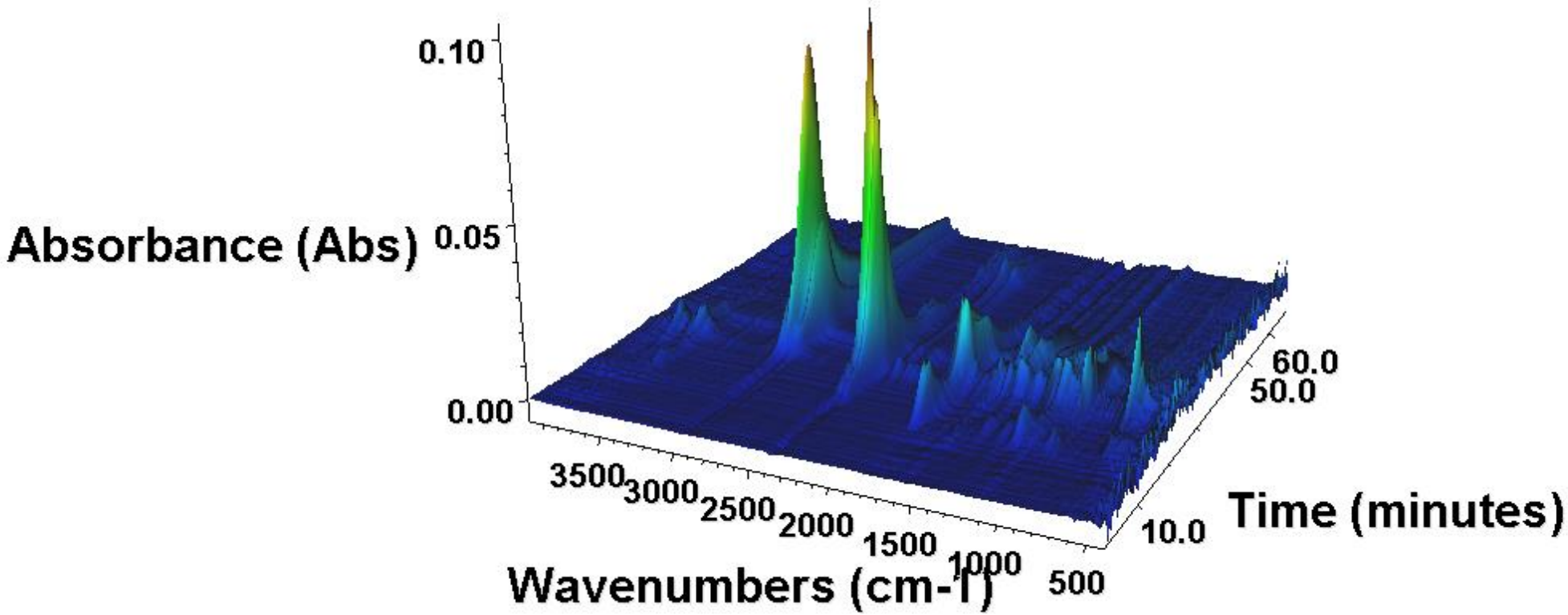
Energy yield

Results

Combustion profile



FTIR profile during combustion



Gas emissions following hydrochar combustion

Normalized average (%)	Raw	0.13	0.24	0.32	0.41
CO2	35	32	23	20	16
CH4	11	24	25	24	45
CO	2	2	2	2	2
NO	12	13	13	11	5
Ether	7	6	7	6	6
NH3	13	7	10	11	12
SO2	6	5	6	7	5
Carbonyl	9	9	10	10	7
C=C	6	3	5	8	2

To conclude

HTC of human excreta resulting in energy rich hydrochar, that can be used for combustion

