BREEDING SORGHUM CULTIVARS FOR PROCESSING

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WHAT IS NEEDED TO IMPROVE A CROP?

- Knowledge of the crop
- Genetic diversity
- Variability for the trait of interest
- Evaluation and screening tools
- Economic benefit for improving the crop
WHAT TRAITS HAVE BEEN IMPROVED?

- Yield – grain or forage
- Resistance – disease, insects, drought
- Adaptation – environmental, acid soils, salt
- Forage quality – many components
- Grain quality – area with great potential

PRIMARY SELECTION EMPHASIS IS FOR YIELD, STRESS RESISTANCE, ADAPTATION
IMPORTANT TRAITS IN U.S. FORAGE PROGRAM

Wet chemistry analysis conducted on all hybrids

- %ADF acid detergent fiber
- %NDF neutral detergent fiber
- %CP crude protein
- %ADIP acid detergent insoluble protein
- % Soluble protein
- %NDIP neutral detergent insoluble protein
- %Ash
- %Fat
- %Starch
- %Lignin
- %IVDMD invitro dry matter disappearance
- %IVTD-30 invitro total disappearance 30 hours
- %NDFD-30 neutral detergent fiber disappearance 30 hour
- %Calcium
- %Phosphorous
- %Magnesium
- %Potassium
- %Sodium
- %Sulfur
- %chloride
- ppm Iron
- ppm Copper
- ppm Zinc
- ppm Manganese
- %NFC non functional carbohydrates
- %Hemicellulose
- %Lactic acid
- %Butyric acid
- pH
- ppm Nitrate
- %Fructose
- %Glucose
- %Sucrose
- %Manitol

MANAGEMENT SYSTEMS ARE IMPORTANT TO PRODUCING QUALITY FORAGE
BREEDING FOR IMPROVED PROCESSING

- Area of untapped potential
- Some research has been done
- Improved food type hybrids
  - High yield, hard endosperm, better mold resistance, decreased pigments in pericarp, testa, associated pigments
- Future: Link breeders, food science, processors, farmers
IMPORTANT GRAIN TRAITS FOR PROCESSING?

- Within the world sorghum collection are thousands of different genotypes
- Types exhibit variation for kernel size, structure, shape, texture, hardness, pigmentation, starch recovery, peripheral endosperm fraction, protein, oil
- Is the natural variation sufficient for progress in the breeding program
- Resistance of mature grain to biotic and abiotic stress
### Chemical Composition (%) of Sorghum and Its Anatomical Tissues

<table>
<thead>
<tr>
<th></th>
<th>Caryopsis</th>
<th>Endosperm</th>
<th>Germ</th>
<th>Pericarp</th>
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<tr>
<td><strong>Caryopsis</strong></td>
<td>100</td>
<td>84.2</td>
<td>9.4</td>
<td>6.5</td>
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<tr>
<td><strong>Range</strong></td>
<td>-</td>
<td>81.7-86.5</td>
<td>8.0-10.9</td>
<td>4.3-8.7</td>
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<td><strong>Protein</strong></td>
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<td>10.5</td>
<td>18.4</td>
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<td>7.3-15.6</td>
<td>8.7-13.0</td>
<td>17.8-19.2</td>
<td>5.2-7.6</td>
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<tr>
<td><strong>Distribution</strong></td>
<td>100</td>
<td>80.9</td>
<td>14.9</td>
<td>4.0</td>
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<tr>
<td><strong>Fiber</strong></td>
<td>2.7</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td><strong>Range</strong></td>
<td>1.2-6.6</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td><strong>Distribution</strong></td>
<td>100</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td><strong>Lipid</strong></td>
<td>3.4</td>
<td>0.6</td>
<td>28.1</td>
<td>4.9</td>
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<td><strong>Range</strong></td>
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<td>0.4-0.8</td>
<td>26.9-30.6</td>
<td>3.7-6.0</td>
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<tr>
<td><strong>Distribution</strong></td>
<td>100</td>
<td>13.2</td>
<td>76.2</td>
<td>10.6</td>
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<tr>
<td><strong>Ash</strong></td>
<td>1.7</td>
<td>0.4</td>
<td>10.4</td>
<td>2.0</td>
</tr>
<tr>
<td><strong>Range</strong></td>
<td>1.1-2.5</td>
<td>0.3-0.4</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Distribution</strong></td>
<td>100</td>
<td>20.6</td>
<td>68.6</td>
<td>10.8</td>
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<tr>
<td><strong>Starch</strong></td>
<td>71.8</td>
<td>82.5</td>
<td>13.4</td>
<td>34.6</td>
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<td><strong>Range</strong></td>
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<td>81.3-83.0</td>
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<td>-</td>
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<tr>
<td><strong>Distribution</strong></td>
<td>100</td>
<td>94.4</td>
<td>1.8</td>
<td>3.8</td>
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</table>
GRAIN MOLDS/WEATHERING

