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Pretreatment for cellulosic ethanol production in the developing world

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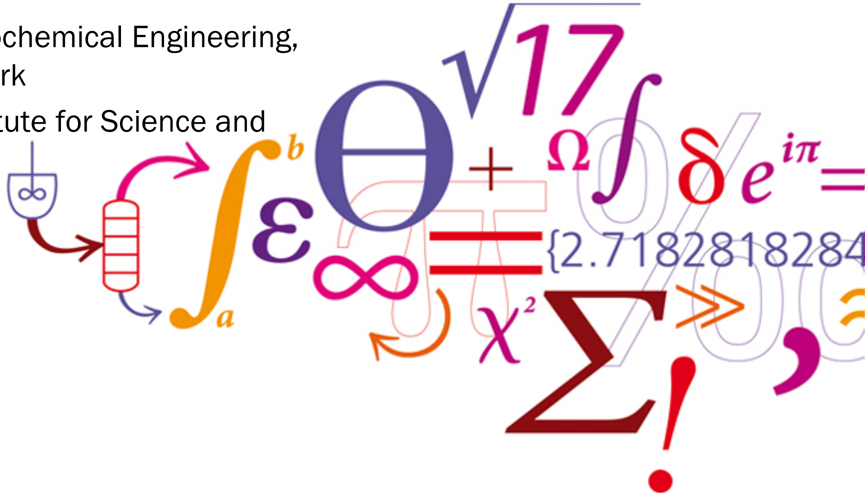

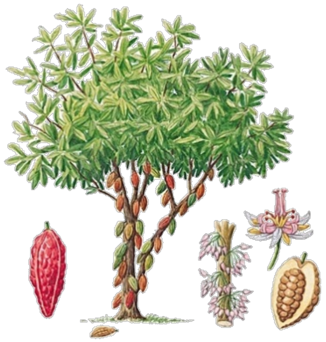

DTU Chemical Engineering
Department of Chemical and Biochemical Engineering

Welcome

And a big thanks to:

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- Colleagues at the Technical University of Denmark, project partners, and especially my co-authors

- The audience – thank you all for coming

Introduction

- Ongoing project conserning production of residue-based biofuels in Ghana
- Several criterias shape the possible biofuels solutions
  - Infrastructure
  - Biomasses
  - Labor
  - Economics
- Screening of suitable pretreatment methods low-tech conditions on Ghanaian biomasses