Hydrochar properties can be predicted by severity model

Process severity is an important tool towards the use of HTC

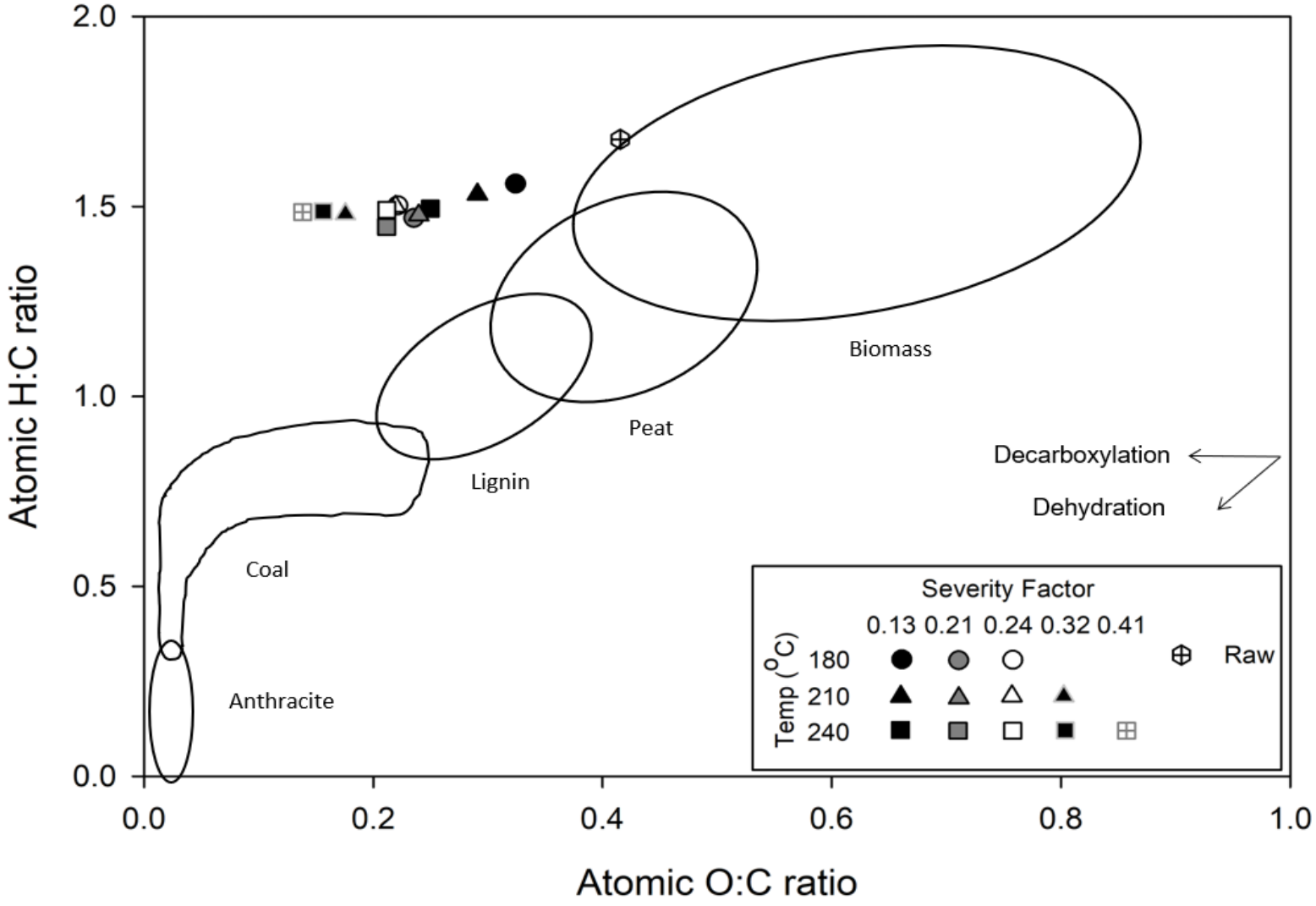
It is FECE-ble! 