Red grain
Susceptible (L) and Resistant (R)

White grain
Resistant (L) and Susceptible (R)
PLANT TRAITS THAT CAN EFFECT PROCESSING CHARACTERISTICS

- Plant color
  - Purple, red or tan
  - Differences in shade
- Glume color
  - Determined by plant color loci
  - Influence on white grain
- Grain color
  - Appearance influenced by several factors
Grain can appear different colors
- red, white, lemon yellow, brown, pink

There are only three grain colors
THICKNESS OF PERICARP (SEED COAT)

- Generally classed as thick or thin
- Many are intermediate
- Effect on end-use processing?
ENDOSPERM TYPES

- Normal (white) or yellow
- Influence on grain appearance
  - Yellow + thin red = Bronze
  - Yellow + thin white = Cream
SPREADER AND INTENSIFIER GENES

- Influence grain appearance
- Brown sorghum contains testa
- Spreader moves color into seed coat

- Controls grain brightness
- Difficult to see in white or lemon yellow
**GRAIN TYPES BASED ON TRAITS**

- Type based on testa and spreader
- U.S. hybrids have no testa and no tannin
- Tannins bring interesting properties

<table>
<thead>
<tr>
<th>Group</th>
<th>Genotype</th>
<th>Image</th>
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<tr>
<td><strong>Group I</strong></td>
<td>$b_1b_1B_2$</td>
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<td></td>
<td>$B_1b_2b_2$</td>
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<tr>
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<td><strong>Group III</strong></td>
<td>$B_1B_2S$</td>
<td><img src="image4.png" alt="Image" /></td>
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GRAIN COLORS IN THE FIELD

- Red
- White
- White, YE
- Lemon Yellow
- Black
RED GRAIN PHENOTYPE

- Red, no uc, no sp
- Red, uc, no sp
- Red, uc, sp
WHITE GRAIN PHENOTYPE

- White
- White, uc, no sp
- White, uc, sp
EFFECT OF ENDOSPERM ON WHITE GRAIN

- Yellow endosperm
- Normal (white) endosperm
THE DIVERSITY OF SORGHUM
ROLE OF BREEDING PROGRAMS

- Knowledge of Crop
  - Diversity
  - Genetics
  - Performance
- Develop new varieties and hybrids in response to need
- Bridge to link research, food science, processors, farmers, other scientists
BREEDING METHODOLOGY

- Screen lines
- Cross lines with needed traits
- Select for plant and grain traits
- Select progeny with grain traits
- Cross to new parents

- What are the traits(s) to evaluate for processing?
- How do the desired traits affect other traits?
  - Susceptibility to grain molds, reduced yield, etc
- What is the evaluation methodology?
- What will the farmer be paid for – yield or quality?
BREEDING METHODOLOGY

PARENT 1 X PARENT 2

SELF – F1
SELF & SELECT – F2

SEGREGATING POPULATIONS

SELF – ADVANCE GENERATIONS
FIELD – SELECT FOR YIELD
DISEASE/GM RESISTANCE
OTHER TRAITS
LAB – GRAIN TRAITS

LAB EVALUATION

GERmplasm with DESIRED TRAITS

PROCESSOR
CONSUMER

VARIETY
OR
HYBRID
FOOD TYPE SORGHUMS

- White Pericarp
- Tan plant color
- Straw-color glumes
- Non-pigmented testa
- Intermediate to hard endosperm
- Milled into products with bland flavor, white color, no off colors
TO DEVELOP NEW GERMPLASM WITH ENHANCED END-USE TRAITS

- Short-term: existing germplasm
- Medium/long-term: screening, inheritance, new germplasm
- New research avenue for breeding programs, little existing activity
- Need
  - Selection protocol
  - Funds to conduct research
  - Knowledge of what to select for
PREVIOUS RESEARCH

- Modest research on proteins
- Less on starches present in sorghum
- Little to improve content or functionality of other components, e.g. lipids, fiber, minerals, antioxidants
- Protein and starch content and composition vary due to genotype and agronomic conditions
- Pericarp rich in fiber; germ high in protein, fat, ash; endosperm contains mostly starch, some protein, small amounts of fat and fiber
RESEARCH TO COMBINE HIGH DIGESTABILITY AND WAXY TRAITS

- Example of the type of research that is on-going or can be initiated
- Dr. Dirk Hays and graduate students – Texas A&M University
- Multiple funding sources – INTSORMIL, SunGrant Initiative, AgriLife Research
PROBLEM

- Assay to phenotype HD trait is time consuming and variable
- Gap in knowledge of major constraints in development of sorghum cultivars with optimal endosperm matrix of bioethanol conversion
SOLUTION

- Develop designer sorghums that optimize the grain’s endosperm matrix for low energy bioethanol conversion and improved grain distiller’s feed value.

