HETEROSIS AND COMPOSITION OF SWEET SORGHUM

A Dissertation

by

REBECCA JOANN CORN

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

December 2009

Major Subject: Plant Breeding

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Approved by:

Chair of Committee,	William Rooney
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ABSTRACT

Heterosis and Composition of Sweet Sorghum. (December 2009)

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Chair of Advisory Committee: Dr. William Rooney

Sweet sorghum (*Sorghum bicolor)* has potential as a bioenergy feedstock due to its high yield potential and the production of simple sugars for fermentation. Sweet sorghum cultivars are typically tall, high biomass types with juicy stalks and high sugar concentration. These sorghums can be harvested, milled, and fermented to ethanol using technology similar to that used to process sugarcane. Sweet sorghum has advantages in that it can be planted by seed with traditional planters, is an annual plant that quickly produces a crop and fits well in crop rotations, and it is a very water-use efficient crop. Processing sweet sorghum is capital intensive, but it could fit into areas where sugarcane is already produced. Sweet sorghum could be timed to harvest and supply the sugar mill during the off season when sugarcane is not being processed, be fit into crop rotations, or used in water limiting environments. In these ways, sweet sorghum could be used to produce ethanol in the Southern U.S and other tropical and subtropical environments.

Traditionally, sweet sorghum has been grown as a pureline cultivar. However, these cultivars produce low quantities of seed and are often too tall for efficient mechanical harvest. Sweet sorghum hybrids that use grain-type seed parents with high sugar concentrations are one way to overcome limitation to seed supply and to capture the benefits of heterosis.

There are four objectives of this research. First to evaluate the importance of genotype, environment, and genotype-by-environment interaction effects on the sweet sorghum yield and composition. The second objective is to determine the presence and magnitude of heterosis effects for traits related to sugar production in sweet sorghum. Next: to study the ability of sweet sorghum hybrids and cultivars to produce a ratoon crop and determine the contribution of ratoon crops to total sugar yield. The final objective is to evaluate variation in composition of sweet sorghum juice and biomass.

Sweet sorghum hybrids, grain-type sweet seed parents, and traditional cultivars that served as male parents were evaluated in multi-environment trials in Weslaco, College Station, and Halfway, Texas in 2007 and 2008. Both genotype and environment influenced performance, but environment had a greater effect than genotype on the composition of sweet sorghum juice and biomass yield. In comparing performance, elite hybrids produced fresh biomass and sugar yields similar to the traditional cultivars while overcoming the seed production limitations. High parent heterosis was expressed among the experimental hybrids for biomass yield, sugar yield and sugar concentration. Additional selection for combining ability would further enhance yields and heterosis in the same hybrid. Little variation was observed among hybrids for juice and biomass composition suggesting that breeding efforts should focus on yield before altering plant composition.

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CHAPTER I

INTRODUCTION

High oil prices and increased awareness of our impact on the environment has led to renewed interest in renewable energy sources. To mitigate these issues, the US has established a goal (and legislative mandate) of replacing 30% of petroleum use with biofuels by 2030. Attaining this goal will not only reduce dependence on oil and gas imports; it will also support the growth of domestic agriculture, forestry, and rural economies. Replacing petroleum with biofuels will also develop biorefineries as a new domestic industry making fuels, chemicals, and other products (Perlack et.al, 2005).

Biomass can be used to generate electricity or to produce liquid transportation fuels. Among the various types of renewable fuels (such as wind, solar, and geothermal), biomass is unique because it is the only current renewable resource of liquid transportation fuel. Currently, there are three categories of crops that are used for biofuel production; carbohydrate-rich crops for conversion to bioethanol, oil-rich crops for conversion to biodiesel, and wood coppice for direct combustion in powerstations (Murphy, 2003).

This dissertation follows the style of *Crop Science Journal.*

Throughout the world, bioethanol is the most widely used biofuel for transportation. In 2007, over 318 million barrels of ethanol were produced with the United States and Brazil being the major producers (EIA, 2009). Starch-based ethanol conversion from corn has been the primary bioethanol production system in the United States while production in Brazil is a sugar-based system from sugarcane. Both of these crops are important as either or both food and feed crops and recent increases in feedstock demand has resulted in higher prices for both food, feed or fuel production. This increased demand leads to the reality that this bioethanol conversion system cannot continue to meet the growing production demands of the market because there is a finite amount of both starch and sugar production from either corn or sugarcane and much of it is required as a food and feed source (Rooney et.al, 2007). Therefore, other ethanol conversion systems that utilize alternate feedstocks must be developed and implemented.

Crop and forest residues are one potential source of biomass that could be converted to ethanol. Corn stover and straw from small grain crops are the primary crop residues; other sources include grains used for production of ethanol and bioproducts, and food processing residues. In 2005, ~194 million dry tons of biomass was available for bioenergy production including 15 million dry tons of starch from grain (Perlack et.al, 2005). Crop and forest residues cannot be removed sustainably at yields great enough to replace 30% of U.S. petroleum use with biofuels unless high yielding dedicated bioenergy crops are produced to provide some of the necessary feedstock (Perlack et.al, 2005). Dedicated bioenergy crops also have an advantage in that they would supply processing facilities with an adequate supply of feedstock with consistent quality.

An ideal bioenergy crop should possess traits that are important in all crop plants including high yield potential, wide adaptation, and resistance to biotic and abiotic stresses. In addition, several other traits are more important in bioenergy crops than in other crop plants. Water use efficiency and drought tolerance are particularly important traits in bioenergy crops because they are likely to be produced in sub-optimal environments with limited inputs where water is often limited. All new bioenergy crops must also fit into crop rotations using the existing agricultural infrastructure. While bioenergy crops will compete with food and feed crops for land, they should not divert crops from use as a food or feed source to use as a bioenergy source, a limitation of the current grain to ethanol conversion system. Dedicated bioenergy crops that can be grown in regions not ideally suited for grain production will minimize food versus fuel production issues (Rooney et.al, 2007) while increasing the need for drought and stress tolerance. Bioenergy crops also need to have desirable composition for ethanol conversion, and a genetic platform for further crop improvement. There are advantages to both annual and perennial crops; annual crops rapidly produce a harvestable crop and easily fit into crop rotations while perennials enjoy the advantage of lower input costs once the crop is established.

Different species of dedicated bioenergy crops will be grown in different geographic regions to efficiently produce bioenergy feedstocks. Regional environments differ in temperature, rainfall, and length of growing season. These differences prompt the production of species that best match the local growing conditions for consistent production of high-yielding bioenergy crops. Another factor in pairing dedicated bioenergy crops with production regions is the necessity to have a continual supply of feedstock at the processing facility. Sugar-based ethanol conversion systems are especially limited by this requirement because simple sugars are not stable in long-term storage unless processed; so these feedstocks fit best in environments where they can be harvested throughout the year.

While several species are prominently cited as potential dedicated bioenergy crops, sorghum (*Sorghum bicolor)* stands out among other annual plants due to its high yield potential, suitability for improvement by breeding, flexibility to fit with other crops to provide year-long supply of raw material for biofuel processing plants, and seed production. The U.S. has a long history of producing grain sorghum; currently grain sorghum production in Kansas and Texas accounts for nearly 80% of US grain sorghum production with the remaining grain sorghum produced primarily in Southern states (NASS, 2009). Grain sorghum is already used as a starch source for the ethanol production; 29.7% of the 2008 sorghum crop was used in ethanol production (Sorghum Grower, 2009).

Grain sorghum is only one type of economically important sorghum crop; sorghum is a diverse species that is also traditionally used for forage and syrup production. More recently, the high biomass yield have led to the concept of bioenergy sorghums. Bioenergy sorghums have been selected from the diversity available among traditional varieties by selecting for traits relevant to ethanol production. Forage sorghums have traditionally been selected for high biomass yields as well as good animal palatability characteristics, but palatability is not important for bioenergy production. Higher yielding bioenergy sorghums can be developed by removing palatability requirements and focusing on yield potential. Similarly, sugar quality characteristics important in producing sorghum syrup are less important in sugar-based ethanol production and greater sugar yields can be produced in sweet sorghum when the focus is increasing total fermentable sugar yield while relaxing the sugar quality requirements.

Three distinctly different types of sorghum can be used and are being developed for use as a bioenergy crop; grain sorghum, lignocellulosic energy sorghums, and sweet sorghums. Grain sorghum is currently used in the starch to ethanol conversion system. Lignocellulosic energy sorghums are similar to forage sorghums and produce large amounts of biomass, but greater biomass yields can be attained in energy sorghums because selection is not restricted by requirements that the crop must be palatable to animals (Rooney et.al, 2007). Sweet sorghums for bioenergy have been selected from syrup varieties by reducing requirements for juice quality and selecting for maximum fermentable carbohydrate production in the stalk juice.