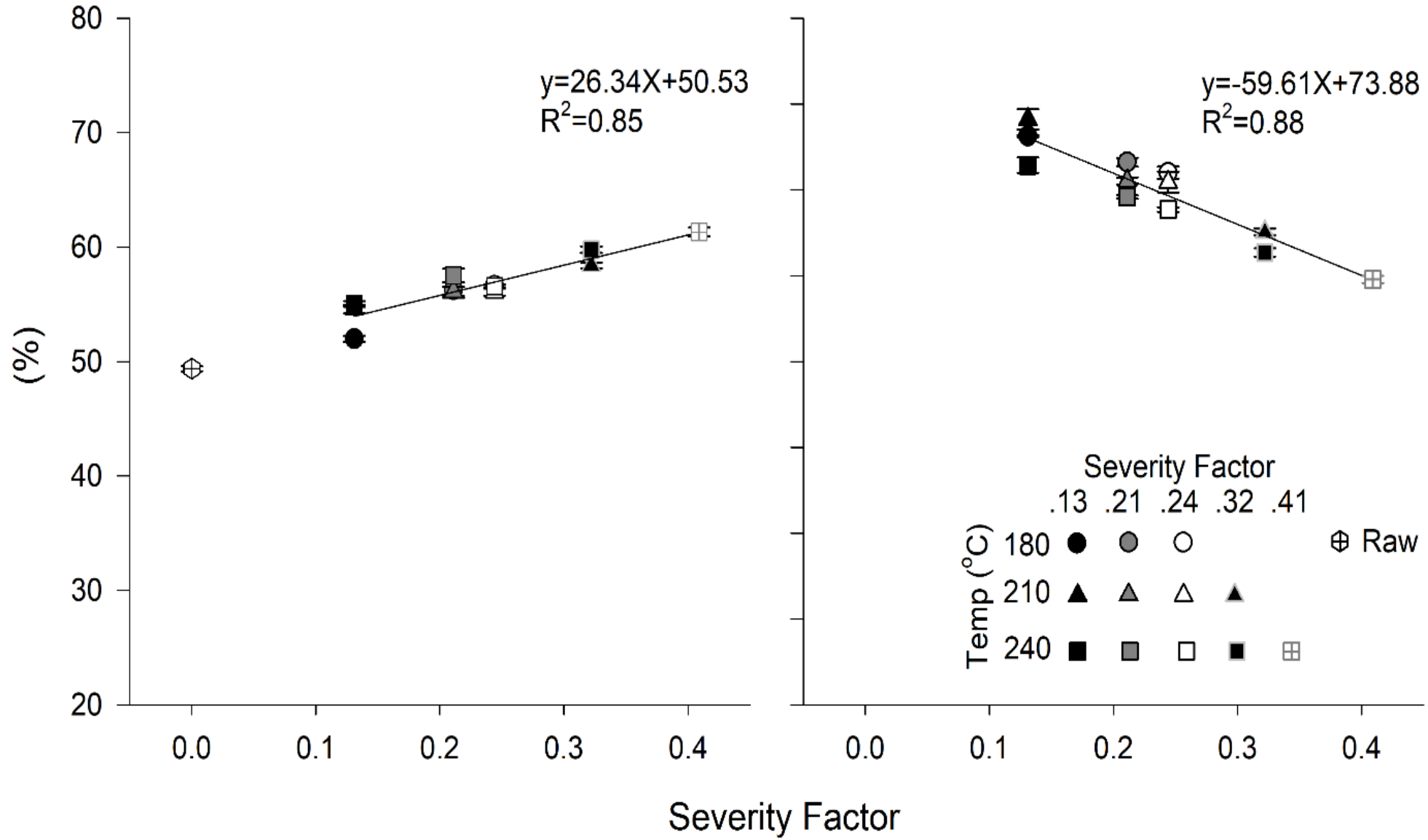
Acknowledgments

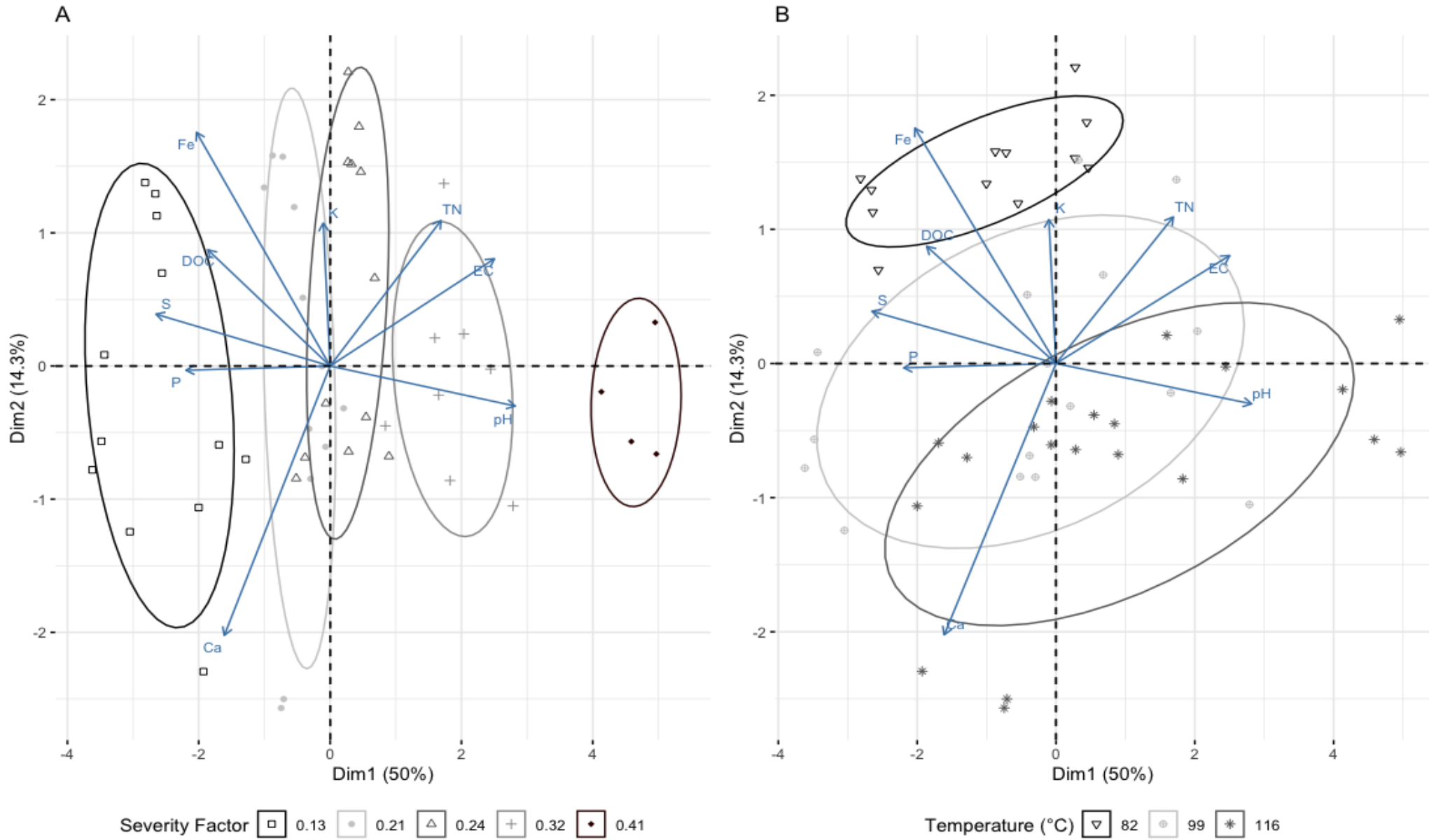
- P.hD Vivian Mau
- Poop volunteers
- Hunter Johanson
- Yonas Zeslase Belete
- Lab and office mates

Rosenzweig–Coopersmith Foundation

Decarboxylation is more pronounced than dehydration




y=26.34X+50.53
R2=0.85
y=-59.61X+73.88
R2=0.88
(%)
80
70
60
50
40
30
20
0.0
0.1
0.2
0.3
0.4
Severity Factor
Severity Factor
.13 .21 .24 .32 .41
Temp (°C)
180
210
240
Raw


A
B
Fe
K
TN
DOC
EC
S
P
pH
Ca
Dim1 (50%)
Dim2 (14.3%)
Severity Factor
0.13
0.21
0.24
0.32
0.41
Temperature (°C)
82
99
116

