



# Yield10 Trait Development: Towards a value-added Camelina crop

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October 24, 2023

24–25 October 2023, Raleigh, NC, USA

Plant Genomics & Gene Editing Congress USA



Global Engage 

**10<sup>TH</sup> PLANT GENOMICS &  
GENE EDITING CONGRESS: USA**

OCTOBER 24-25, 2023 - RALEIGH, USA



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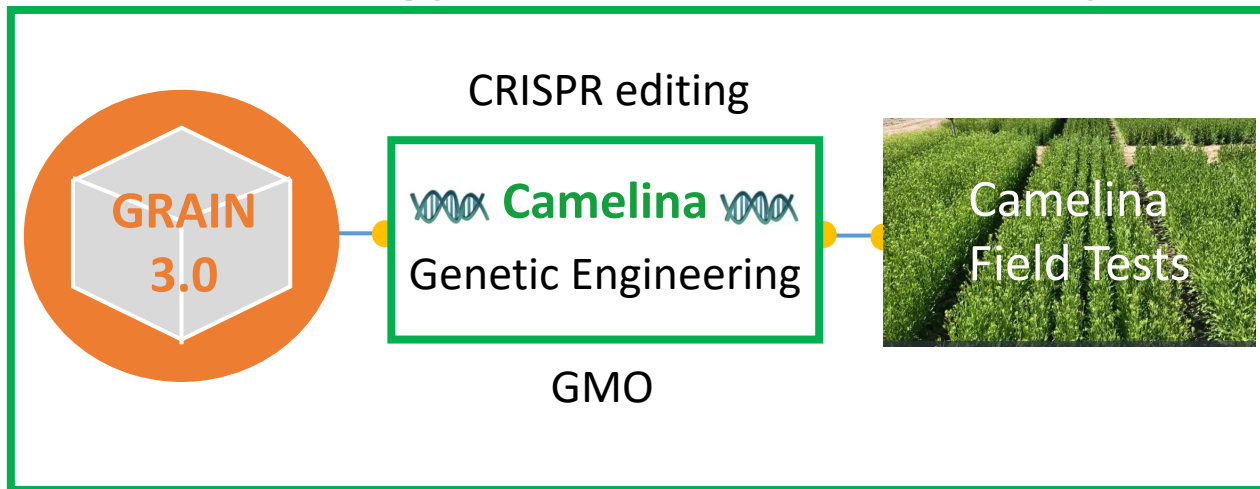
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# Yield10's Trait Factory

## From Crop Science to Market

### Technology Platform - "Trait Factory"<sup>1</sup>



### Camelina Seed Products

1. Feedstock Oil (Biofuel)



2. Omega-3 Oil (EPA+DHA)




3. PHA Bioplastics





# Why Camelina?

- Promising oilseed crop
  - Seed oil levels ~ 40% of seed weight
- Both spring and winter varieties
  - Winter varieties, potential use as cover crop for corn and soybean acres
- Doesn't outcross with canola
- Excellent platform crop for novel high value seed products - value proposition for farmer 



Greenhouse grown Camelina



Camelina field plots at flowering



Large scale winter Camelina growth

# Camelina Based Biofuel Feedstocks

## The Potential of the Camelina Crop for Biofuel Feedstocks is Driven by:

**Grower adoption – Weed control** and seamless integration into crop rotations

**Grower adoption & business success – Revenue** - increasing harvest value for biofuel feedstocks

- Camelina grain (seed) yield per acre, oil as a percent of seed weight (oil/acre)
- Carbon intensity (CI) score of the oil (carbon score as a trait target?)
- Improved protein meal value

