Evaluating Corn-to-Ethanol Production with the Addition of Sorghum Grain

Krystin Polhemus, Elijah Switzer, Dr. Mingjun Ma and Dr. Yan Zhang

National Corn-to-Ethanol Research Center (NCERC)
at Southern Illinois University Edwardsville

For FELC 2024

NCERC at SIUE
Advancing Biorenewables Research

Section I	Ethanol from 100% Sorghum and Mixed with Corn, 1G
Section II	Ethanol from 100% Sorghum, *in situ* 1.5G and 1G
Section III	Use NCERC's Starch and Cellulose Testing Methods to Build Mass Balance for Flask Fermentation
Section IV	Hemicellulose in Feedstocks (corn, sorghum), and in DDGS
Section V	Cellulose methods: NCERC method and NREL method

1G Ethanol Production
100% Sorghum vs 100% Corn

Sorghum	Ethanol level (g/L) in final beer compared with 100% Corn 1G	Ethanol production (g) per flask* compared with 100% Corn 1G
Total of 6 varieties¥, plus samples from three states# in the U.S.	88% to 102%	88% to 102%

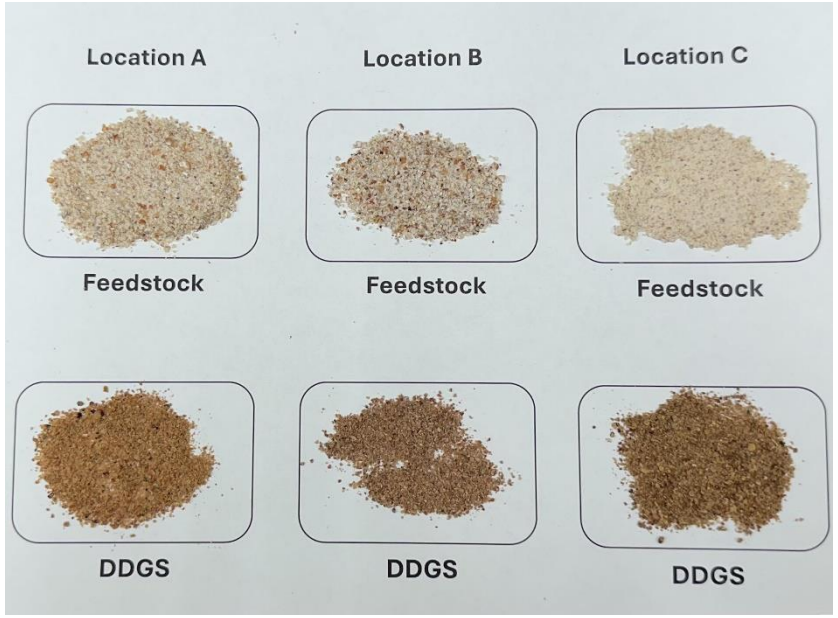
* Ethanol production per flask data were consistent with carbon dioxide production data
¥ Sorghum varieties received from Nuseed
Location A, B, C