Parameters	Raw human excreta	HTC severity factor															
		0.13				0.21				0.24				0.32			0.41
		180 (°C)	210 (°C)	240 (°C)	Average	180 (°C)	210 (°C)	240 (°C)	Average	180 (°C)	210 (°C)	240 (°C)	Average	210 (°C)	240 (°C)	Average	240 (°C)
Elemental analysis																	
H (%)	6.90^{j}	6.76^{a}	6.97^{a}	6.86^{a}	6.86^{j}	6.89^{a}	6.91^{a}	6.93^{a}	6.91^{jk}	7.09^{a}	7.01^{a}	7.03^{a}	7.05^{k}	7.21^{a}	7.41^{b}	7.31^{l}	7.59^{m}
	(0.02)	(0.08)	(0.07)	(0.05)	(0.04)	(0.01)	(0.04)	(0.12)	(0.04)	(0.06)	(0.01)	(0.11)	(0.04)	(0.05)	(0.04)	(0.05)	(0.04)
C (%)	49.37^{j}	51.99^{a}	54.58^{b}	55.04^{b}	53.87^{k}	56.27^{a}	56.12^{a}	57.54^{a}	56.64^{kl}	56.65^{a}	56.07^{a}	56.59^{a}	56.43^{kl}	58.40^{a}	59.79^{b}	59.10^{lm}	61.34^{m}
	(0.00)	(0.27)	(0.37)	(0.25)	(0.43)	(0.68)	(0.46)	(0.60)	(0.36)	(0.13)	(0.31)	(0.17)	(0.14)	(0.25)	(0.28)	(0.31)	(0.37)
O (%)	27.34^{j}	22.47^{a}	21.15^{b}	18.32^{c}	20.65^{k}	17.64^{a}	17.91^{a}	16.23^{b}	17.26^{kl}	16.72^{a}	16.40^{ab}	15.97b^{a}	16.36^{lm}	13.66^{a}	12.44^{b}	13.05^{lm}	11.32^{m}
	(0.12)	(0.50)	(0.12)	(0.36)	(0.55)	(0.16)	(0.48)	(0.20)	(0.28)	(0.04)	(0.09)	(0.19)	(0.11)	(0.08)	(0.16)	(0.25)	(1.28)
N (%)	4.66^{j}	4.69^{a}	4.66^{a}	4.82^{a}	4.72^{j}	4.58^{a}	4.30^{ab}	4.15^{b}	4.34^{jk}	3.24^{a}	2.45^{b}	2.94^{ab}	2.88^{k}	4.41^{a}	4.81^{a}	4.61^{j}	4.73^{j}
	(0.17)	(0.07)	(0.21)	(0.21)	(0.09)	(0.09)	(0.06)	(0.08)	(0.07)	(0.22)	(0.08)	(0.16)	(0.13)	(0.19)	(0.15)	(0.14)	(0.13)
Proximate analysis																	
Organic matter (%)	88.15	89.48^{a}	87.74^{b}	87.40^{b}	88.21	85.95^{a}	85.83^{a}	85.44^{a}	85.74	84.64^{a}	83.89^{b}	84.55^{a}	84.36	83.33^{a}	83.84^{b}	83.58	83.14
	(0.03)	(0.29)	(0.25)	(0.38)	(0.31)	(0.38)	(0.27)	(0.14)	(0.16)	(0.15)	(0.07)	(0.07)	(0.12)	(0.12)	(0.17)	(0.14)	(0.09)
Ash (%)	11.85	10.52^{a}	12.26^{b}	12.60^{b}	11.79	14.05^{a}	14.17^{a}	14.56^{a}	14.26	15.36^{a}	16.11^{b}	15.45^{a}	15.64	16.67^{a}	16.16^{b}	16.42	16.86
	(0.03)	(0.29)	(0.25)	(0.38)	(0.31)	(0.38)	(0.27)	(0.14)	(0.16)	(0.15)	(0.07)	(0.07)	(0.12)	(0.12)	(0.17)	(0.14)	(0.09)
HHV (MJ/kg)	22.32	23.54	24.79	25.10^{a}	24.48^{ik}	25.60	25.55	26.23^{a}	25.79^{kl}	26.03	25.76^{a}	26.02^{a}	25.94^{kl}	27.05	27.91^{b}	27.48^{l}	28.76