Sweet and grain sorghums are similar and may only differ by a few genes controlling plant height, juicy stalks, and presence of sugar in the juice (Schaffert, 1992). Sweet sorghums produce more biomass than grain sorghums, and have more rapid growth and wider adaptation (Reddy et.al, 2007). Sweet sorghums are even more similar to forage sorghums. Biomass yields of sweet and forage sorghums were not significantly different in a trial in Italy (Dolciotti et.al, 1998) while the forage sorghum produced significantly more grain than the sweet sorghum in a similar trial in Louisiana (3527 and 651 kg ha^{-1} respectively) (Morris and McCormick, 1994).

Sweet sorghum cultivars are typically tall, high biomass types with juicy stalks and high sugar concentration in the stalk juice. These sorghums can be harvested, milled, and fermented to ethanol using the same technology used to process sugarcane. Sweet sorghum has some relative advantages over sugarcane in that it is planted from seed with traditional planters and it is an annual plant that produces a crop in about four months compared to 12-16 months required for sugarcane (Reddy et.al, 2005). Sorghum fits easily into crop rotations and can extend harvest windows with staggered planting dates or correct cultivar selection. At the same time, it is also more water-use efficient than other sugar-producing crops, and this water-use efficiency is estimated to reduce water requirements by 33-50% of that required by sugarcane (Hunter and Anderson, 1997). Compared to grain sorghum, sweet sorghum is less drought tolerant, but it is more tolerant than corn (Kresovich and Henderlong, 1984). Water use efficiency and drought tolerance are important traits in bioenergy crops that will be produced in marginal environments where rainfall is limited and irrigation is too expensive (Rooney et.al, 2007).

Producing two complimentary bioenergy crops like sweet sorghum and sugarcane can greatly reduce the cost of producing ethanol (Nguyen and Prince, 1996). The cane milling and ethanol distillation facilities are a large portion of the cost to produce ethanol from sugarcane or sweet sorghum. Staggering the planting dates of sweet sorghum crops to be harvested before and after the sugarcane crop in the same region will extend the amount of time an ethanol plant operates each year and reduces cost per unit of production.

Currently, large-scale sweet sorghum production for conversion to ethanol is limited by seed availability. Sweet sorghum has traditionally been grown as a pure-line cultivar, but these cultivars produce very little seed and are too tall to harvest efficiently. The development of sweet sorghum hybrids, produced on grain-type females with high sugar concentrations is a practical way to overcome this limitation. These types of lines have been developed by the Texas Agrilife Research sorghum breeding program at College Station by crossing a grain-type female to a sweet sorghum cultivar, then backcrossing to the grain-type female to regain the short stature and large panicle characteristics of the grain-type parent with increased sugar concentration in the stalk. Increased sugar concentration in the seed parent is important because the preponderance of reports indicate that stem sugar concentration is an additively inherited trait; both parents must have high sugar concentration to obtain it in a desirable hybrid. Development of reliable seed parents will allow the production of hybrids in sweet sorghum utilizing the male sterile cytoplasm that is used in grain sorghum for hybrid production. First generation sweet sorghum hybrids need to be evaluated for biomass and sugar production as well as hybrid performance relative to the traditional cultivars. The objectives of this dissertation are:

1. To determine the presence and magnitude of heterosis effects for traits related to sugar production in sweet sorghum.

2. To evaluate the importance of genotype, environment, and genotype by environment interaction effects on sweet sorghum yield and composition.
3. To study the ability of sweet sorghum hybrids and cultivars to produce a ratoon crop and determine the contribution of ratoon crops to total sugar yield.
4. Evaluate variation in composition of sweet sorghum juice and biomass.

CHAPTER II

HETEROSIS AND SUGAR YIELD IN SWEET SORGHUM HYBRIDS AND PARENTAL LINES IN THREE TEXAS ENVIRONMENTS

Introduction

The United States and countries around the world have experienced a renewed interest in producing bioethanol for use as an automotive fuel to reduce the use of non-renewable fossil energy reserves, reduce dependence on fossil fuel imports, and reduce the negative impact on the environment (Gnansounou et.al, 2005). In the U.S. the transportation sector is responsible for >70% of the petroleum consumed and >30% of the carbon dioxide emissions (Murphy, 2003). To reduce emissions and dependence on foreign oil imports, the U.S. has established a goal of replacing 30% of petroleum use with biofuels by 2030 (Perlack et.al, 2005). Biomass is unique as a renewable energy source because it is the only current renewable resource of liquid transportation fuel. There are three main categories of crops used for biofuel production: carbohydrate rich crops for conversion to bioethanol, oil rich crops for conversion to biodiesel, and wood coppice for direct combustion in powerstations (Murphy, 2003). Bioethanol is the most widely used biofuel for transportation.

Starch based ethanol conversion from corn has been the primary bioethanol production system in the United States. This bioethanol conversion system cannot continue to meet the growing production demands of the market because there is a finite amount of grain production and grain is more highly valued as a food and feed source (Rooney et.al, 2007). Other ethanol conversion systems utilizing alternate feedstocks must be developed and implemented. Crop and forest residues can be converted to ethanol, but dedicated bioenergy crops are necessary to supply processing facilities with adequate inputs of consistent quality feedstocks while minimizing transportation costs.

Many dedicated bioenergy crops will be developed and adapted to specific production environments, cropping systems, and processing methodology (Rooney et.al, 2007). Sorghum *(Sorghum bicolor)* has potential as a bioenergy crop in the Southern and Midwestern United States. Grain sorghum is already used as a feedstock in the starch to ethanol conversion system accounting for about four percent of the feedstock processed in 2007 (Renewable Fuels Association, 2007). Other types of sorghum can also be used as bioenergy feedstocks in different conversion systems. Photoperiod sensitive high biomass sorghums have potential as a feedstock for lignocellulosic ethanol conversion which converts structural carbohydrates in the cell walls of plants into ethanol. Sweet sorghum, which accumulates high concentration of fermentable sugar in soluble form in the stalks, can be converted directly to ethanol by fermentation. Sugar produced in the stalk of sweet sorghum can be extracted and fermented directly without the additional processing required by grains to hydrolyze starch before fermentation (Bryan et.al, 1981).

Typical sweet sorghum cultivars are 2.4-3.0 meters (8-10 feet) tall, can produce up to 30 Mg ha^{-1} of dry biomass per acre in favorable environments (Rooney et.al, 2007), and accumulate large amounts of juice in the stalk with a high sugar concentration in the juice. Sugar yield varies depending on variety, location, and maturity, but can exceed 4 Mg ha^{-1} (Morris and McCormick, 1994). Brix, the percent soluble solids in the juice, ranges from 12-18 percent in typical sweet sorghum cultivars and is affected by maturity and environment. The concentration of non-structural carbohydrates in sweet sorghum stalks is 1.4 times higher than grain sorghum in the upper stalk internodes and 2.7 times higher than grain sorghum in the lower stalk internodes (Hunter and Anderson, 1997). Sweet sorghum has a rapid growth rate and matures in 90-120 days (Prasad et.al, 2006) and can produce a ratoon crop in subtropical environments. Ratoon capability is dependent upon genotype and environment (Rooney et.al, 2007).

Sweet sorghum could fit well in areas that grow sugarcane, utilizing the same processing equipment (Rooney et.al, 2007) while extending the harvest season. In Louisiana, pairing sweet sorghum and sugarcane production can extend the harvest season from 100 days a year to 200 days a year with sweet sorghum harvests before and after the sugarcane harvest (Bradford, 2008).

There are some limitations to using sweet sorghum as an ethanol feedstock. As with sugarcane, the sugars stored in the stalks of sweet sorghum deteriorate rapidly during storage so the sugar must be converted to ethanol soon after harvest or preserved as syrup for storage and later processing (Bryan et.al, 1981). Whole stalks and billets did not deteriorate significantly during one week of storage, but sweet sorghum harvested with a forage chopper lost half of the fermentable sugars in one week with rapid losses occurring within 24 hours (Eiland et.al, 1983). Juice maintained at ambient temperatures must be processed within five hours to prevent spoilage (Daeschel et.al, 1981). Freezing weather can also lead to loss of sugar content, reduced ethanol yields, or failed fermentation (Bennett and Anex, 2008).

Sweet sorghum accumulates sugar in the stem near the time of grain maturity (Almodares et.al, 2007). Several studies have found the highest sugar concentration in the stalk during the hard dough stage (Almodares et.al, 2007; Hunter and Anderson, 1997; Lingle, 1987; McBee et.al, 1983). Duration of peak sugar period may vary. McBee et al. (1983) found that total sugars in sorghum juice increased to a maximum after soft dough, and then changed little as the season progressed. The best stage to harvest may be dependent upon genotype or environment (Hunter and Anderson, 1997). Some cultivars may not reach peak sugar until after physiological maturity in some northern climates. Other studies have found peak maturity as early as the milky stage of grain maturity (Bradford, 2008). Sugar may continue to accumulate in fully developed internodes well into seed development (Hunter and Anderson, 1997).