**Grower adoption & business success – Partnerships** across the biofuel value chain

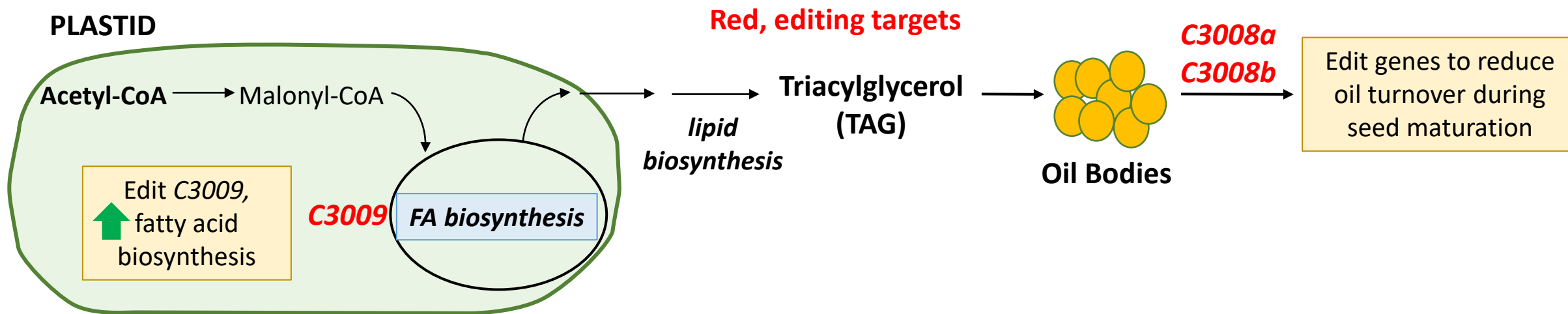
### Yield10 has pipeline of Camelina lines and proprietary gene traits to increase value of Camelina

Priority 1: Herbicide tolerant Camelina to enable seamless integration into grower crop rotations

Priority 2: Seed yield and seed oil content to increase the harvest value for biofuels

Priority 3: Meal quality traits to improve meal value

## Gene combinations to increase oil biosynthesis and prevent oil turnover<sup>1</sup>



### 1. C3009 - transcription factor target to upregulate fatty acid biosynthesis

— regulation of embryo fatty acid biosynthetic genes, + regulation of genes responsible for pigment in seed coat

### 2. C3008a and C3008b - gene targets to reduce oil turnover during seed maturation

C3008a and C3008b, oil body associated lipases

<sup>1</sup>Editing work supported in part by U.S. Department of Energy – BETO, Grant No. DE-EE0007003

# Multiplex Genome Editing of Three Genes in Camelina

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## Strategy 1: Editing of lipase genes (*C3008a*, *C3008b*) and transcription factor gene (*C3009*)

- Identified best Camelina orthologs to Arabidopsis genes based on homology
- Simultaneous editing of 9 genes (3 target genes present in 3 copies each) using CRISPR
- Lines with different combinations of edits obtained and characterized
  - *Very difficult to get all 9 gene copies edited in same line, only one line obtained with all 9 genes edited*
- Fully edited *C3009* gene, loss of pigmentation in seed coat
  - *Unique distinction to track edited seed*



Wild-type control

*C3009* 100% edited (yellow seeded)



Received 2018 confirmation that USDA-APHIS does not consider lines to be regulated<sup>1</sup>

## 2019 field test of edited lines at site in US

(randomized complete block design, lines replicated 6 times)



- E3902 oil trait stable in 2019, 2020, 2021, 2022 field trials. Demonstrated increased total oil produced per acre

## 2019 Field Data for E3902

% Increase, oil per individual seed (mgs)	% Increase, individual seed weight (mgs)	% Increase, seed yield (kg seed per hectare)	% Increase, seed oil content (% of seed weight)	% Increase, number of seeds harvested	% Increase, total oil produced per hectare
11.8*	8.7*	9.7	4.7*	- 3.7	15.0

\*statistically significant (t-test)