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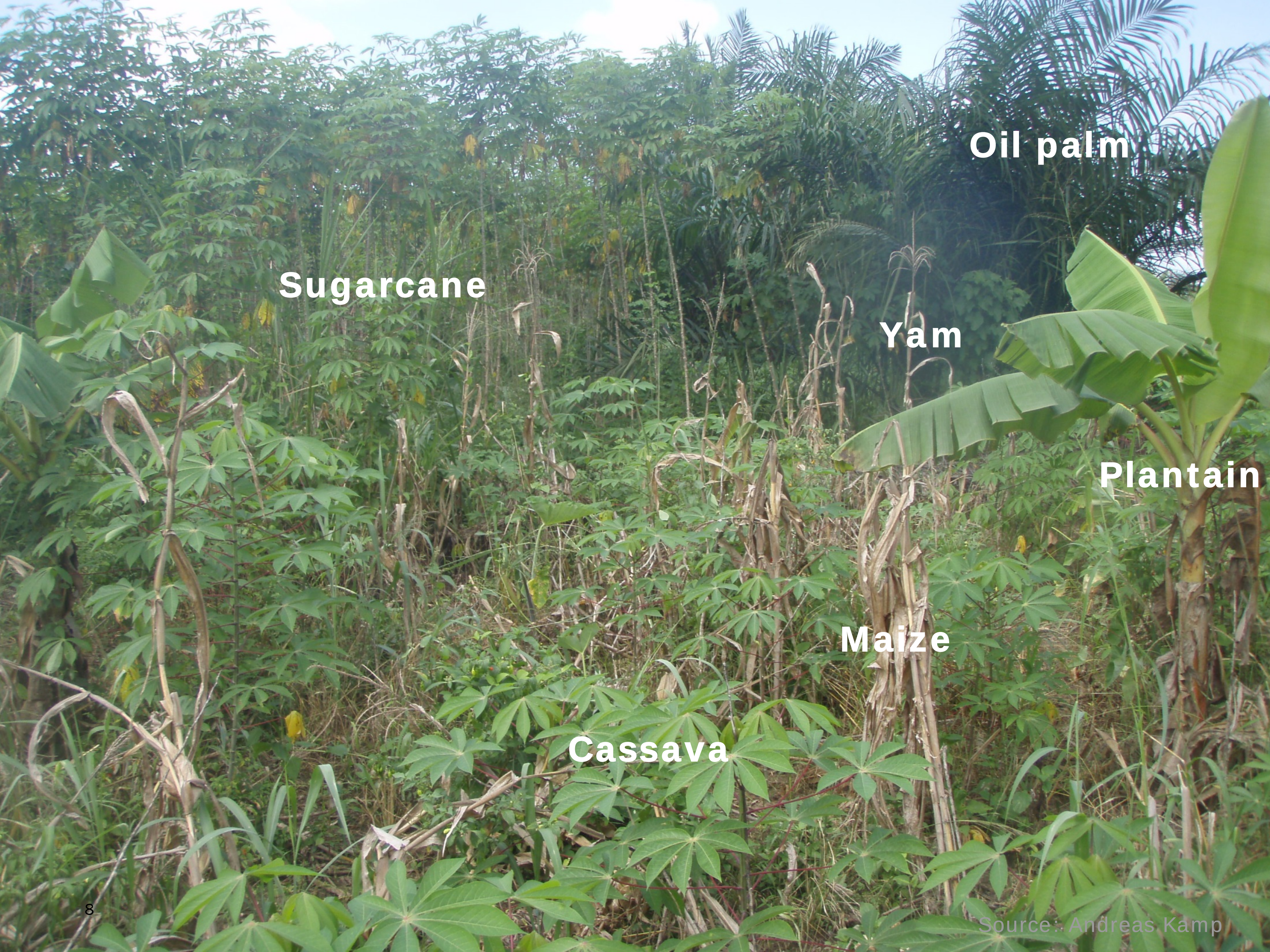


Source: Andreas Kamp

Pineapple

Source: Andreas Kamp

Cocoa

Source: www.worldcocoafoundation.org

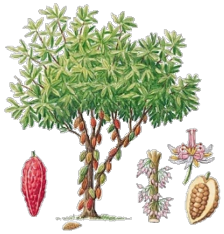
The Betarenewables full-scale plant in Crescentino, Italy

Utilize more than 700 tons of biomass per day

Source: www.betarenewables.com

Therefore…

- Pretreatment for cellulosic ethanol should be optimized within the constraints of a significant smaller scale
- Methods that are more labor intensive than methods developed for the industrialized world
- We investigated three alternative pretreatment methods applicable for small-scale low-tech conditions



Pretreatment: Investigated methods

- Soaking in aqueous ammonia (SAA)
- Boiling pretreatment (BP)
- White rot fungi pretreatment (WRF)

Benchmarked against

- Hydrothermal treatment (HTT)

Soaking in aqueous ammonia (SAA)

- Can be done with long retention times and at ambient temperatures.
- Highly scalable thus suited for low-tech solution
- Swelling of cellulose and delignification
  - Cleavage of ether bonds in lignin
  - Cleavage ether and ester bonds coupling lignin to hemicellulose
- A recovery system for the ammonia is needed

solid to liquid loadings of 1:4 (w/w). After soaking for 10 days at 30° C

SAA pretreated maize stalks

Boiling pretreatment (BP)

- Very simple method
- Solubilizes some non-structural components such as proteins, waxes, and inorganic compounds
- When BP has been applied as lignocellulose pretreatment method, it has been with a limited effect
- Starch fractions swell and become exposed for enzymatic breakdown

100° C
10 minutes
10% TS

White rot fungi pretreatment (WRF)