- Combing high digestability and waxy optimize the grain for bioethanol conversion.
- α-kafirins form the center of protein bodies surrounded by γ-kafirins and β-kafirins (fig: Oria et al., 2000)
- α-kafirins are highly digestible (Hamaker)
- γ-kafirins have plenty of disulphide bounds
- Resistant to digestion after cooking (Oria et al. 1995b)
- γ-kafirins form enzyme resistant layer around α-kafirins
A highly digestible protein (HD) / high lysine lines derived from a high lysine chemical mutant (P271Q) (Weaver et al., 1998; Mohan, 1975)

- 10-15% higher protein digestibility when uncooked
- 25% higher digestibility when cooked
- $\alpha$-kafirin digestibility increased to 90-95% (Weaver et al., 1998)
Rearrangement of the $\gamma$-kafirins
Found only in pockets of folds (fig: Oria et al., 2000)
The interior $\alpha$-kafirins are exposed
More total surface area available for hydrolysis
DDGS produced has higher lysine content (Xiaroang et al., In press)
WAXY TRAIT

- It is associated with little or no amylose in the endosperm
- Starch is nearly amylopectin (100%)
- It gives appearance of candle wax, hence the name “waxy” (Rooney and Miller, 1982)
- This trait was recognized in 1933
- Due to absence or inactivation of granule-bound starch synthase (Pedersen et al., 2005)
WAXY LINES

- Relatively weak endosperm protein matrix
- Better for brewing and bioethanol (Del Pozo-Insfran et al., 2004)
- Waxy and heterowaxy need shorter times (Figueoroa et al., 1995)
- Attributed to the lower starch gelatinization temperatures
  - 69.6 °C - waxy
  - 71.1 °C - heterowaxy
  - 71.1-73.3 °C - wild types
Solves the four major limitations:

- Inhibitory kafirin protein matrices surrounding the starch granules
- High temperature to starch gelatinization
- High temperature enzymatic hydrolysis
- Low lysine DDG protein composition
OBJECTIVES

- Phenotyping of HD trait in RIL population
- Validate and fine map QTLs regulating HD trait in NILs
RESEARCH METHODOLOGY

- RIL population developed
- Protein digestibility assay
- Different method of phenotyping to visually identify selections for presence of traits
- DNA extraction of individual lines of RIL
- Phenotypic and genotype data used to identity, validate, fine map HD QTLs
HD X WAXY SORGHUM

- Combination of the two modified endosperm traits HD and waxy
  - 62% faster efficiency at 24 hr
  - 15% greater final efficiency at 72 hr
- Maintains 100% higher lysine content in DDG
- HD combined with waxy trait also increases the FAN and beer making quality of sorghum

<table>
<thead>
<tr>
<th>Genotype</th>
<th>% Efficiency 24 hr</th>
<th>% Efficiency 72 hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>HD</td>
<td>75</td>
<td>82</td>
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<tr>
<td>HD x WAXY</td>
<td>96</td>
<td>92</td>
</tr>
<tr>
<td>WAXY</td>
<td>59</td>
<td>91</td>
</tr>
<tr>
<td>WT</td>
<td>57</td>
<td>81</td>
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</table>
RESEARCH TO DETERMINE PROCESSING QUALITIES OF EXISTING VARIETIES

- Dr. Bruce Hamaker and graduate students (Purdue University) in collaboration with INRAN (Niger)
- Use of an incubation concept to transfer processing technologies to entrepreneurs in Niger
Sorghum and pearl millet are important food crops but have made little progress in processed product markets.

Expanded market to sell surplus grain will generate income.

Processing technologies exist to transform grain into high quality flours, etc.
METHODOLOGY

- Research was conducted toward optimization of flour, grit and agglomerated products.

- Couscous color of sorghum cultivars at 80% decortication compared to wheat couscous.
PROCESSED FOOD PRODUCTS FROM SORGHUM ARE NOT NEW TO SOUTHERN AFRICA
WHAT PROPERTIES ARE NEEDED IN CULTIVARS IMPROVED FOR PROCESSING?

- Grain yield and quality
- Resistance to molds/weathering/headbugs
- Tan plant, straw glumes
- Bright white or red color, no pigmented testa
- Milling yield – hardness, spherical shape, white
HOW CAN BREEDERS CONTRIBUTE TO DEVELOPING NEW PRODUCTS?

- Provide end-users with germplasm to evaluate for processing into products
- End-users provide feedback on the best germplasm for their product(s)
- Determine the traits needed and inheritance
- Collaborate with food scientists to develop screening methodology
- Develop new germplasm with enhanced traits
SORGHUM IS THE CROP OF THE FUTURE