Patent pending



## E3902 is Yield10's first spring variety in pre-commercial stage

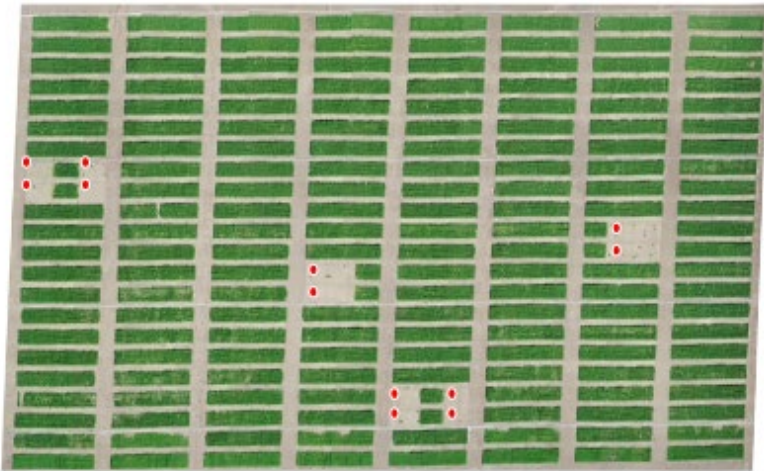
- US: Am I Regulated Process, line not considered to be regulated article under 7 CFR part 340
- Chile: Ministry of Agriculture on Agricultural Protection- line would not be subject to regulation
- Argentina: Ministry of Agriculture, Livestock and Fisheries in Argentina - line would not be subject to regulation
- Documentation to determine regulatory status in Canada is being compiled

## Trait stacking in E3902

**Herbicide Tolerance Traits:** E3902 is germplasm background for our herbicide tolerant lines

- Over the top spray weed control line
- Group 2 residue tolerance, over the top spray weed control line

**Omega 3 oil:** Develop lines producing EPA and DHA



*Herbicide Tolerant event selection trials in the U.S. in spring 2022.*

Red dots in photos, control plots where plants died with herbicide application

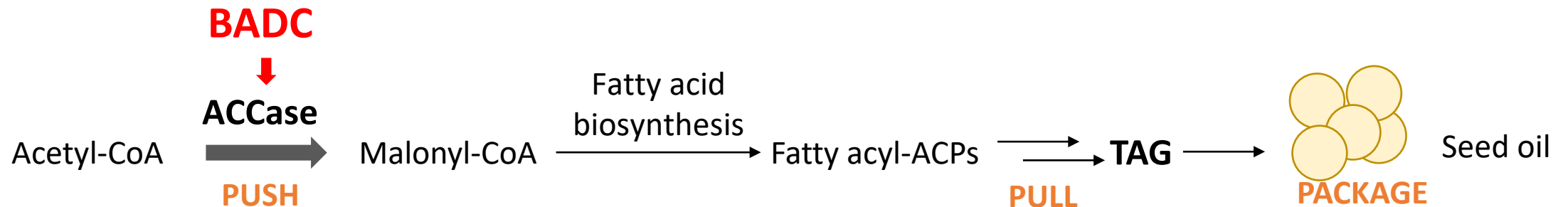


*Camelina containing the omega-3 EPA trait growing at acre-scale in the U.S. in spring 2023.*

