Breeding Sorghum Cultivars for Processing

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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
<table>
<thead>
<tr>
<th>Trait</th>
<th>Trait</th>
</tr>
</thead>
<tbody>
<tr>
<td>%ADF  acid detergent fiber</td>
<td>%Sodium</td>
</tr>
<tr>
<td>%NDF  neutral detergent fiber</td>
<td>%Sulfur</td>
</tr>
<tr>
<td>%CP  crude protein</td>
<td>%chloride</td>
</tr>
<tr>
<td>%ADIP acid detergent insoluble protein</td>
<td>ppm Iron</td>
</tr>
<tr>
<td>%Soluble protein</td>
<td>ppm Copper</td>
</tr>
<tr>
<td>%NDIP neutral detergent insoluble protein</td>
<td>ppm Zinc</td>
</tr>
<tr>
<td>%Ash</td>
<td>ppm Manganese</td>
</tr>
<tr>
<td>%Fat</td>
<td>%NFC non functional carbohydrates</td>
</tr>
<tr>
<td>%Starch</td>
<td>%Hemicellulose</td>
</tr>
<tr>
<td>%Lignin</td>
<td>%Lactic acid</td>
</tr>
<tr>
<td>%IVDMD invtro dry matter disappearance</td>
<td>%Butyric acid</td>
</tr>
<tr>
<td>%IVTD-30 invtro total disappearance 30</td>
<td>pH</td>
</tr>
<tr>
<td>hours</td>
<td>ppm Nitrate</td>
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<tr>
<td>%NDFD-30 neutral detergent fiber</td>
<td>%Fructose</td>
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<tr>
<td>disappearance 30 hour</td>
<td>%Phosphorous</td>
</tr>
<tr>
<td></td>
<td>%Magnesium</td>
</tr>
<tr>
<td></td>
<td>%Potassium</td>
</tr>
<tr>
<td></td>
<td>%Sucrose</td>
</tr>
<tr>
<td></td>
<td>%Manitol</td>
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**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.
<table>
<thead>
<tr>
<th>Component</th>
<th>Caryopsis</th>
<th>Endosperm</th>
<th>Germ</th>
<th>Pericarp</th>
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<td>84.2</td>
<td>9.4</td>
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<tr>
<td>Range</td>
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<td>81.7-86.5</td>
<td>8.0-10.9</td>
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<tr>
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<td>8.7-13.0</td>
<td>17.8-19.2</td>
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<td>80.9</td>
<td>14.9</td>
<td>4.0</td>
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<tr>
<td>Fiber</td>
<td>2.7</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Range</td>
<td>1.2-6.6</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Distribution</td>
<td>100</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Lipid</td>
<td>3.4</td>
<td>0.6</td>
<td>28.1</td>
<td>4.9</td>
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<td>Range</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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<td>Distribution</td>
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<td>13.2</td>
<td>76.2</td>
<td>10.6</td>
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<tr>
<td>Ash</td>
<td>1.7</td>
<td>0.4</td>
<td>10.4</td>
<td>2.0</td>
</tr>
<tr>
<td>Range</td>
<td>1.1-2.5</td>
<td>0.3-0.4</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Distribution</td>
<td>100</td>
<td>20.6</td>
<td>68.6</td>
<td>10.8</td>
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<tr>
<td>Starch</td>
<td>71.8</td>
<td>82.5</td>
<td>13.4</td>
<td>34.6</td>
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<tr>
<td>Range</td>
<td>55.6-75.2</td>
<td>81.3-83.0</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Distribution</td>
<td>100</td>
<td>94.4</td>
<td>1.8</td>
<td>3.8</td>
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</tbody>
</table>
GRAIN MOLDS/WEATHERING

Red grain
Susceptible (L) and Resistant (R)

White grain
Resistant (L) and Susceptible (R)
Plant traits that can affect 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
SORGHUM GRAIN COLOR

- 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
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 for 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
- α-kafirin digestibility increased to 90-95% (Weaver et al., 1998)
HD MUTANT SORGHUM

- 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 (Figueoraoa 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
COMBINE HD AND WAXY TRAITS

- 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</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>24 hr</td>
</tr>
<tr>
<td>HD</td>
<td>75</td>
</tr>
<tr>
<td>HD x WAXY</td>
<td>96</td>
</tr>
<tr>
<td>WAXY</td>
<td>59</td>
</tr>
<tr>
<td>WT</td>
<td>57</td>
</tr>
</tbody>
</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
CONCEPT

- 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