- White rot fungi degrades lignin and carbohydrates through extracellular enzymes over an extended time
- Strain: *Ceriporiopsis subvermispora*
  - Degrades mainly lignin and metabolizes only a little C5 sugars and no C6
- Time consuming and labor intensive but scaleable and suitable for low-tech

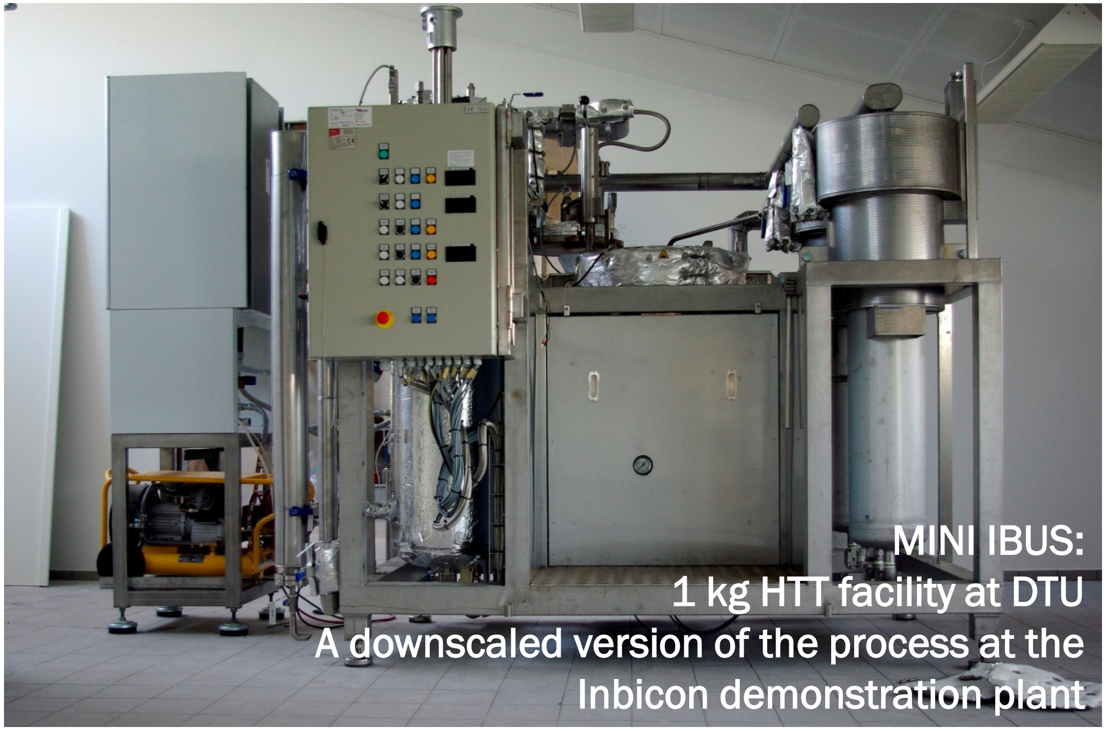
Moist straw inoculated with *C. subvermispora*

25% initial TS (sterilised biomass)
30 days at 28° C, 90% relative humidity

Hydrothermal treatment (HTT

- Autohydrolysis with water at 160-230°C
- High pressure
- High temperature
- High efficiency
- High costs

- Applied by e.g.
  - Inbicon
  - Betarenewables


MINI IBUS:
1 kg HTT facility at DTU
A downscaled version of the process at the Inbicon demonstration plant

190° C
10 minuttes

Investigated agricultural residues from West Africa

Cassava	Plantain	Maize	Rice	Oil palm	Groundnut	Cocoa
Stalks	Peelings Trunks Leaves	Cobs Stalks	Straw	EFB	Straw	Pods Husks