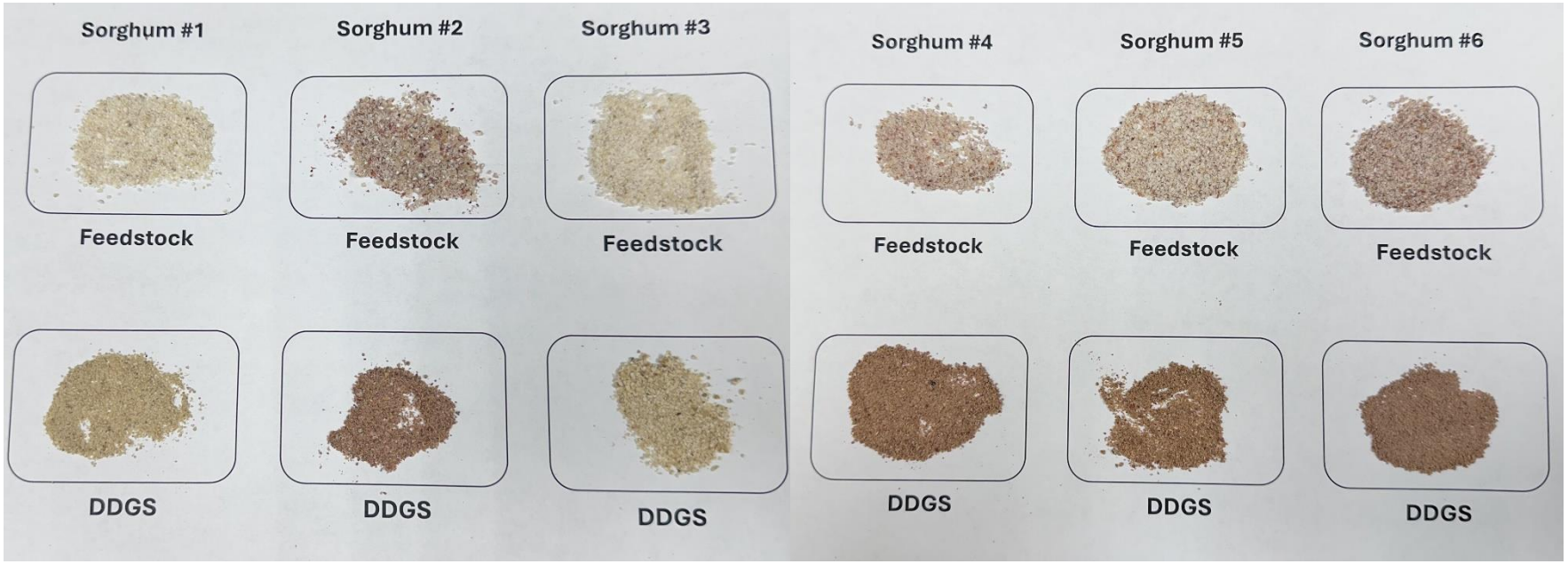
NCERC at SIUE
Advancing Biorenewables Research

nuSEED

100% Sorghum Flour
vs
100% Sorghum DDGS

Nuseed Variety 3 Best Performer





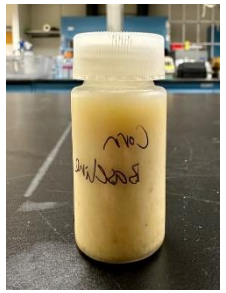
NCERC at SIUE
Advancing Biorenewables Research

Flask Fermentation to Make Ethanol from Corn Mixed with Sorghum

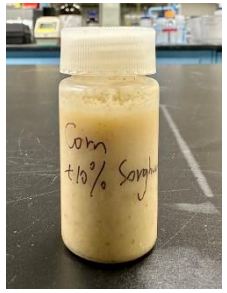
Corn; Sorghum

Final Beer from

100% Corn



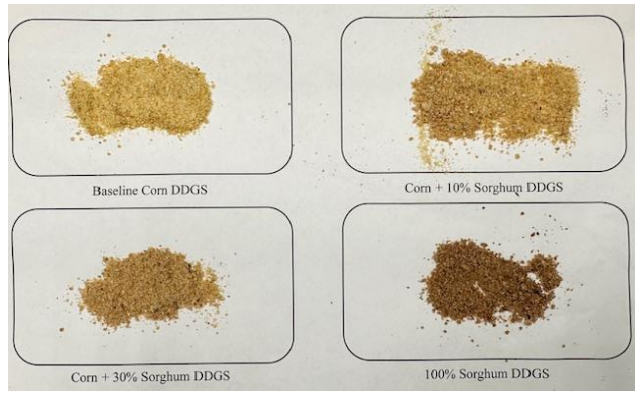
10% Sorghum in Corn



30% Sorghum in Corn

100% Sorghum

DDGS from corn,
10% sorghum in corn
30% sorghum in corn
100% sorghum



NCERC at SIUE
Advancing Biorenewables Research

Section I Summary

- **The 1G ethanol production from sorghum can range between 88% and 102% of that from corn, depending on the sorghum variety**

- **When mixing sorghum with corn, the ethanol production level could be reduced, if the sorghum variety has lower starch content and lower conversion capability of the starch in sorghum under 1G conditions**