Production of ethanol from simple sugars of sweet sorghum is established technology. Sweet sorghum can produce 5.2-8.4 g ethanol per 100 g fresh biomass (Sakellariou-Makrantanaki et.al, 2007). Reported bioethanol yields from sweet sorghum range from 6500 to 8000 liter ha^{-1} in tropical and sub-tropical environments (Sakellariou-Makrantanaki et.al, 2007; Bennet and Anex, 2008; Dolciotti et.al, 1998). Sweet sorghum ethanol yields were lower in more temperate environments with a reported yield of 3000-4000 liters per hectare reported in Minnesota (Keeney and DeLuca, 1992). Ethanol yields from sweet sorghum are often greater than from maize in tropical environments, and have compared favorably with maize in more temperate regions (Putnam et.al, 1990).

Sweet sorghum breeding efforts have been limited, but additional breeding efforts are expected to produce significant improvements in fermentable sugar yield in sweet sorghum (Smith et.al, 1987). Open pollinated cultivars were developed and released from breeding programs in Mississippi, Texas, Virginia, and Georgia (Hunter and Anderson, 1997). Several sweet sorghum cultivars were developed in the 1950's and 1960's and remain important today. Other important cultivars were released as late as the 1980's (Hunter and Anderson, 1997). These cultivars serve as the primary germplasm base for developing improved sweet sorghum cultivars or hybrids.

Sorghum is a diploid plant with a relatively small genome allowing more efficient breeding of improved varieties. Experience breeding sweet sorghum and grain sorghum will benefit plant breeders and provide an advantage not available to switchgrass and other newly developing biofuel feedstocks. Breeding and selection in sweet sorghum could increase sugar yield, reduce lodging, and increase seed production to overcome some current challenges.

Current opportunities to produce ethanol from sweet sorghum are limited by seed stock of acceptable cultivars. Traditional cultivars produce low yields of seed on tall plants that are difficult to harvest mechanically. While these cultivars produce enough seed to support a relatively small and artisan sorghum syrup industry, they do not produce enough seed to plant the large acreages necessary to provide enough feedstock to a large scale ethanol processing plant. Ethanol processors are reluctant to build a processing facility without assurance that feedstocks will be available, a guarantee that cannot be made until producers have adequate seed available for planting.

Utilizing a hybrid production system based on cytoplasmic male sterility, well established in grain sorghum and forage sorghum production, would ease the seed production limitations of the current sweet sorghum cultivar system. Female seed parents can be selected for greater seed yields, increased sugar concentration in the stalks, and combining ability to develop hybrids that produce large amounts of fermentable sugar. In addition to making seed production more reliable, sorghum hybrids typically express a moderate level of heterosis. Heterosis is the superiority of a hybrid over its parents and can be defined as mid-parent heterosis, hybrid performance superior to the mean performance of the two parents, or high parent heterosis, hybrid performance superior to the better performing parent. Mid-parent and high-parent heterosis are calculated by the following formulas:

Mid-parent heterosis

$$MPH\ (\%) = \frac{F1 - \left(\frac{P1 + P2}{2}\right)}{\frac{P1 + P2}{2}} * 100$$

$$where\ F1 = hybrid\ performance\ and\ P1\ and\ P2 = performance\ of\ parents$$

High-parent heterosis

$$HPH\ (\%) = \frac{F1 - HP}{HP} * 100$$

$$where\ F1 = hybrid\ performance\ and\ HP = performance\ of\ superior\ parent$$

While quantitative genetics typically defines heterosis based on mid-parent calculations, it is high parent heterosis that is important in a practical situation. If the hybrid does not out-yield the best parent, the producer will simply grow the cultivar or parental variety. However, if hybrid production solves a seed production limitation in the cultivar itself, then the process of hybridization in itself is of significant value and equal yields will be enough to justify production and adoption. In addition to heterosis per se, hybrids have additional benefits which include, but are not limited to uniformity and reproducibility. Hybrids can also be used as a means to protect investment in new cultivars and transgenes (Lamkey and Edwards, 1999).

In sweet sorghum, very low high parent heterosis for maturity, and brix, and moderate values for plant height have been observed (Table 2.2). Greater levels of heterosis were observed for grain yield, stalk yield, and juice yield which was highly variable. The wide range of variability of brix, percent sucrose, stalk yield, and biomass yield indicate the high potential for genetic improvement to produce high sweet-stalked yield coupled with high sucrose percent sweet sorghum lines (Reddy et.al, 2005). The predominant role of non-additive gene action for plant height, stalk diameter, brix, stalk yield, and extractable juice yield indicates the importance of breeding for heterosis for improving these traits (Reddy et.al, 2005; Sankarapandian et.al, 1994). Another study found sugar concentration to be primarily additive in nature while dominance heterosis up to 150 percent was observed for biomass, juice volume, and grain yields (Murray et.al, 2008). Transgresive segregation was observed for glucose and fructose content, total dry matter, and grain yield in two sweet by grain sorghum recombinant inbred line populations (Ritter et al., 2007).

Table 2.1. Range of percent high parent heterosis expressed by sweet sorghum for yield and agronomic traits (Meshram et. al, 2005)

Trait	Minimum	Maximum
Maturity	87.62	103.29
Plant height	102.09	131.47
Brix	91.13	106.14
Stalk yield	87.30	169.52
Juice yield	67.29	242.06
Grain yield	37.33	153.45

The development of sweet sorghum hybrids, produced on grain-type females with high sugar concentrations is a practical way to overcome the seed supply limitation of traditional cultivars. Sweet grain-type female lines have been developed by the Texas Agrilife Research sorghum breeding program at College Station by crossing a grain-type female to a sweet sorghum cultivar, then backcrossing to the grain-type female to regain the short stature and large panicle characteristics of the grain-type parent with increased sugar concentration in the stalk. Increased sugar concentration in the seed parent is important because the preponderance of reports indicate that stem sugar concentration is an additively inherited trait; both parents must have high sugar concentration to obtain it in a desirable hybrid. Development of reliable seed parents will allow the production of hybrids in sweet sorghum utilizing the male sterile cytoplasm that is used in grain sorghum for hybrid production. First generation sweet sorghum hybrids need to be evaluated for biomass and sugar production as well as hybrid performance relative to the traditional cultivars.

The objective of this project is to:

1. identify the presence and magnitude of heterosis for traits contributing to sugar yield in sweet sorghum.
2. determine the importance of genotype, environment, and genotype by environment interaction effects on sugar yield and related traits.
3. evaluate the ability of sweet sorghum hybrids and cultivars to produce a ratoon crop and determine the contribution of the ratoon crops to total sugar yield per hectare.

Materials and Methods

Sweet sorghum hybrids were produced using grain-type females selected for high sugar concentration in the stalk crossed to pureline cultivars which served as male parents in first generation hybrids. The hybrids along with the female and male parents were planted in replicated field trials in 2007 and 2008 in a randomized complete block design with three replications. The 2007 trial included 50 entries in College Station, TX; 40 entries in Weslaco, TX; and 30 entries in Halfway, TX due to limited quantities of seed available for some hybrids. The 2008 field trials included 80 entries at all locations and were planted in the same three locations (Table 2.2). All trials were irrigated and managed for high sugar yields (Table A.1).

Table 2.2. Hybrid and parental lines included in the 2007 and 2008 trials

		Pollen Parent Cultivars							
Seed Parent	Seed Parent per se	R.07001	R.07002	R.07003	R.07004	R.07005	R.07006	R.07010R	R.07011R
A.B05034-1-1-4	2007 2008		2008	2007 2008		2007 2008			
A.B05034-1-3-3	2008			2008					
A.B05034-1-3-4	2008	2008		2008					
A.B05034-1-4-2	2007 2008		2008	2007 2008		2007			
A.B05034-1-4-4	2007 2008		2008	2007 2008	2008	2007 2008			
A.B05035-2-1-4	2007 2008		2008	2008			2007	2007	
A.B05035-2-2-1	2007 2008	2008	2008	2007 2008		2007 2008	2007		2007
A.B05035-2-2-3	2007 2008	2008	2008	2007 2008		2007	2007		2007
A.B05035-2-2-4	2007 2008	2008	2008	2007 2008		2007 2008	2007		2007
A.B05036-4-2-4	2007 2008			2007 2008			2007		
A.B05036-4-3-4	2007 2008	2008	2008	2007 2008				2007	
A.B05037-3-1-4	2007 2008		2008			2007			
A.B05037-3-4-1	2007 2008			2008		2007		2007	2007
A.B05038-4-1-3	2007 2008	2008	2008	2008				2007	
A.B05039-3-4	2007 2008	2008	2008	2008	2007	2007			
A.B05040-3-2-1	2007 2008	2008	2008	2008	2007	2007			
A.B05042-1-3-4	2007 2008	2008	2008	2007 2008		2007			
A.B05042-1-4	2007 2008			2007			2007		
A.B05043-2-4-2	2007 2008		2008	2007 2008	2007 2008	2007			
A.B05043-2-4-4	2008	2008							
Pollen Parent Cultivars		2008	2008	2007 2008	2007	2007 2008	2007 2008	2007	2007

Trials were harvested at hard dough maturity stage. A sample of plants from two meters of each plot was cut by hand just above the soil surface. The trials in College

Station and Weslaco in 2007 were cut, wrapped in sheets of plastic, and transported to the lab for processing. Based on previous research which indicated that extracted juice maintained at 4 degrees Celsius remained stable with regard to sugar concentration and quality (Daeschel, 1981), samples not processed immediately were stored in a cold vault to prevent spoilage. All other trials were processed in the field immediately after harvest. All plots, with the exception of the trial in Halfway 2007, were harvested prior to 10:00 am to reduce the diurnal effect. Time of harvest was used as a covariate to control the diurnal effect in the Halfway 2007 trial. The sorghum in the Halfway 2007 trial was too tall to fit in the trailer to transport for processing in the lab as the College Station and Weslaco samples were harvested and processed that year.