Chemical composition

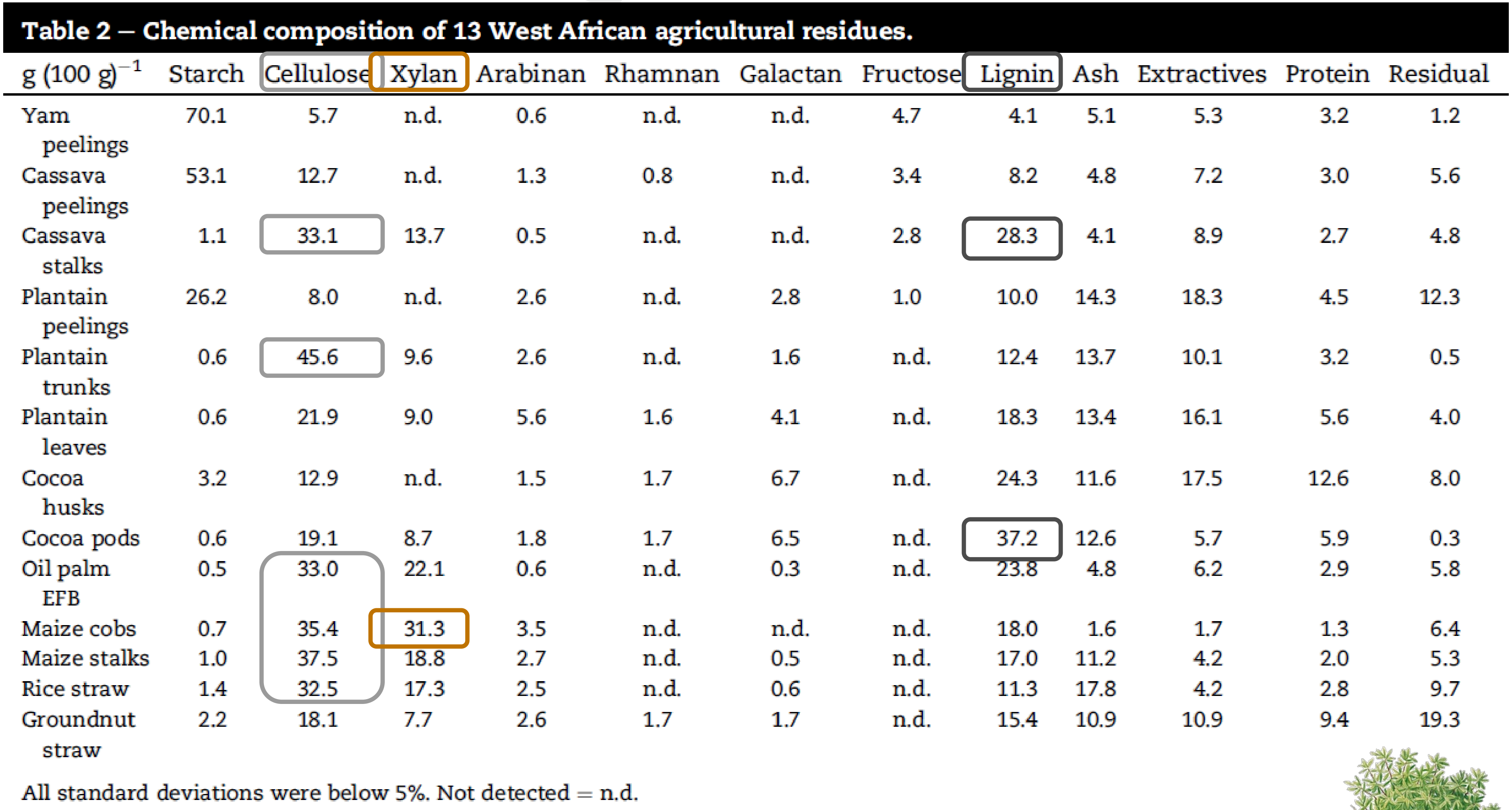


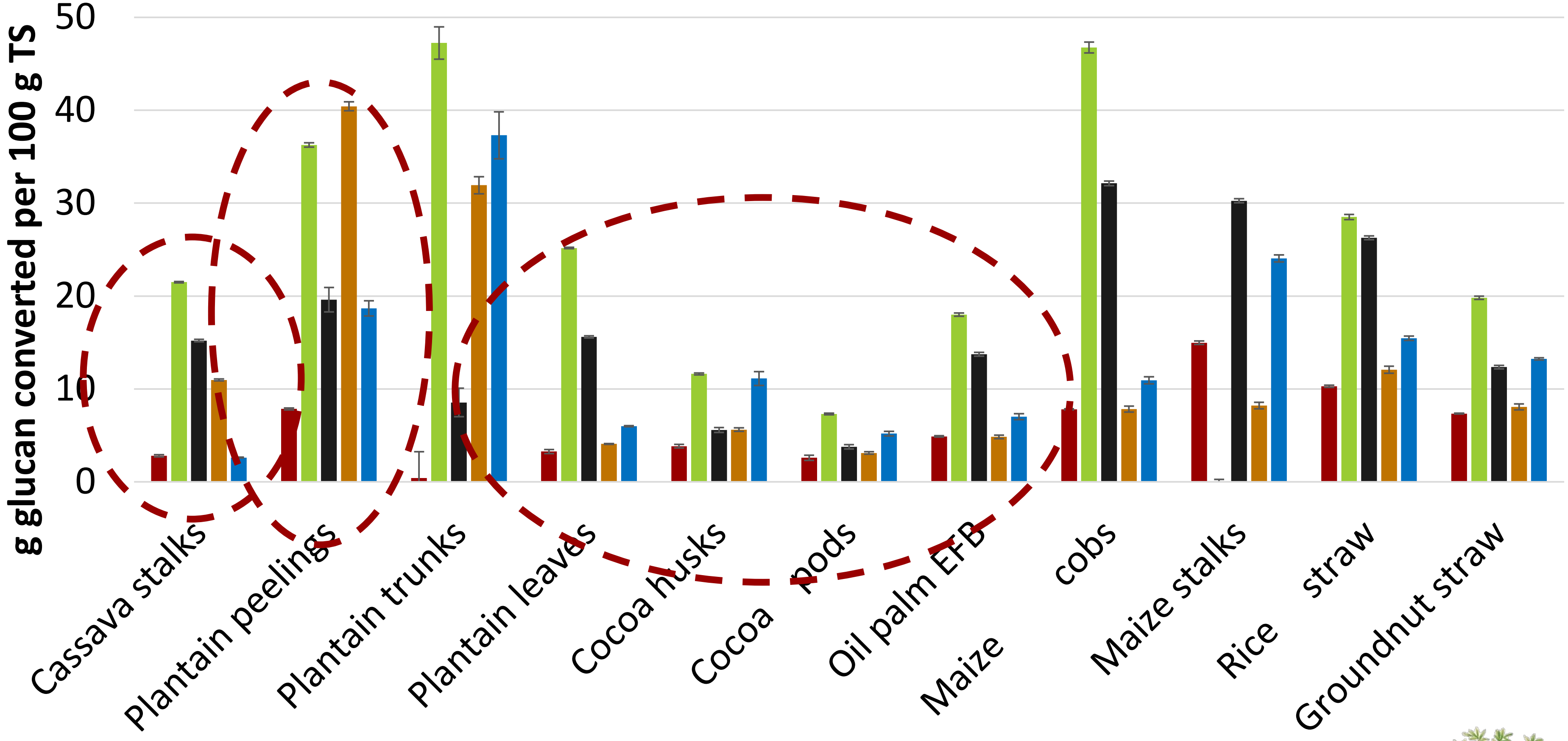
Table 2 – Chemical composition of 13 West African agricultural residues.