# Gene Combinations to Increase Oil Content

## Strategy 2: Edit a negative regulator of acetyl-CoA carboxylase (ACCase)

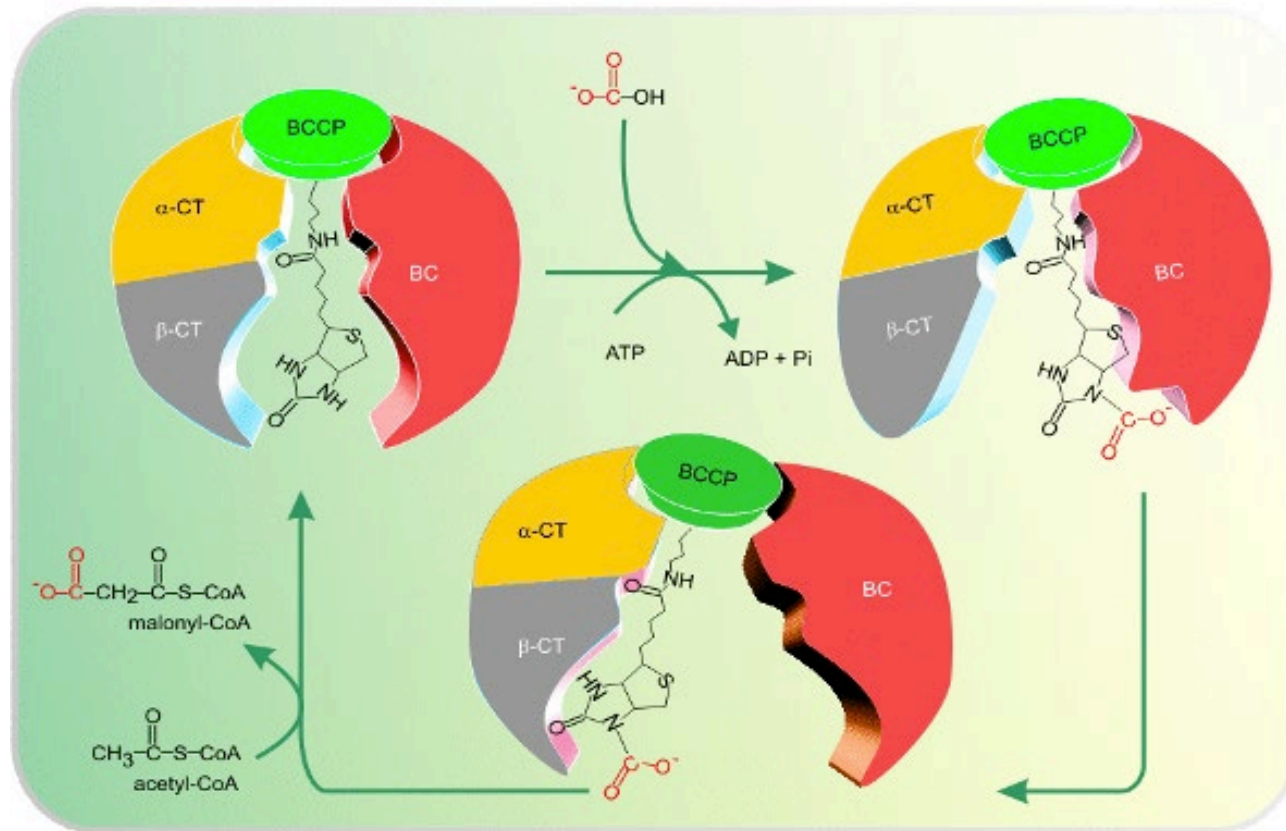
- ACCase - considered to be rate-limiting step in fatty acid biosynthesis
- **Jay Thelen** (University of Missouri) identified role for BADC as a novel negative regulator of the heteromeric ACCase



C3007 (BADC) trait in-licensed from University of Missouri

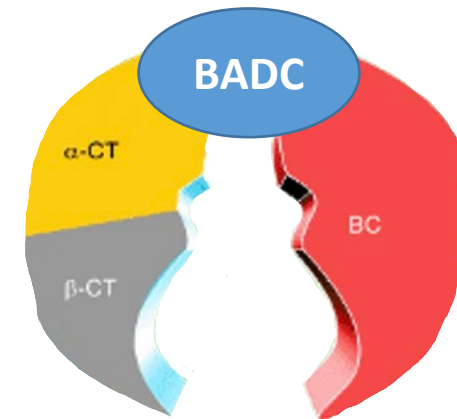
# BADC can displace BCCP, but lacks active site motif

Active heteromeric ACCase with **BCCP** and biotinylation motif in active site



Li-Beisson Y et al., (2013) Acyl-lipid metabolism. Arabidopsis Book 11: e0161

Inactive heteromeric ACCase, **BCCP** displaced by **BADC**



*No biotinylation motif essential for ACCase enzyme activity*

**Reduce/eliminate BADC with genome editing to increase ACCase activity**



# Genome Editing of *badc* Genes

Species	Ploidy/genome	# of BADC homologs
<i>Arabidopsis</i>	2n=2x, diploid	<b>3</b> ( <i>badc1</i> , <i>badc2</i> , <i>badc3</i> ; <i>Salie et al.</i> ) <sup>1</sup>
<b><i>Camelina</i></b>	2n=6x, hexaploid (Cs-G1, -G2, -G3)	<b>9</b> (3 <i>badc1</i> , 3 <i>badc2</i> , 3 <i>badc3</i> ) (1 copy on each subgenome; <i>Yield10</i> ) <sup>2</sup>