Total biomass of all samples harvested in 2007 was weighed immediately after cutting, after which the leaves and panicles were removed and weighed as well. The stripped stalks were milled using a three-roller mill (Ampro Sugar Cane Crusher model diamond); extracted juice was measured for weight and volume. Brix was immediately measured using a digital refractometer (Atago pocket refractometer, range 0~53%), and a 15 ml juice sample was collected. Juice samples were stored on ice as they were collected, pasteurized, and frozen for further analysis. Additionally, four whole plants were fed through a wood chipper and sampled to determine moisture content and biomass composition. In 2008 trials, sample processing procedures were altered to accommodate more entries. A subsample of plants with the panicles removed but leaves intact was milled using the three roller mill to extract the juice. Biocide Bussan 881 was added to the juice samples to eliminate microbial activity in the juice rather than relying on pasteurization which could not occur before returning to the lab.

Trials were harvested at the early hard dough stage when most genotypes of sweet sorghum reach peak sugar yield, prior to grain maturity. Immature grain yield estimations were determined using the ratio of panicle to stalk and leaf biomass yield per hectare and the threshing percentage. Threshing percentage was estimated by collecting panicle samples from each replication of 7 genotypes including hybrids, pollen parent cultivars, and seed parents at harvest and dividing the dry grain weight by the fresh panicle weight. Panicle samples of all genotypes were weighed separately from the stalks and leaves of a small sample and the ratio of panicle to stalk multiplied by the threshing percentage was then multiplied by the biomass yield per hectare to estimate immature grain yield for each genotype.

Sugar yield was estimated using the following equation:

$$Sugar = .95 * juice * .97 * .873 * (\frac{brix}{100})$$

where sugar and juice are measured in Mg ha^{-1} and brix is expressed in percent soluble solid. This equation accounts for commercial sugar extraction rate, using brix of first juice expressed to represent the entire juice volume, and concentration of fermentable sugar in brix. Modern sugarcane processing facilities have achieved an extraction efficiency of 95% (Bennett and Anex, 2008). Single-pass three-roll mills typically have extraction efficiencies ranging from 42-68% for whole stalks with leaves removed or 37% for whole stalks with leaves intact (Bennet and Anex, 2008). The second constant in the formula adjusts for using the first expressed juice to represent all juice. For every

100 parts brix in the first roller juice, there are approximately 97 parts in the whole juice of cane (Engelke, 2005). The final constant accounts for percent fermentable sugars present in the brix and will be illustrated in the following chapter.

Data analysis

The data was analyzed using SAS proc mixed within and across locations and years. Genotype was considered a fixed effect in the model, while location and year were considered random effects. Data was first analyzed by environment and was combined when there was homogeneous error variance among environments. Genotype by environment interaction effects were examined in the combined data analysis. Best linear unbiased predictors (BLUPs) for random effects and best linear unbiased estimators (BLUEs) for fixed effects were calculated to accommodate unbalanced entries. All entries were included in the analysis of variance, but the mean of elite hybrids is reported rather than all experimental hybrids. The elite hybrids are the top five percent of sugar yielding hybrids across environments; the same hybrids are included in the elite hybrid mean for all traits. Orthogonal contrasts were used to detect significant differences between hybrids and parents indicating a heterosis effect. A confidence interval for heterosis was established using bootstrap analysis.

Results and Discussion

The yields of elite hybrids, the top five percent sugar yielding hybrids, were similar to the cultivars that served as their pollen parents (Table 2.3). Combined analysis across locations and years revealed that the fresh biomass yield, brix, and sugar yield of elite hybrids was not significantly different from their pollen parents. The hybrids did produce significantly larger dry biomass than their pollen parents while the pollen parents had higher fresh and dry biomass yield, sugar yield, and brix than the seed parents. The elite hybrids expressed high parent heterosis for dry biomass yield, but they were not significantly higher for other traits of interest.

Table 2.3. Mean biomass and sugar yields and sugar concentration in elite hybrids, pollen parents, and seed parents across locations and years. Letters designate significant differences between hybrids and parent types for each trait determined by orthogonal contrasts

	Elite Hybrids*	Pollen Parents	Seed Parents
Biomass (Mg ha^{-1})	61.37^a	57.86^a	26.20^b
Dry Biomass (Mg ha^{-1})	22.19^a	19.08^b	10.13^c
Brix (%)	15.65^a	15.04^a	12.43^b
Sugar (Mg ha^{-1})	5.76^a	4.79^a	1.38^b

*Elite Hybrids = top 5% sugar yielding hybrids across locations and years

Year was not a significant factor in this trial, but location had a significant effect. Weslaco was the lowest yielding location (Table 2.4). The elite hybrids produced significantly more fresh and dry biomass than their pollen parents in College Station but were not significantly different from their pollen parents for any other trait or location.

Environment had a greater effect than genotype on biomass yield and sugar concentration (Table 2.5). The environment effect was not significant for sugar yield. Genotype by environment interaction had a significant effect on sugar yield, but not on biomass yield or brix.

Table 2.4. Mean biomass and sugar yields of sweet sorghum hybrids and parental lines in each location across years. Letters designate significant differences between hybrids and parental types for each trait within each environment determined by orthogonal contrasts

	Weslaco			College Station			Halfway		
	Elite Hybrids*	Pollen Parents	Seed Parents	Elite Hybrids	Pollen Parents	Seed Parents	Elite Hybrids	Pollen Parents	Seed Parents
Fresh Biomass (Mg ha^{-1})	31.02^{a}	39.37^{a}	20.74^{b}	73.04^{a}	66.30^{b}	29.87^{b}	67.98^{a}	69.98^{a}	26.75^{b}
Dry Biomass (Mg ha^{-1})	11.19^{a}	12.77^{a}	7.54^{b}	28.03^{a}	21.37^{b}	11.45^{c}	20.79^{a}	22.23^{a}	10.91^{b}
Brix (%)	13.36^{a}	15.41^{a}	14.02^{a}	15.90^{a}	14.89^{a}	12.12^{b}	16.20^{a}	16.07^{a}	11.14^{b}
Sugar (Mg ha^{-1})	2.15^{a}	3.34^{a}	1.51^{b}	5.74^{a}	5.32^{a}	1.76^{b}	5.08^{a}	5.75^{a}	1.00^{b}

*Elite Hybrids = top 5% sugar yielding hybrids across locations and years

In 2007, two ratoon crops were harvested in Weslaco and a single ratoon crop was harvested in College Station. In Halfway, the growing season is not long enough to produce a ratoon crop. The ratoon crops contributed to total biomass and sugar yield (Table 2.6). However, the ratoon crops were not harvestable in 2008 due to separate hurricane and tropical storm damage in Weslaco and College Station, respectively.

Genotype and environment are both significant factors affecting ratoon efficiency (Table 2.7). Ratoon efficiency equals ratoon yield divided by yield of the primary harvest. The hybrids have greater ratoon efficiency than the pollen parent cultivars. The first ratoon crop in Weslaco produced more biomass than the primary crop due to the longer day lengths during that period. The second ratoon harvest in Weslaco was similar to the ratoon crop in College Station yielding about half the fresh biomass of the primary crop. The ratoon crop tends to have lower plant moisture at harvest than the primary crop. While the sugar concentration of the ratoon crops was similar to the primary harvests, the reduction in biomass and juice yield greatly reduced sugar yield in comparison to the primary harvest. Ratoon crops have potential to increase total sugar yield per hectare in a growing season, but ratoon crops are less efficient than the primary crop. This implies that additional acres must be planted; economic analysis and crop production logistics will dictate the most efficient approach between planting and rationing.