g (100 g)$^{-1}$	Starch	Cellulose	Xylan	Arabinan	Rhamnan	Galactan	Fructose	Lignin	Ash	Extractives	Protein	Residual
Yam peelings	70.1	5.7	n.d.	0.6	n.d.	n.d.	4.7	4.1	5.1	5.3	3.2	1.2
Cassava peelings	53.1	12.7	n.d.	1.3	0.8	n.d.	3.4	8.2	4.8	7.2	3.0	5.6
Cassava stalks	1.1	33.1	13.7	0.5	n.d.	n.d.	2.8	28.3	4.1	8.9	2.7	4.8
Plantain peelings	26.2	8.0	n.d.	2.6	n.d.	2.8	1.0	10.0	14.3	18.3	4.5	12.3
Plantain trunks	0.6	45.6	9.6	2.6	n.d.	1.6	n.d.	12.4	13.7	10.1	3.2	0.5
Plantain leaves	0.6	21.9	9.0	5.6	1.6	4.1	n.d.	18.3	13.4	16.1	5.6	4.0
Cocoa husks	3.2	12.9	n.d.	1.5	1.7	6.7	n.d.	24.3	11.6	17.5	12.6	8.0
Cocoa pods	0.6	19.1	8.7	1.8	1.7	6.5	n.d.	37.2	12.6	5.7	5.9	0.3
Oil palm EFB	0.5	33.0	22.1	0.6	n.d.	0.3	n.d.	23.8	4.8	6.2	2.9	5.8
Maize cobs	0.7	35.4	31.3	3.5	n.d.	n.d.	n.d.	18.0	1.6	1.7	1.3	6.4
Maize stalks	1.0	37.5	18.8	2.7	n.d.	0.5	n.d.	17.0	11.2	4.2	2.0	5.3
Rice straw	1.4	32.5	17.3	2.5	n.d.	0.6	n.d.	11.3	17.8	4.2	2.8	9.7
Groundnut straw	2.2	18.1	7.7	2.6	1.7	1.7	n.d.	15.4	10.9	10.9	9.4	19.3

All standard deviations were below 5%. Not detected = n.d.

Thomsen et al., Compositional analysis and theoretical biofuel potentials from various West African agricultural residues, *Biomass & Bioenergy (2014)*

Glucose yield after enzymatic conversion with cellulase of raw and pretreated agricultural residues