## Work at Yield10 to edit *badc* in Camelina

- Identified 3 Camelina *badc* genes (9 alleles total)
- Obtained stable edits for select *badc* genes/gene combinations
  - **Complete editing of all alleles was not obtained, possibly lethal**
- Crossed lines edited in all 3 copies of *badc1* with lines containing combinations of *badc2* or *badc3* edits
- Field trials completed in 2022, 2023

<sup>1</sup>Salie et al., 2016, Plant Cell, 28, 2312. <sup>2</sup>Camelina genes identified at Yield10

# Field Trial of Edited *badc* Lines

Lines tested in field trial

Entry	<i>badc1</i>	<i>badc2</i>	<i>badc3</i>
E4757	X X X		
E4724-C	X X X		
E4806-B	X X X		
E4816-A	X X X		
WT43-F	— — —	— — —	— — —
E6146	X X X	X X _	
E6154	X X X	X X _	
E6119	X X X		X X _
WT43-G	— — —	— — —	— — —

“X” denotes gene is edited; “\_” denotes wild-type gene; Control line.

US field site (July 14, 2022)



plots (63 days old)

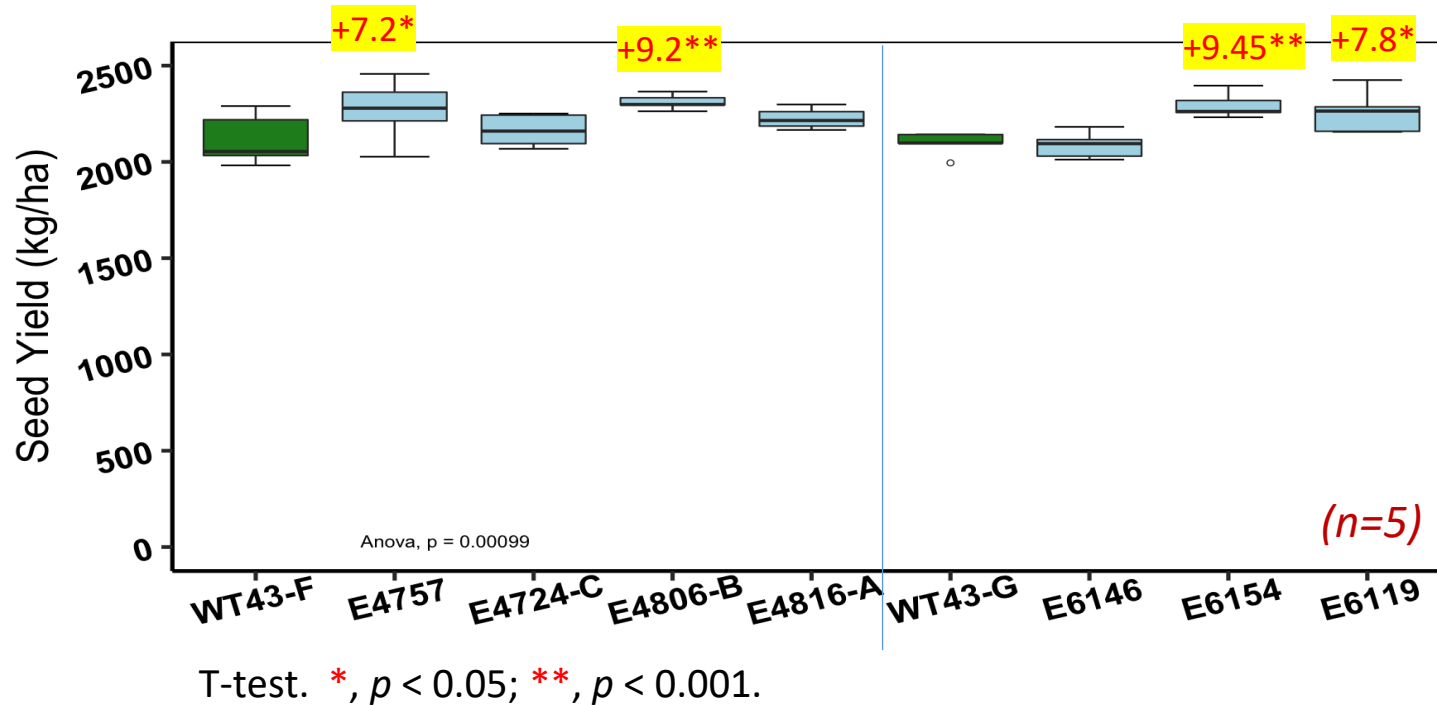
Field trial drone photo



Plan to submit lines with all 3 *badc1* genes edited through USDA-APHIS Regulatory Status Review (RSR)

# Spring 2022 Camelina *badc* Field Trial – Seed Yield

Seed Yield of C3007 Edited Lines, Measured in Replicated Plots



Lines tested in field trial

Entry	<i>badc1</i>	<i>badc2</i>	<i>badc3</i>
E4757	X X X		
E4724-C	X X X		
E4806-B	X X X		
E4816-A	X X X		
WT43-F	---	---	---
E6146	X X X	X X _	
E6154	X X X	X X _	
E6119	X X X		X X _
WT43-G	---	---	---

“X” denotes gene is edited; “\_” denotes wild-type gene; Control line.

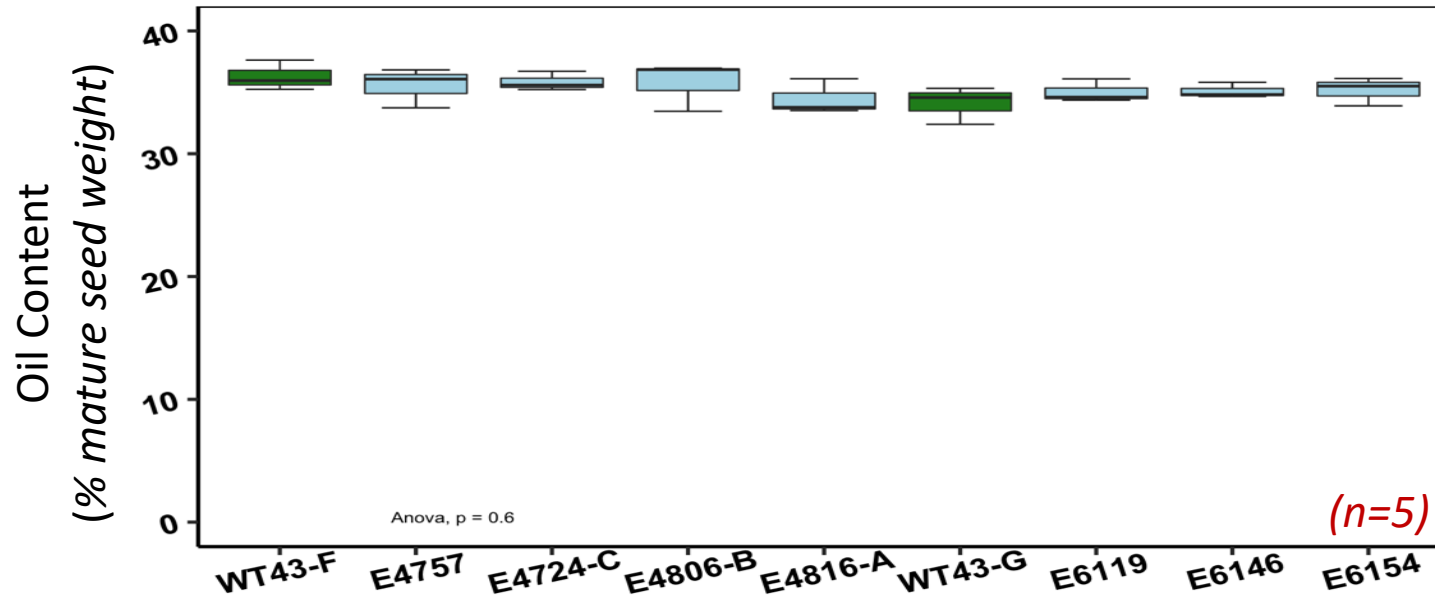
**Significant yield increase observed for four C3007 (*badc*) edited lines**