Table 2.5. Mean squares for sources of variation affecting biomass yield, brix, and sugar yield across locations and years

Source	DF	Biomass	Dry Biomass	Brix	Sugar
Year	1	13.83^{ns}	26.63^{ns}	83.55^{ns}	3.31^{ns}
Genotype	95	1459.55**	135.82^{ns}	19.81*	13.86**
Env(Year)	2	6756.29**	1386.93**	139.32**	1.93^{ns}
Rep(Year*Env)	12	431.20**	61.11**	48.40**	5.63**
Genotype*Year	25	442.74**	79.78*	4.33^{ns}	3.5**
Genotype*Env	171	235.65^{ns}	30.75^{ns}	5.28^{ns}	2.51*
Genotype*Year*Env	39	163.75**	38.49**	5.96**	1.34^{ns}
Residual	672	85.19	18.81	3.31	0.98

*Significant at p=.05
**Significant at p=.01
^{ns} Non-significant at p=.05

Table 2.6. Total yields and average brix for primary and ratoon harvests in Weslaco and College Station in 2007

	Weslaco			College Station			Across Locations		
	Elite Hybrids	Pollen Parents	Seed Parents	Elite Hybrids	Pollen Parents	Seed Parents	Elite Hybrids	Pollen Parents	Seed Parents
Fresh Biomass (Mg ha^{-1})	115.82^{a}	96.45^{b}	57.22^{c}	113.82^{a}	105.01^{a}	44.80^{b}	94.84^{a}	85.41^{b}	41.07^{c}
Dry Biomass (Mg ha^{-1})	49.53^{a}	38.29^{b}	24.77^{c}	44.88^{a}	38.94^{a}	18.53^{b}	36.77^{a}	32.10^{a}	16.91^{b}
Brix (%)	13.51^{ab}	14.20^{a}	12.59^{b}	14.16^{a}	14.03^{a}	11.40^{b}	14.89^{a}	15.17^{a}	11.30^{b}
Sugar (Mg ha^{-1})	7.06^{a}	6.66^{a}	3.25^{b}	8.03^{a}	7.41^{b}	2.22^{c}	7.13^{a}	6.47^{a}	2.24^{b}

*Elite Hybrids = top 5% sugar yielding hybrids across locations

Table 2.7. Ratoon efficiency of sweet sorghum hybrids and pollen parent cultivars for biomass yield, brix concentration, and sugar yield by location in 2007

	Hybrids				Pollen Parents			
	Fresh Biomass	Dry Biomass	Brix	Sugar	Fresh Biomass	Dry Biomass	Brix	Sugar
Across Environments	0.85	1.08	1.03	0.72	0.81	1.03	0.93	0.62
Weslaco 1st Ratoon	1.29	1.71	0.85	0.96	1.20	1.61	0.81	0.82
Weslaco 2nd Ratoon	0.50	0.63	0.98	0.45	0.45	0.57	0.96	0.39
College Station	0.41	0.46	1.20	0.49	0.42	0.43	1.05	0.43

The primary advantage of these first-generation sweet sorghum hybrids is a viable seed production system (Table 2.8). The mature seed yields of the seed parents ranged from 2763 to 5520 kg ha^{-1} in Halfway, a typical sorghum seed production environment. The traditional cultivars produced only 824 and 1207 kg ha^{-1} mature seed in Halfway in 2007. The trial was planted twice in Halfway in 2007, one trial was harvested for sugar at the hard dough stage and the seed parents and two cultivars were harvested for grain yield at grain maturity. Mature seed was only harvested in one location and year.

Table 2.8. Best linear unbiased estimators of mature seed yield in Halfway 2007

Entry	Mature Seed Yield
Seed Parents	
B05035-2-2-3	5520.55
B05035-2-1-4	5418.40
B05034-1-1-4	4857.09
B05036-4-2-4	4305.85
B05042-1-4-4	4092.55
B05043-2-4-4	3877.32
B05035-2-2-4	3745.83
B05042-1-3-4	3665.09
B05040-3-2-1	2975.72
B05037-3-1-4	2781.48
B05036-4-3-4	2763.70
Cultivars	
R07010R	1207.42
R07003	823.86

Immature grain yield was estimated in the trials in College Station and Halfway during both years of the experiment. The immature grain yields also illustrate the significantly higher grain yields of the seed parents compared to the traditional cultivars (Table 2.9).

Table 2.9. Immature seed yields of cultivars and seed parent of elite hybrids in College Station and Halfway

	Cultivars	Seed Parents of Elite Hybrids*
College Station		
2007	1644.58^b	2978.26^a
2008	1221.04^b	2006.22^a
across years	1494.29^b	2443.77^a
Halfway		
2007	888.86^b	1982.36^a
2008	785.65^b	1932.91^a
across years	878.90^b	1960.64^a

*Elite hybrids are top 5% of sugar yielding hybrids across locations and years

An additional advantage of producing seed on grain-type seed parents is the plant height. The traditional cultivars average 1.99 to 2.88 meters tall depending upon the environment (Table 2.10). The average height of the seed parents is 1.34 to 1.57 meters depending upon the growing conditions. The short-statured seed parents can be mechanically harvested efficiently. The hybrids were similar in height to the pollen parent cultivars in most environments.

The hybrids as a group are significantly different that the parents for biomass and sugar yield as well as brix. High parent heterosis was observed among the hybrids for all traits of interest (Table 2.11). The mean and range of heterosis observed for each trait are similar. There is a greater range of heterosis expressed for sugar yield than other traits as both biomass, which is highly correlated to juice yield, and brix both contribute to sugar yield.

Table 2.10. Mean plant height (meters) for sweet sorghum hybrids, pollen parent cultivars, and seed parents by location. Means with the same letter designation within an environment are not significantly different

Year	Location	Hybrids	Pollen Parents	Seed Parents
2008	College Station	2.44^{a}	2.53^{a}	1.48^{b}
2007	College Station	2.56^{b}	2.88^{a}	1.45^{c}
2007	Halfway	2.81^{a}	2.80^{a}	1.57^{b}
2007	Weslaco Primary	2.01^{a}	1.99^{a}	1.34^{b}
2007	Weslaco Ratoon	2.65^{a}	2.51^{b}	1.48^{c}

Table 2.11. High parent heterosis (%) for biomass and sugar yield and brix across locations and years

	Mean	90 % Confidence Interval*	Minimum	Maximum
Biomass	93.26	55.74 - 140.86	36.30	194.86
Dry Biomass	97.39	50.64 - 149.42	37.86	199.13
Brix	90.04	63.45 - 120.54	44.51	164.58
Sugar	84.43	38.01 - 161.74	20.10	235.34

* Determined by bootstrap analysis

Conclusions

Sweet sorghum has potential as a feedstock for production of bioethanol. Developing sweet sorghum hybrids will overcome challenges with limited seed availability so enough sweet sorghum can be produced to support a processing facility. The primary advantage of the first generation sweet sorghum hybrids is the seed availability. The elite hybrids are similar to the traditional cultivars for biomass and sugar yield, but some hybrids express high parent heterosis for biomass and sugar yield so selection for improved inbreds and combining ability could increase sugar yield per hectare. Mean high parent heterosis was less than 100% for biomass yield, sugar concentration, and sugar yield, but heterosis observations ranged from approximately 40-190% depending on the specific hybrid combination.

The hybrids have greater ratoon efficiency than the traditional cultivars, but environment has a large effect on ratoon efficiency and genotype also has a significant effect. Ratoon harvests can contribute to sugar yield per hectare in a growing season, but replanting should also be considered. Average ratoon yields are ~75% of the primary harvest yield.

First generation sweet sorghum hybrids overcome the seed production limitations and produce sugar yields similar to the traditional cultivars. Additional breeding will increase sugar and biomass yield and improve agronomics including reduced lodging.

CHAPTER III

JUICE COMPOSITION OF SWEET SORGHUM HYBRIDS AND PARENTAL LINES IN MULTIENVIRONMENT TRIALS IN TEXAS

Introduction

Sweet sorghum is a traditional crop in the Southeastern U.S. where it is grown to produce syrup used as a sweetener in food products. More recent interest in crops that produce large quantities of easily fermented carbohydrates (e.g., sugar) has renewed interest in sweet sorghum as a potential feedstock for bioethanol production. While there is an obvious connection of sweet sorghum to these end uses, the shift of sweet sorghum from syrup production to ethanol production requires that the definition of juice quality change to reflect the value of the juice to producing ethanol rather than syrup.

Sweet sorghums accumulate large amounts of fermentable sugars that are soluble in juice that can be extracted from the stalks. Juice extracted from the stalks by milling typically contains 10-13% fermentable sugars, similar to the concentration found in sugarcane juice (Bradford, 2008). Sucrose is the primary sugar found in the juice, but significant quantities of glucose, fructose and even starch can be recovered as well. Juice composition varies and appears to be influenced by both cultivar and environment. Saballos (2008) reports 89% sucrose, 8% simple sugars, and 3% starch while Kundiyana et.al (2006) reports 85% sucrose, 9% glucose, and 6% fructose. Hexose sugars, glucose and fructose, are the dominant non-structural carbohydrates in young and elongating internodes (Hoffman-Thoma et.al, 1996) while sucrose is found at much higher concentration than either glucose or fructose in ripening internodes (Tarpley and Vietor, 2007).