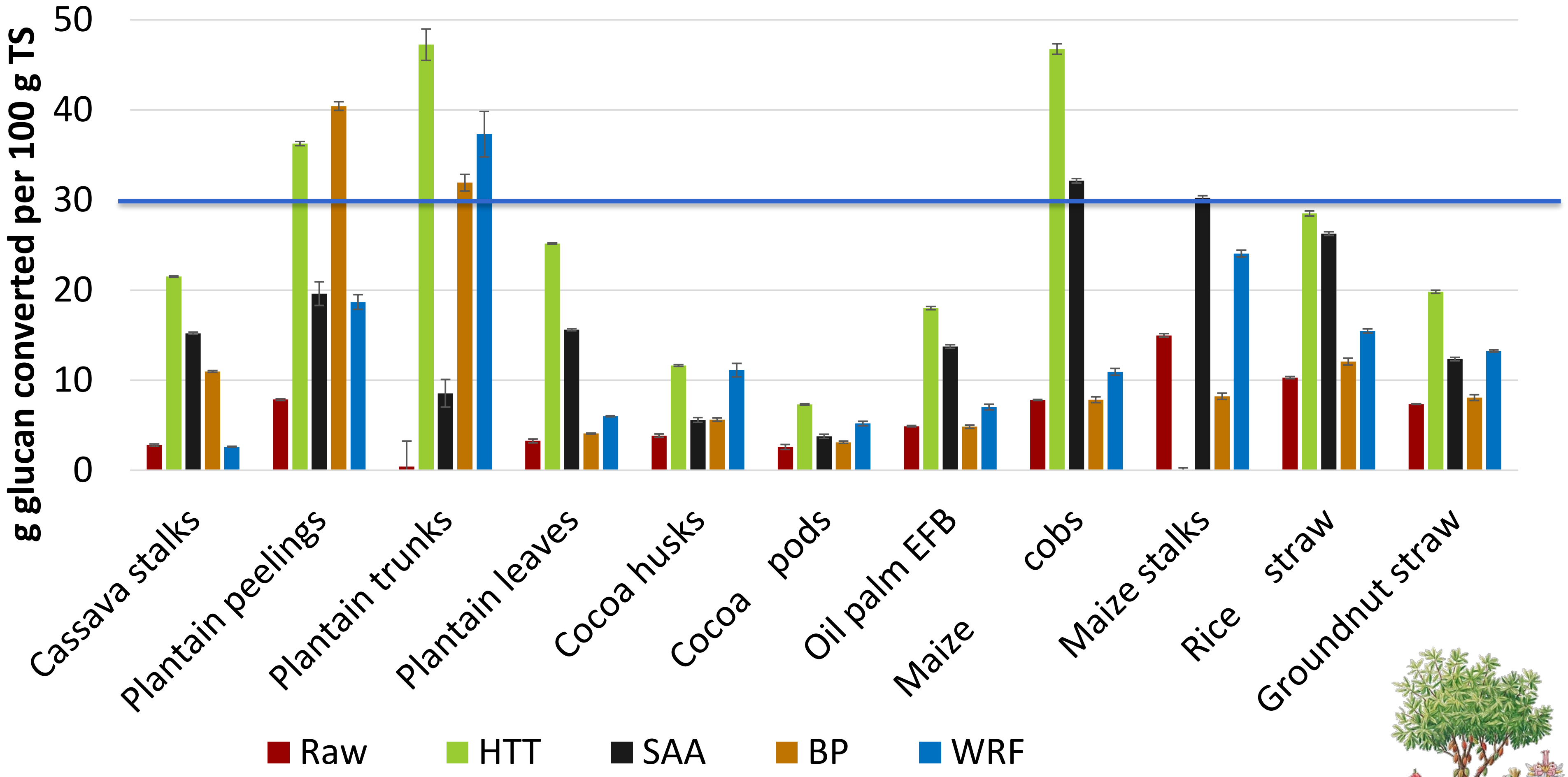
🟥 Raw 🟩 HTT ⬛ SAA 🟧 BP 🟦 WRF

5 %TS, Cellic CTec 2® + HTec 2®, 72h

Threshold for glucose yield after enzymatic conversion

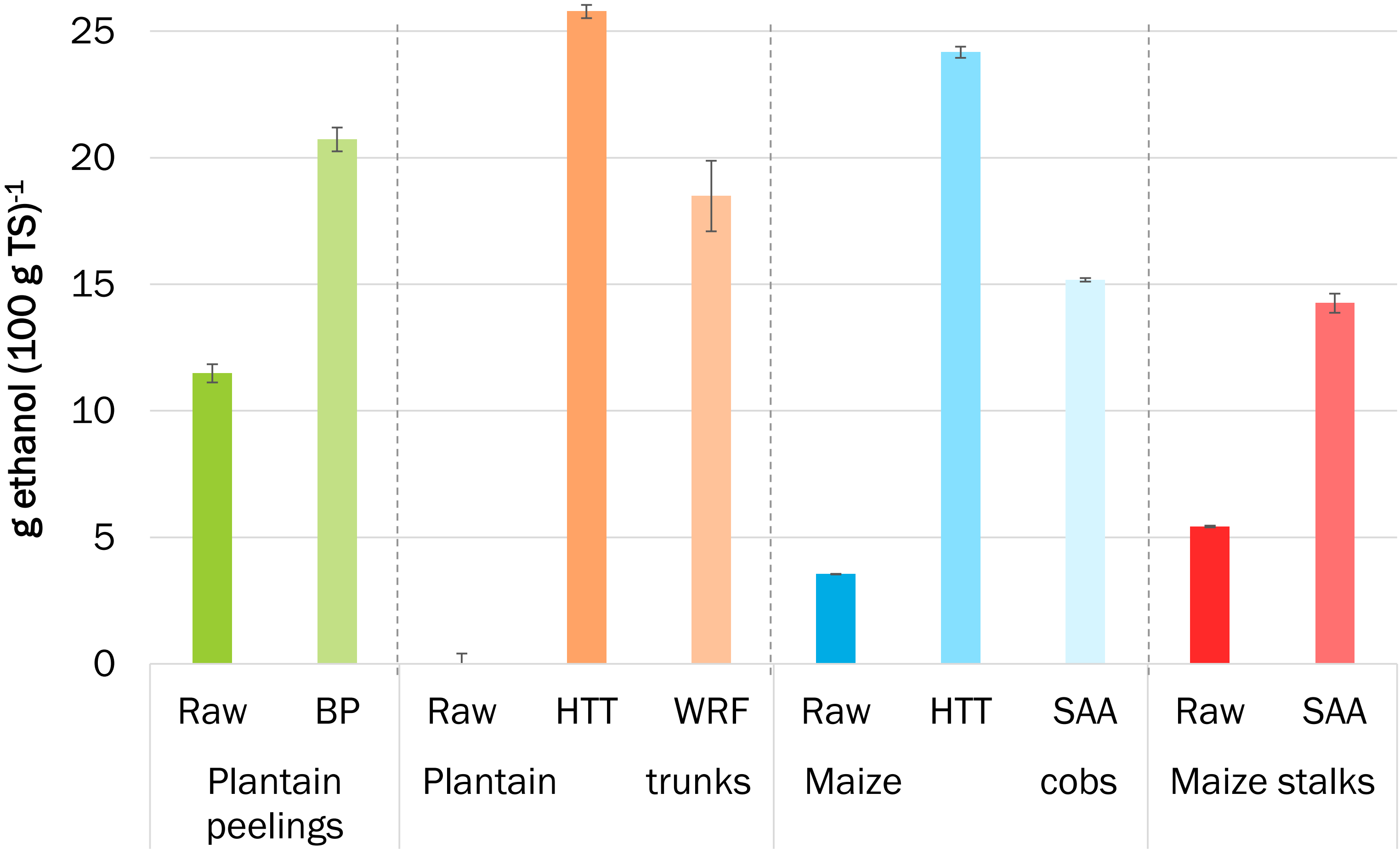
- Based on two criteria:
  - At least 4 w/w % ethanol after fermentation is needed in order to make cost-effective destillation
  - Maximum 25 % TS in prehydrolysis
- These factors can be calculated into a required conversion of glucan of at least **30 g per 100 g of TS**