Industrial *in situ* 1.5G Ethanol Production Comparison

Feedstocks	*In situ* 1.5G ethanol production per flask compared with Corn 1G	Ethanol production per flask *in situ* 1.5G / 1G sorghum
Location A	98%	104%
Location B	94%	106%
Sorghum V1	96%	102%
Sorghum V4	101%	102%
Corn	101%	

NCERC in situ 1.5G Ethanol Production Comparison

Feedstocks	*NCERC In situ* 1.5G ethanol production per flask compared with Corn 1G	Ethanol production per flask *NCERC in situ* 1.5G / 1G sorghum
Location B	96%	108%
Sorghum V3	105%	
Corn	104%	

Section II Summary

- **1G to industrial *in situ* 1.5G,**

  1% ethanol production increase corn

  2 - 6% ethanol production increase sorghum

- **1G to NCERC *in situ* 1.5G,**

  4% ethanol production increase corn,

  8% ethanol production increase sorghum

Mass Balance

1G Ethanol, Starch in Feedstocks and in DDGS

Feedstock	Ethanol production per flask (g)	Total Starch in feedstock (%, DWB)	Total starch in DDGS (%, DWB)	Starch/ash in DDGS / starch/ash in feedstock (%)
Sorghum V1	10.5	69.9	9.0	4
Sorghum V2	10.4	61.5	15.0	8
Sorghum V3	11.4	70.7	6.0	2
Sorghum V4	11.1	65.1	8.7	5
Corn Baseline	11.2	70.6	3.9	2

Mass Balance: Industrial *in situ* 1.5G / 1G

Feedstock	Ethanol production per flask		Residual starch in DDGS		Residual cellulose in DDGS
	g		%, dwb		%, dwb
Corn 1G*	13.1		2.6		9.4
Corn *in situ* 1.5G	13.4		1.8		7.1
1.5 G/1G	*102%*		*71%*		*75%*
Sorghum Location A 1G	12.4		15.7		10.7
Sorghum Location A *in situ* 1.5G	12.9		13.0		4.4
1.5 G/1G	*104%*		*83%*		*41%*
Calculated ethanol increase from the reduction of starch or cellulose (g)			0.16**		0.37
Ethanol increase (g)	0.50				0.53 g

*Corn DDGS data were from the publication of *Industrial Biotechnology 19 (3), 163-167*

**Estimated by 1. Carbohydrate mass in DDGS: DDGS mass X residual carbohydrate level

2. Reduction of carbohydrates: carbohydrate mass in 1G DDGS – mass in 1.5G DDGS

3. Ethanol (g): results from #2 X 0.57 (assuming 100% carbohydrate conversion to ethanol and CO_2)

Mass Balance: *in situ* 1.5G / 1G

Feedstock	Residual starch in DDGS		Residual cellulose in DDGS
	%, dwb		%, dwb
Sorghum V1 1G	9.0		11.0
Sorghum V1 1.5G	4.3		7.6
1.5 G/1G	*48%*		*70%*
Sorghum V3 1G	6.0		10.6
Sorghum V3 NCERC Boost 1.5G	5.4		6.6
1.5 G/1G	*90%*		*62%*

Section III Summary

- **Under 1G, higher starch in sorghum leads to higher ethanol production; the residual starch level in sorghum DDGS was likely higher than that in corn DDGS**
- **Under *in situ* 1.5G, sorghum likely has more potential to make cellulosic ethanol production than corn**
- **Nuseed Variety 3 can make more total ethanol and cellulosic ethanol than corn under various conditions**

Hemicellulose in Grains

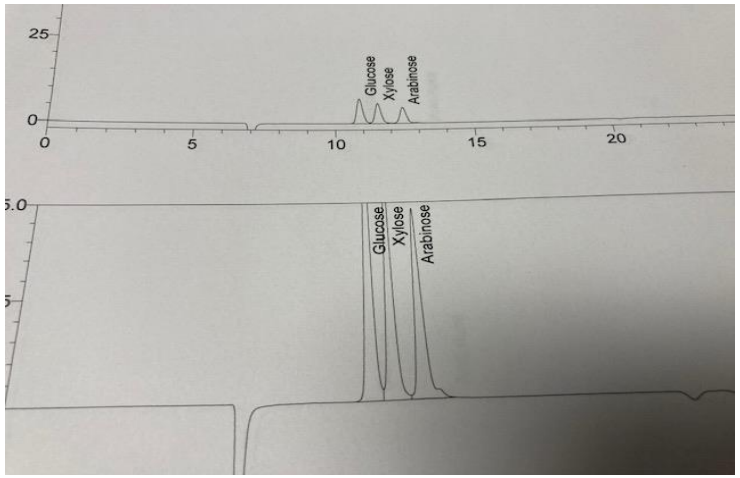
Definition: Xylan, dominant, β-1,4-linked xylose