Sucrose accumulation is slow prior to anthesis as stalk elongation is a strong carbohydrate sink (Hunter and Anderson, 1997). Grain filling is a less competitive carbohydrate sink than elongating internodes in sweet sorghum, possibly due to the reduced sink size of the panicle compared to traditional grain sorghum genotypes (Amaducci et.al, 2004). Sucrose concentrations begin increasing after heading and they reach peak accumulation at the transition to the hard dough maturity stage (Amaducci et.al, 2004; Hunter and Anderson, 1997; Dolciotti et.al, 1998). Total sugar in the juice changed little as the season progressed after soft dough stage (McBee et.al, 1983). Other studies have found that sucrose storage occurs after internode elongation ceases in an internode to internode process beginning with the lowermost parts of the stalk (Hoffman-Thoma et.al, 1996). This model for sugar accumulation is similar to sucrose storage in sugarcane. There appear to be biochemical differences in sucrose accumulation in sweet sorghum compared to sugarcane (Hunter and Anderson, 1997) and may be due to differences in the competitiveness of elongating and mature internodes. In sweet sorghum, sucrose accumulation is accompanied by a decline in soluble acid invertase and sucrose synthase activities (Lingle, 1987). Internode elongation is associated with high acid invertase activity, thus sucrose accumulation in sweet sorghum is associated with the onset of the reproductive growth phases and corresponding decline in acid invertase activity (Lingle, 1987). Many enzymes associated with sugar accumulation in sugarcane do not appear to play important roles in sweet sorghum sugar accumulation (Murray et.al, 2008).

Sugar concentration in the stem and stem juice yield per hectare determine total sugar yield per hectare. In sugarcane, increases in total sugar yield have been achieved primarily through increasing stem juice yield per hectare, perhaps because sugar concentration has been maximized (Murray et.al, 2008).

The objectives of this research are:

1. determine the sugar composition of the juice from milled sweet sorghum stalks,
2. determine the relative importance of genotype, environment, and genotype by environment interaction effects on sweet sorghum juice composition,
3. develop a strategy for breeding advanced sweet sorghum hybrids.

Materials and Methods

Sorghum juice from selected high sugar yielding entries of experimental hybrids, seed parents, and traditional cultivars that served as pollen parents of the hybrids described in the previous chapter were analyzed (Table 3.1). A 15 milliliter juice sample was collected from each plot in the first two replications of the experiment in all three locations in 2007 and 2008. In 2007 the samples were collected and stored on ice, pasteurized by heating to 71 degrees Celsius in a hot water bath for one minute, then frozen for long term storage. In 2008, biocide Bussan 881 was added to the juice samples as they were collected to eliminate microbial contamination of the samples, but the samples were not pasteurized prior to freezing for storage.

Table 3.1. Hybrids, pollen parent cultivars, and seed parent selected for juice composition analysis

Pedigree
Hybrids
A.B05043-2-4-2/R07003
A.B05042-1-4/R07003
A.B05036-4-3-4/R07002
A.B05034-1-1-4/R07005
A.B05042-1-3-4/R07003
A.B05036-4-2-4/R07003
A.B05035-2-2-1/R07005
A.B05035-2-2-1/R07003
A.B05038-4-1-3/R07002
A.B05037-3-1-4/R07001
A.B05040-3-2-1/R07002
A.B05034-1-1-4/R07003
Cultivars/Pollen Parents
R07005
R07003
Seed Parent
B05037-3-1

Compositional Analysis

Composition of selected juice samples was analyzed by high performance liquid chromatography (HPLC). Using 2 ml Eppendorf tubes, 1.5 ml of the juice was heated for 2 minutes in briskly boiling water; the pasteurized juice was centrifuged at 3000 rpm for 10 minutes. The samples were filtered through 0.22 μm membrane filter prior to HPLC analysis. The Waters Alliance® HPLC system with 2690 Separation Modules (integrates five 24-vial carrousel, solvent delivery system, onboard controller, compartment for column and column heater) and Waters 2410 RI detector were used for the analysis of glucose conversion. The Shodex SP0810 column (8.0 mm id x 300 mm) equipped with SP-G guard column (6.0 mm id x 50 mm) were used at column temperature of 60 degrees Celsius using filtered and degassed deionized water as the eluent at 0.7 ml/minute. Each sample was analyzed for 30 minutes and standards were run at the start, middle and end of sample analysis. For quality assurance, 20% of the samples were analyzed in duplicate and a blank was run every 10 sample injections.

Statistical Analysis

The data was analyzed using SAS data analysis software in the mixed procedure considering genotype as a fixed effect and replication and environment to be random effects. Single environments were analyzed and environments with homogeneous error variances were combined for multi-environment analysis.

Results and Discussion

Sucrose concentration in all hybrids and parents across environments was 65% of total sugar in 2007 and 78% in 2008 (Figure 3.1). In both years the sucrose concentrations were lower than previously reported. The entries in this test also had a greater concentration of glucose and fructose than has been reported which may be due to environment, genotype, maturity, or degradation of the juice samples prior to analysis.

Year had a significant effect on the concentration of sucrose, glucose, and fructose in the sweet sorghum juice, but it did not affect total sugar concentration in the juice. While the total sugar concentration in the juice was similar in both years, the composition differed indicating a variable amount of sucrose in the samples had degraded to glucose and fructose. The samples collected in 2007 had significantly greater concentrations of glucose and fructose than the 2008 samples which had biocide added to each sample during harvest. It appears that the biocide effectively reduced sucrose degradation to glucose and fructose. The effect of year was exaggerated by the effect of adding biocide to the samples in 2008, but not in 2007.

2007

2008

Figure 3.1. Mean sweet sorghum juice composition by year across locations

A significant genotype effect was detected for total sugar and the concentration of each component sugar in both (Table 3.2). In 2007, the effect of harvest, comparing primary and ratoon harvests, was highly significant for total sugar concentration in the juice and for the concentration of all three component sugars. The environment effect was significant for total sugar and component sugar concentration in both years except for fructose concentration in 2008. The environment effect was much larger than the genotype effect with the exception of the concentration of glucose and fructose in 2008. Overall, environment tends to have a larger effect than genotype. The interaction of genotype by environment effects was only significant for total sugar concentration in 2007.

Ratoon crops were harvested in College Station and Weslaco in 2007, but were destroyed by storms in 2008. In 2007, the hybrids and pollen parent cultivars produced the greatest concentration of total sugar in the stalk juice in Halfway where the seed parent had the lowest total sugar concentration (Table 3.3).

Table 3.2. ANOVA mean squares for sources of variance affecting sweet sorghum juice composition within years across locations

2007	df	Total Sugar	Sucrose	Glucose	Fructose
Genotype	9	2978.96**	4240.70**	336.25**	182.47**
Harvest	2	3928.24**	22631.00**	2002.51**	2212.95**
Rep	2	834.83^{ns}	1351.79^{ns}	229.85^{ns}	199.95^{ns}
Environment	2	4713.85**	16601.00**	1676.78**	1528.60**
Genotype*Env	18	902.23*	962.81^{ns}	63.66^{ns}	45.69^{ns}
Residual	85	448.36	872.54	78.49	72.24
2008					
Genotype	8	2023.74*	1711**	106.64**	45.94**
Rep	1	2097.93^{ns}	989.96^{ns}	94.26^{ns}	21.48^{ns}
Environment	2	8131.94**	6732.33**	78.73*	5.38^{ns}
Genotype*Env	14	708.29^{ns}	550.60^{ns}	19.99^{ns}	10.70^{ns}
Residual	18	875.37	554.9	49.26	25.32

Sucrose concentration was highly correlated to total sugar concentration in the hybrids (r=0.89), pollen parent cultivars (r=0.91), and a weaker correlation in the seed parent (r=0.67) across locations and harvests. There was a moderate negative correlation between total sugar and glucose in the hybrids (r=-0.58) and pollen parents (r=-0.64) and between total sugar concentration and fructose concentration in the hybrids (r=-0.57) and pollen parents (r=-0.65). The seed parent had a positive correlation between total sugar concentration and glucose (r=0.45) and fructose (r=0.31) across years and locations. The sucrose concentration in the seed parent was only slightly higher than the concentration of glucose and fructose in most locations and harvests while the hybrids and pollen parent cultivars produced primarily sucrose with low concentrations of monosaccharides except in the first ratoon harvest at Weslaco.