Glucose yield after enzymatic conversion with cellulase of raw and pretreated agricultural residues



5 %TS, Cellic CTec 2® + HTec 2®, 72h

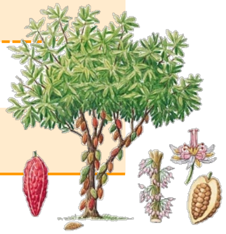
Fermentation* of raw and pretreated residues



*SSF, 6 days, 10 %TS, Cellic CTec 2® + HTec 2®, Ethanol Red®

Glucan recovery, ethanol conversion efficiency and overall ethanol yield of raw and pretreated residues

		Glucan recovery	Ethanol conversion efficiency	Overall ethanol yield
		w/w %	g eth./100 g potential eth. from pretreated material	g eth./100 g TS raw material
Plantain peelings	Raw	100%	59.4	11.5
	BP	81%	85.9	13.4
Plantain trunks	Raw	100%	0.0	0.0
	HTT	77%	74.1	15.0
	WRF	89%	63.7	14.8
Maize cobs	Raw	100%	17.3	3.6
	HTT	81%	91.1	15.2
	SAA	81%	92.7	15.2
Maize stalks	Raw	100%	25.0	5.4
	SAA	90%	72.4	13.7



Summary

- Pretreatment for cellulosic ethanol should be optimized for smaller scale for most developing world scenarios (exemplified by West African conditions)

- We find that the alternative methods are viable, especially when looking at the overall utilization of the biomasses
- Only less than half of the tested biomasses are suitable for cellulosic ethanol production with sufficiently high yields

- Outlook:
  - Low-tech small-scale distillation
  - Implementation studies on site

References:

- Kemausuor et al., Assessment of biomass residue availability and sustainable bioenergy yields in Ghana, *Resources, Conservation and Recycling (2014)*
- Thomsen et al., Compositional analysis and theoretical biofuel potentials from various West African agricultural residues, *Biomass & Bioenergy (2014)*
- Thomsen et al., Screening of pretreatments of common West African lignocellulosic biomass residues for ethanol production, *submitted to Renewable Energy (2014)*