Arabinan, minor, alpha-1, 5 linked arabinose

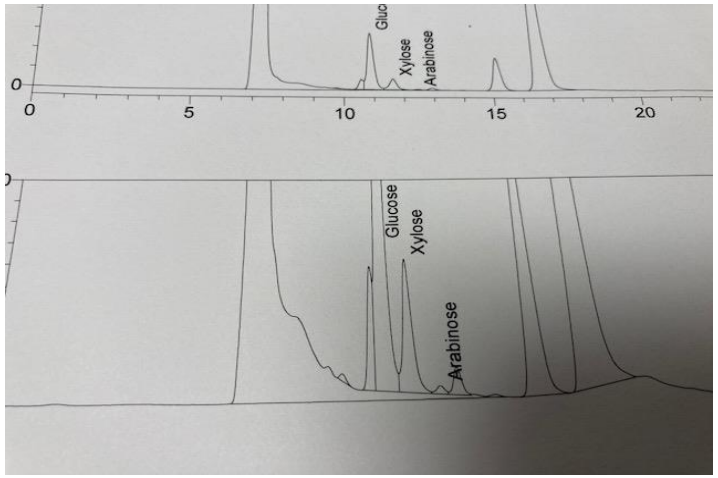
Testing method: NREL Technical Report NREL/TP-510-42618

(can be validated with the help of LC/MS/MS, to verify the selectivity of the xylose peak identified using LC/RID)