Table 3.3. Mean juice composition by plant type for 2007 primary and ratoon harvests by location. Observations with different letter designations within a harvest and location are significantly different for a given trait

Location	Harvest	Total Sugar (g/L)			Sucrose (g/L)		
		Hybrids	Pollen Parents	Seed Parent	Hybrids	Pollen Parents	Seed Parent
College Station	Primary	102.04^{ab}	138.86^{a}	95.08^{b}	60.70^{b}	89.26^{a}	18.57^{c}
College Station	Ratoon	111.95^{b}	129.78^{a}	87.84^{b}	87.94^{b}	102.28^{a}	57.34^{c}
Halfway	Primary	144.87^{b}	171.98^{a}	54.12^{c}	117.67^{a}	126.44^{a}	21.20^{b}
Weslaco	Primary	120.81^{b}	137.48^{a}	118.92^{b}	62.37^{b}	94.42^{a}	60.14^{b}
Weslaco	Ratoon	98.92^{a}	105.60^{a}	106.88^{a}	35.16^{a}	15.46^{a}	38.51^{a}
Weslaco	2nd Ratoon	136.36^{b}	166.25^{a}	117.56^{c}	111.79^{b}	138.53^{a}	82.63^{c}
		Glucose (g/L)			Fructose (g/L)		
		Hybrids	Pollen Parents	Seed Parent	Hybrids	Pollen Parents	Seed Parent
College Station	Primary	23.14^{b}	28.06^{b}	41.19^{a}	18.19^{b}	21.54^{b}	35.32^{a}
College Station	Ratoon	14.87^{b}	17.67^{a}	18.95^{a}	8.92^{b}	9.51^{a}	12.00^{a}
Halfway	Primary	15.79^{b}	26.88^{a}	18.14^{b}	11.58^{c}	18.83^{a}	14.95^{b}
Weslaco	Primary	31.92^{a}	24.75^{a}	33.19^{a}	26.52^{a}	18.31^{a}	25.59^{a}
Weslaco	Ratoon	34.52^{b}	48.79^{a}	37.26^{ab}	29.24^{b}	41.35^{a}	31.10^{ab}
Weslaco	2nd Ratoon	15.86^{b}	17.67^{ab}	21.26^{a}	8.72^{b}	10.05^{b}	13.68^{a}

The total sugar concentration of the sweet sorghum hybrids was intermediate to the traditional cultivars and the seed parent selected for juice composition analysis across locations in each year with the exception of hybrid A.B05043-2-4-2/R07003. This hybrid had a greater total sugar concentration than any of the parent types (Table 3.4). The concentration of sucrose, glucose, and fructose was measured in grams per liter of juice by HPLC. Total sugar concentration is the sum of the three component sugars; then each component sugar's concentration was divided by the total sugar concentration to determine the percent of the total sugar that is sucrose, glucose, and fructose. The hybrids were significantly different than the cultivars for total sugar concentration in the juice and the concentration of sucrose and glucose, but there was no difference in sucrose, glucose, or fructose as a percent of the total sugar. This indicates that although the cultivars produce a greater concentration of sugar in the juice, the distribution of sugars is similar. The hybrids produced a significantly higher concentration of total sugar than the seed parent and also have a different relative distribution of sugars. There was a significant difference between the hybrids and the representative seed parent in the percent sucrose, glucose, and fructose of the total sugar produced. A similar trend was observed between the pollen parent cultivars and the seed parent.

The distribution of sucrose, glucose, and fructose in the juice was similar in the primary crops harvested from all three locations (Figure 3.2) while more variation was observed among the hybrids than the pollen parent cultivars. The greater variation among hybrids was expected as these are first generation hybrids while the cultivars have been selected over many years. The percent sucrose in the ratoon crop in College Station and the second ratoon crop in Weslaco was significantly greater than the primary harvests. The juice yield of those two ratoon harvests was significantly lower than the primary harvest. The first ratoon crop in Weslaco produced significantly more biomass and juice than the primary crop in that location, but the sucrose concentration was significantly lower than the primary crop. While the pollen parent cultivars had a higher percent sucrose than the hybrids in the primary crop at Weslaco, the pollen parents had a lower percent sucrose than the hybrids in the first ratoon. In Weslaco, the first ratoon crop was taller and produced more biomass than the primary crop due to longer day lengths while the ratoon crop was growing. The hybrids expressed a sugar distribution pattern similar to the pollen parent cultivars across locations and ratoon harvests. The seed parent analyzed expressed a similar pattern across locations and primary and ratoon crops, but a greater percentage of the sugar content in the seed parent was in the form of monosaccharides glucose and fructose.

Table 3.4. BLUE of primary harvest juice composition across years and locations

	Total Sugar g/L	Sucrose g/L	Glucose g/L	Fructose g/L	Sucrose %	Glucose %	Fructose %
Hybrids							
A.B05043-2-4-2/R07003	153.73	104.90	27.61	19.30	70.00	17.73	12.27
A.B05042-1-4/R07003	143.11	93.35	25.86	17.06	69.29	18.59	12.13
A.B05036-4-3-4/R07002	130.40	95.19	20.37	14.25	72.60	16.11	11.29
A.B05034-1-1-4/R07005	125.72	94.87	18.12	12.74	73.53	15.53	10.94
A.B05042-1-3-4/R07003	125.34	86.46	21.87	15.10	68.78	18.36	12.86
A.B05036-4-2-4/R07003	115.89	84.90	18.18	12.81	73.47	15.75	10.79
A.B05035-2-2-1/R07005	114.75	86.86	15.95	11.18	75.73	14.24	10.02
A.B05035-2-2-1/R07003	114.06	86.25	16.71	10.79	73.86	15.86	10.28
A.B05038-4-1-3/R07002	113.57	70.47	25.99	17.93	59.63	23.54	16.83
A.B05037-3-1-4/R07001	112.82	75.24	21.85	14.55	66.67	19.70	13.63
A.B05040-3-2-1/R07002	112.61	90.30	14.51	9.64	78.10	13.04	8.86
A.B05034-1-1-4/R07003	108.44	82.96	15.11	10.37	76.34	14.23	9.43
Cultivars/Pollen Parents							
R07005	150.46	120.99	18.85	9.99	79.83	13.11	7.06
R07003	142.24	89.46	30.75	19.52	63.42	22.32	14.26
Seed Parent							
B05037-3-1	80.94	34.20	24.90	19.84	43.68	31.25	25.06

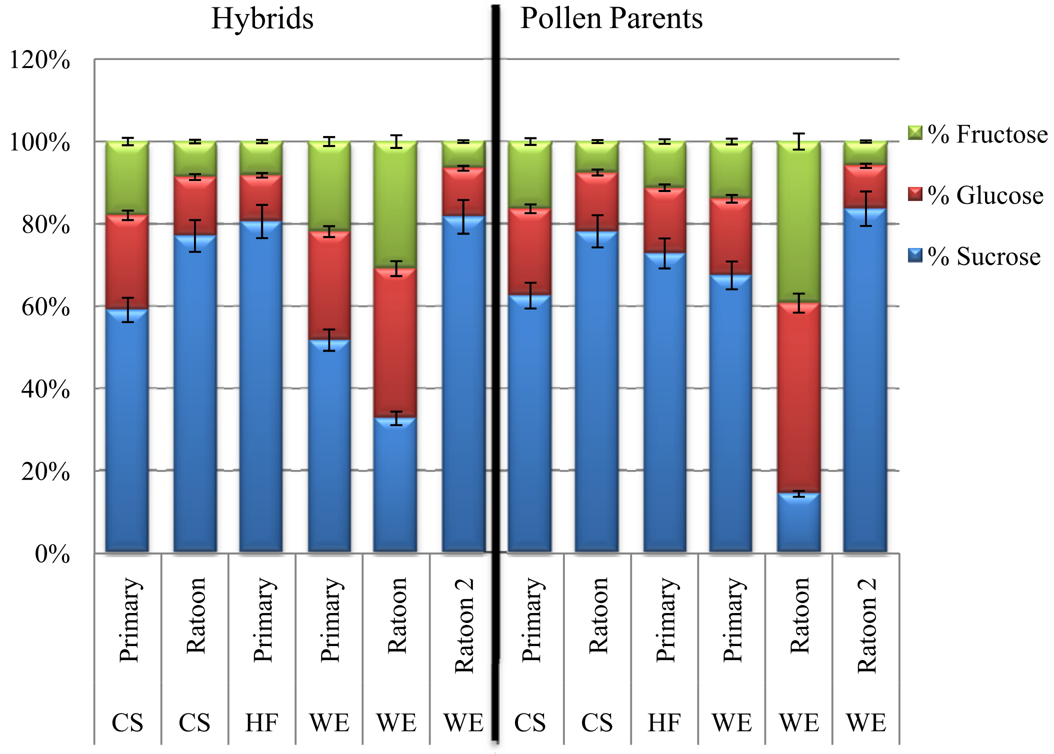

Figure 3.2. 2007 Juice composition by harvest for hybrids and pollen parent cultivars

Conclusions

Environment had a stronger effect on juice composition than the effect of genotype while genotype by environment interaction tended to be non-significant. The effect of year was exaggerated by adding biocide to control microbial conversion of sucrose to glucose and fructose.

Nearly all of the hybrids accumulated total sugar at concentrations greater than the seed parent but lower than the pollen parent cultivars. Only one hybrid accumulated greater sugar concentrations than both parental types.

While the concentration of sugar in the juice was greater in the pollen parent cultivars than the hybrids, the profile of sucrose, glucose, and fructose percent of the total sugar was similar between the hybrids and cultivars while the seed parent displayed a different sugar profile. The primary crops in all three locations had a similar distribution of sugars while the juice of the ratoon crops differed. The first ratoon crop in Weslaco produced more biomass than the primary crop, but had a very low sucrose concentration. The second ratoon crop in Weslaco and the ratoon crop in College Station produced lower biomass yields than the primary harvests and had high concentrations of sucrose in the juice.