Plan to submit lines with all 3 *badc1* genes edited through USDA-APHIS Regulatory Status Review (RSR)



# Spring 2022 Camelina *badc* Field Trial – Seed Oil Content

Seed Oil Content of C3007 Edited Lines, Measured from Replicated Plots



T-test. \*,  $p < 0.05$ ; \*\*,  $p < 0.001$ .

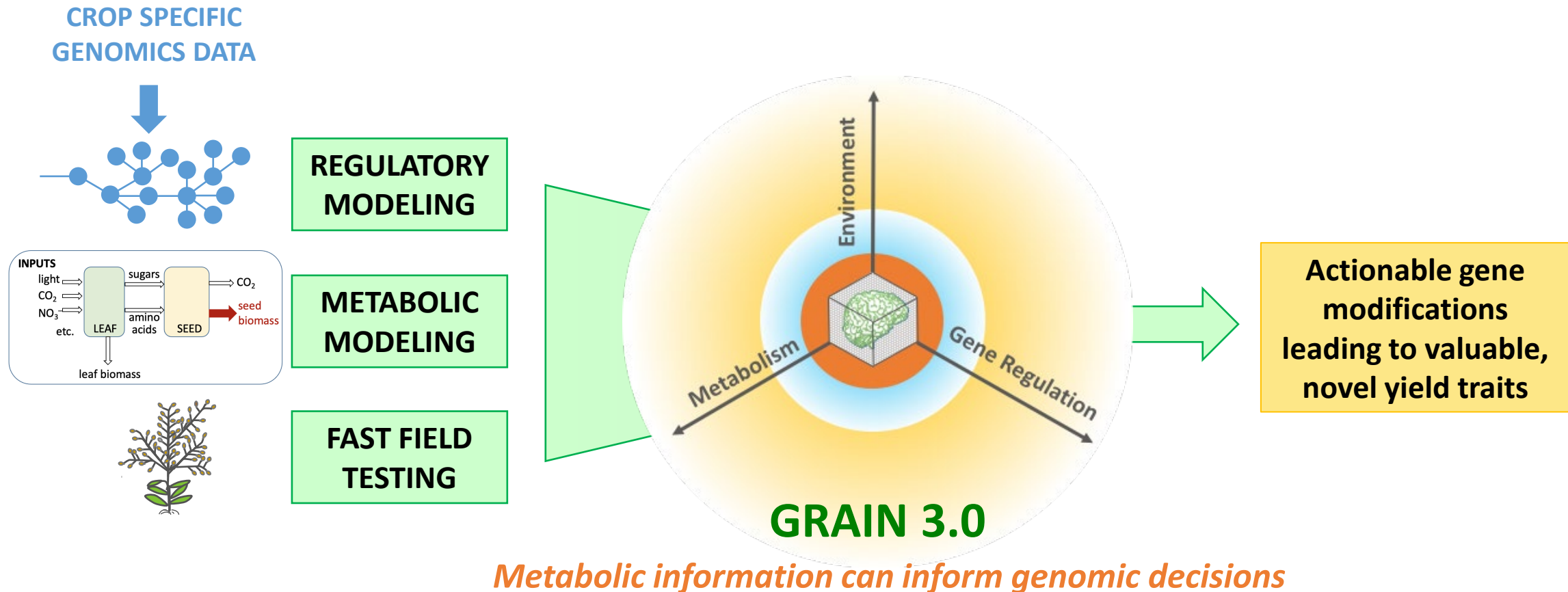
Lines tested in field trial

Entry	<i>badc1</i>	<i>badc2</i>	<i>badc3</i>
E4757	X X X		
E4724-C	X X X		
E4806-B	X X X		
E4816-A	X X X		
WT43-F	---	---	---
E6146	X X X	X X _	
E6154	X X X	X X _	
E6119	X X X		X X _
WT43-G	---	---	---

“X” denotes gene is edited; “\_” denotes wild-type gene; Control line.