Typical HPLC Chromatograms



HPLC Check Standard



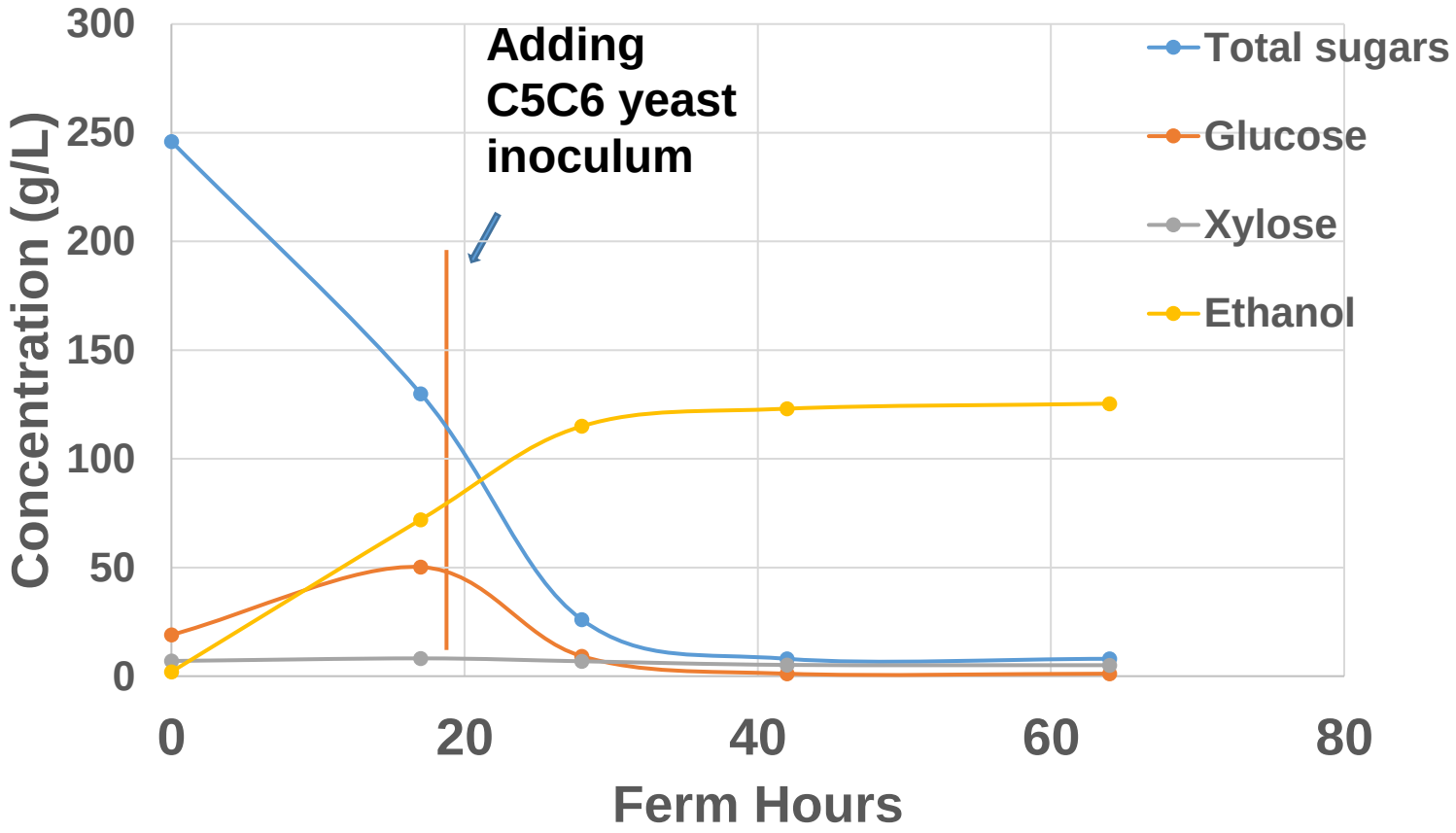
Sorghum flour

Carbohydrates in Flour and DDGS*

Samples	Starch	Cellulose	Xylan
	%, dwb	%, dwb	%, dwb
Corn flour	76	1.8	4.0
Corn 1G DDGS	3.9	9.4	N.A.
Sorghum flour V3	71	3.9	3.4
Sorghum V1 1G DDGS	9.0	11.0	9.5
Sorghum V3 1G DDGS	6.0	10.6	10.1

* The error bar for data points from 10% to 20%; also consider the range for each data category

HPLC for 150 L Fermentation
Corn Starch, Cellulose and Xylose Conversion



NCERC at SIUE
Advancing Biorenewables Research

NCERC Cellulose Method for Corn Matrix

- **A VCSB Method - Published in *Industrial Biotechnology 19 (3), 163-167***

- **Used to test the following samples:**
  - ❑ **Two NIST biomass samples**
  - ❑ **A pair of before conversion (BC) and after conversion (AC) samples from three dry grind ethanol plants in the U.S.**
  - ❑ **NCERC in-house synthetic standard run with every batch**

When using the testing method on sorghum-based samples, the data on cellulose and starch change from 1G to 1.5G can explain the ethanol increase with accurate mass balance

Results - NIST Samples (corn matrix)

NIST BC Biomass			NIST AC Biomass		
NREL method	NCERC method	NREL/NCERC	NREL method	NCERC method	NREL/NCERC
2.00%	2.80%	0.7	5.20%	8.60%	0.6

Results - Dry Grind Ethanol Plant Samples (corn matrix)

	Plant BC Sample			Plant AC Sample		
	NREL Method	NCERC Method	NREL/NCERC	NREL Method	NCERC Method	NREL/NCERC
Plant I	1.9	3	0.6	6.5	9.1	0.7
Plant II	2.2	2.2	1	6.4	8.9	0.7
Plant III	1.8	2.7	0.7	5.8	8.5	0.7

Summary

- **The NCERC proprietary analytical methods for testing starch and cellulose in both corn and sorghum matrix have delivered scientifically sound results**
- **Those methods are strong to be used to support D3RINs analytical testing package for ethanol plants**
- **In general, the NCERC cellulose method delivered about 30% higher value than the NREL method when testing the same corn matrix samples**

Acknowledgement

Illinois Corn Marketing Board
Renewable Fuels Association
Southern Illinois University Edwardsville