Normalized area under the curve by gas (%)	Raw human excreta	HTC severity factor											
		0.13				0.24				0.32			0.41
		180 (°C)	210 (°C)	240 (°C)	Average	180 (°C)	210 (°C)	240 (°C)	Average	210 (°C)	240 (°C)	Average	240 (°C)
CO2	34.6	34.2^{a}	34.7^{a}	26.2^{b}	31.7^{j}	20.5^{a}	24.0^{b}	23.6^{b}	22.7^{jk}	20.1^{a}	19.4^{a}	19.8^{k}	11.8^{k}
	(2.5)	(1.7)	(1.2)	(1.7)	(1.6)	(1.6)	(0.3)	(0.7)	(0.6)	(0.5)	(1.1)	(0.2)	(2.7)
CO	2.3	1.8^{a}	1.8^{a}	1.7^{a}	1.7^{j}	1.1^{a}	1.7^{b}	1.7^{b}	1.5^{j}	1.7^{a}	1.6^{a}	1.6^{j}	1.7^{j}
	(0.4)	(0.1)	(0.0)	(0.1)	(0.0)	(0.1)	(0.1)	(0.0)	(0.1)	(0.2)	(0.2)	(0.0)	(0.1)
CH4	10.9	22.1^{a}	23.7^{ab}	25.0^{b}	23.6^{j}	26.1^{a}	24.9^{a}	25.5^{a}	25.5^{j}	25.4^{a}	23.2^{a}	24.3^{j}	41.6^{k}
	(1.5)	(0.4)	(1.0)	(0.4)	(0.5)	(2.0)	(2.2)	(1.6)	(0.2)	(2.3)	(2.3)	(0.6)	(2.6)
NO	11.9	13.6^{a}	12.0^{b}	12.4^{ab}	12.7^{j}	13.2^{a}	12.4^{a}	12.0^{a}	12.5^{j}	11.7^{a}	10.7^{a}	11.2^{k}	6.3^{l}
	(1.5)	(0.4)	(0.1)	(0.4)	(0.3)	(0.4)	(0.4)	(0.2)	(0.2)	(0.5)	(0.5)	(0.3)	(1.4)
Ether	7.2	7.0^{a}	5.9^{a}	6.4^{a}	6.5^{jk}	7.0^{a}	7.2^{a}	6.6^{a}	6.9^{j}	6.5^{a}	5.8^{a}	6.2^{jk}	5.6^{k}
	(0.2)	(0.5)	(0.2)	(0.2)	(0.2)	(0.2)	(0.3)	(0.3)	(0.1)	(0.7)	(0.7)	(0.2)	(0.1)
NH3	12.5	6.7^{ab}	6.1^{a}	9.1^{b}	7.3^{j}	10.1^{ab}	9.3^{a}	11.2^{b}	10.2^{k}	10.8^{a}	11.6^{a}	11.2^{k}	11.6^{k}
	(0.1)	(1.0)	(0.4)	(0.5)	(0.5)	(0.2)	(0.4)	(0.4)	(0.3)	(0.8)	(0.8)	(0.2)	(0.5)
SO2	5.8	4.4^{a}	4.5^{a}	4.9^{a}	4.6^{j}	6.0^{a}	5.8^{a}	5.9^{a}	5.9^{k}	6.8^{a}	7.7^{a}	7.2^{kl}	7.5^{l}
	(0.8)	(0.8)	(0.2)	(0.1)	(0.1)	(0.1)	(0.3)	(0.2)	(0.0)	(0.3)	(0.3)	(0.2)	(1.2)
Carbonyl	8.8	8.3^{a}	9.1^{a}	9.4^{a}	8.9^{jk}	10.1^{a}	9.5^{ab}	9.0^{b}	9.5^{kl}	10.0^{a}	10.5^{a}	10.3^{l}	8.6^{j}
	(0.2)	(0.2)	(0.3)	(0.3)	(0.2)	(0.2)	(0.4)	(0.2)	(0.2)	(0.2)	(0.2)	(0.1)	(1.1)

Sanitation categories

"Improved" sanitation:

- Flush toilet [v]
- Piped sewer system [v]
- Septic tank [v]
- Flush/pour flush to pit latrine [v]
- Ventilated improved pit latrine (VIP) [v]
- Pit latrine with slab [v]
- Composting toilet [v]
- Special case [v]

"Unimproved" sanitation:

- Flush/pour flush to elsewhere [v]
- Pit latrine without slab [v]
- Bucket [v]
- Hanging toilet or hanging latrine [v]
- Shared sanitation [v]
- No facilities or bush or field [v]

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