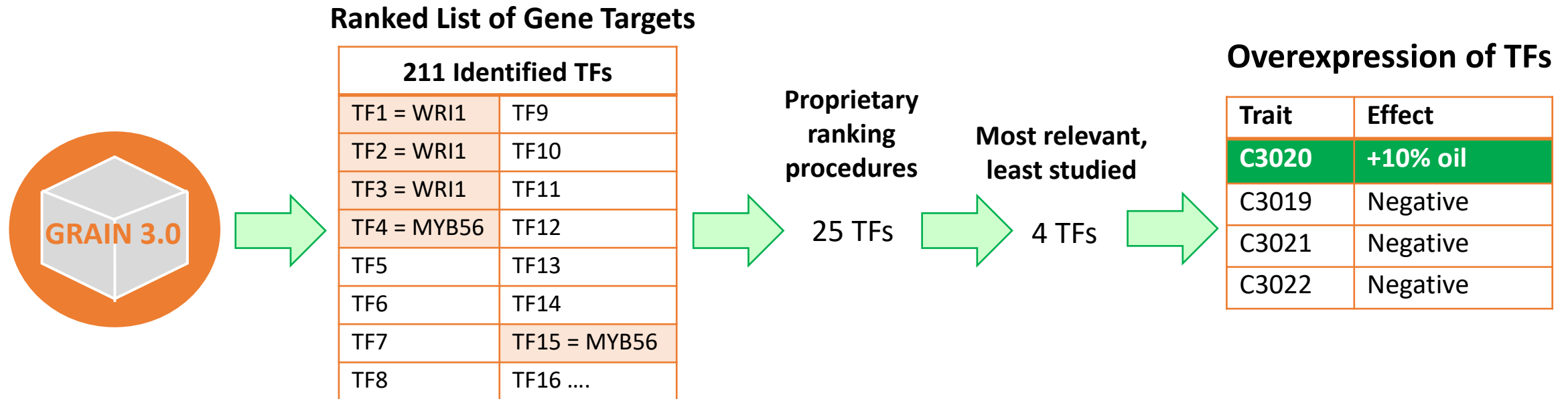
- No significant change in oil content observed in C3007 (*badc*) edited lines
- *badc* edits analyzed increase seed yield but not seed oil content
- Field trials repeated in spring 2023

How do you move beyond known genes and identify new combinations?



# GRAIN Identifies New Gene Targets: C3019 – C3022

GRAIN - Searches for transcription factors (TFs) to increase seed oil content in Camelina



- Ranked list of TFs obtained - Includes known genes in top spots validating approach (WRI1, MYB56)
- Many uncharacterized genes identified, IP white space
- Overexpression of C3020 increases seed oil content by up to 10%, validated in 2021 and 2022 field seasons.
- Genes overexpressed giving a negative phenotype are good editing targets C3019, C3021 and C3022
- Editing of C3021 resulted in higher number of tertiary branches, more orthologs may need editing
- Yield10 now has ~10 Camelina gene targets for combinatorial editing to achieve step change increases in oil



## Yield10 is Harnessing The Potential of Camelina for Biofuel Feedstocks

### Grower adoption – Weed control

- *Developed and field-tested herbicide tolerant lines for over-the-top spray weed control*
- *Completed field testing of next generation stacked herbicide tolerance lines (over-top-spray & soil residue tolerance) in spring 2023*

### Grower adoption & business success – Revenue – increased harvest value for biofuel feedstocks

- *Edited E3902 line has ~5% increase in oil in multiple years of field trials*
- *Additional testing of badc edited lines that have shown increased seed yield in the field - in progress*
- *GRAIN modeling has identified additional genes to increase oil content*
- *Improved protein meal value: Gene editing targets have been identified*

### Grower adoption & business success – Partnerships across the biofuel value chain

- *Discussions with potential partners in progress*



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NASDAQ: YTEN

**Thank you**

*Sustainable Growth Starts with a Seed*