Juice purity has traditionally been defined by the sucrose concentration relative to total soluble solids in the juice, but all fermentable sugars need to be quantified when ethanol is the final product.

CHAPTER IV

BIOMASS COMPOSITION OF SWEET SORGHUM HYBRIDS AND PARENTAL LINES IN MULTIENVIRONMENT TRIALS IN TEXAS

Introduction

Several bioenergy crops are being developed to be produce simple sugars, starch, and lignocellulosic biomass as feedstocks for multiple ethanol conversion systems. Simple sugars readily ferment to ethanol while the ethanol plants in the US primarily rely on converting grain starch to ethanol. Plant biomass can be converted to ethanol, methanol, methane, and hydrogen by combustion, gasification, pyrolysis and biological treatment (Antonopoulou et.al, 2008).

Different bioenergy crops will be needed for different regions of the world because no single crop can be produced year around and different crops are adapted to seasonal growth and environmental variation. While several crops are being developed, sorghum is an annual crop likely to fit in multiple production systems. For example, sorghum fits well in the environments of the Southern US. Three distinctly different types of sorghum can be used as ethanol feedstocks and they supply three different ethanol conversion systems – grain sorghum producing starch, sweet sorghum producing simple sugars, and high biomass energy sorghum for lignocellulosic conversion to ethanol. Sweet sorghum hybrids were developed at the Texas Agrilife Research Center in College Station, Texas and evaluated as a potential bioenergy feedstock. The parental lines of these hybrids are grain type female lines bred and selected for high sugar concentration in the stalk juice and high seed yields crossed to traditional pureline cultivars that served as the pollen parents. The agronomic performance of the hybrids and parental lines is reported in chapter II.

Sweet sorghum produces simple sugars in the stalks and structural carbohydrates in the biomass, both of which can be fermented. While the simple sugars in juice extracted from the are the most readily fermentable product of sweet sorghum, an efficient method to transform the energy from the bagasse into a useable form would increase the profitability of the crop because the bagasse that remains after sweet sorghum stalks are milled contain 3-5 times the energy of the juice sugars (Saballos, 2008). The bagasse can be burned to power the ethanol distillery, converted to ethanol through lignocellulosic conversion, fed to livestock, or used for other purposes (Saballos, 2008; Gnansounou et.al, 2005). Lignocellulose is a more complex substrate than sugar or starch for ethanol conversion. It contains a mixture of the carbohydrate polymers cellulose and hemicelluloses and it also contains lignin, a non-carbohydrate polymer that provides rigidity to plant cells and cements the cells together. Available markets for sweet sorghum by-products could increase the profitability of sweet sorghum production making it a more viable option as an ethanol feedstock (Worley et.al, 1992).

Biomass is primarily composed of complex carbohydrates cellulose and hemicelluloses as well as the non-carbohydrate polymer lignin. Cellulose is a glucan, a chain of glucose molecules, which can be hydrolyzed to glucose and further fermented to ethanol. Cellulose has a simple linear structure with repeating identical bonds so few enzymes are required to break cellulose into individual glucose molecules.

Hemicelluloses are complex carbohydrates that contain glucose, mannose, xylose, arabinose, and galactose sugars in branched chains. The structure and composition of hemicellulose is more complex than cellulose thus more enzymes are required to hydrolyze hemicellulose than cellulose. Xylan is the predominant sugar in hemicelluloses contained in the cell walls of herbaceous plants. The sweet sorghum cultivar M81E contains 11.98 percent xylan by mass, 1.31 percent arabinan, 0.40 percent galactan, and 0.12 percent mannan sugars for a total of 13.81 percent hemicellulose by mass (NREL, 2009).

Lignin is the major non-carbohydrate component of cell walls. Lignin links cellulose and hemicelluloses and provides the cell with both mechanical strength and hydrophobicity (Theander et.al, 1993). Lignin also decreases the ability of polysaccharide degrading enzymes to reach the cellulose and hemicelluloses present in the cell walls reducing the efficiency of converting biomass into simpler, fermentable sugars. The effect of lignin on bioavailability of other cell wall components appears to be due to physical restriction by reducing the surface area of other molecules available to enzymatic penetration and activity (Haug, 1993). Plant biomass also contains soluble material including non-structural carbohydrates, chlorophyll, waxes, nitrogenous material, and other minor components (Sluiter et.al, 2008.) Commercial cellulose to ethanol conversion systems have not yet been established so the optimal feedstock composition has yet to be determined, but high cellulose concentration and low lignin concentration will be preferable. Hemicelluloses contain fermentable sugars, but require more complex processing to convert their mixture of six-carbon and five-carbon sugars to ethanol.

Forage biomass composition is often determined based on the extraction of forage samples with different detergent solutions. An extraction with neutral detergent solution isolates neutral detergent fiber (NDF) which includes the cell wall fraction of the forage. Hemicelluloses present in the NDF are extracted with sulfuric acid leaving the acid detergent fiber (ADF) fraction that includes the cellulose and lignin. Hemicellulose can be estimated by subtracting ADF from NDF. Lignin can be measured by treating ADF with sulfuric acid or permanganate. Near infrared spectroscopy (NIR) methods were developed to reduce the analytical labor and costs compared with the detergent fiber analysis method. NIR calibration equations developed from the NIR spectra and laboratory analytical data explain 90-99% of sample variation in crude protein, NDF, ADF, and digestibility (Collins and Fritz, 2003). NIR methods can also be applied to compositional analysis of biomass for ethanol conversion. Calibration equations are being developed from the NIR spectra and laboratory analytical procedures for cellulose, hemicellulose, lignin, and solubles content in sorghum biomass. Standard wet chemical methods for the compositional analysis of biomass are ineffective in a commercial setting because they are expensive, labor intensive, and cannot provide analysis in a timeframe useful for process control (Hames et.al, 2003).

Composition is influenced by genotype, environment and their interactions. Like any trait is influenced by these factors, it is critical to determine the relative magnitude of these effects. Once the type and magnitude of effects is determined, this information can be used to mitigate changed to optimize composition. The objectives of this research are to:

1. determine the composition of whole plant biomass and of sweet sorghum,
2. determine the relative importance of genotype and environment effects on biomass composition,
3. identify differences in biomass composition between sweet sorghum hybrids, pollen parent cultivars, and inbred seed parents.

Materials and Methods

A total of 100 entries, composed of sweet sorghum hybrids, their seed parents, and the traditional cultivars that served as pollen parents for the hybrids were grown in replicated field trials in Weslaco, College Station, and Halfway, Texas in 2007 (Table 4.1). From each plot, four to six stalks were cut just above the soil surface and the whole plants were sent through a wood chipper to chop the plants. A sample of the chopped plant material was collected and weighed fresh and oven dry to determine the moisture content in the plants at harvest. Samples were ground using a Wiley mill until they passed through a 2 mm sieve. The dry, ground samples were scanned by near infrared spectroscopy (NIR) with a Foss XDS machine measuring at wavelengths from 400-2500nm and using Foss ISI-scan software. Biomass composition predictions for cellulose, hemicellulose, lignin, and solubles content were based on a model developed through cooperation of Texas A&M University and National Renewable Energy Laboratory (Nilesh Dighe and Ed Wolfrum, personal communication).

Table 4.1. Hybrid and parental lines included in the 2007 and 2008 trials

		Pollen Parent Cultivars							
Seed Parent	Seed Parent per se	R.07001	R.07002	R.07003	R.07004	R.07005	R.07006	R.07010R	R.07011R
A.B05034-1-1-4	2007 2008		2008	2007 2008		2007 2008			
A.B05034-1-3-3	2008			2008					
A.B05034-1-3-4	2008	2008		2008					
A.B05034-1-4-2	2007 2008		2008	2007 2008		2007			
A.B05034-1-4-4	2007 2008		2008	2007 2008	2008	2007 2008			
A.B05035-2-1-4	2007 2008		2008	2008			2007	2007	
A.B05035-2-2-1	2007 2008	2008	2008	2007 2008		2007 2008	2007		2007
A.B05035-2-2-3	2007 2008	2008	2008	2007 2008		2007	2007		2007
A.B05035-2-2-4	2007 2008	2008	2008	2007 2008		2007 2008	2007		2007
A.B05036-4-2-4	2007 2008			2007 2008			2007		
A.B05036-4-3-4	2007 2008	2008	2008	2007 2008				2007	
A.B05037-3-1-4	2007 2008		2008			2007			
A.B05037-3-4-1	2007 2008			2008		2007		2007	2007
A.B05038-4-1-3	2007 2008	2008	2008	2008				2007	
A.B05039-3-4	2007 2008	2008	2008	2008	2007	2007			
A.B05040-3-2-1	2007 2008	2008	2008	2008	2007	2007			
A.B05042-1-3-4	2007 2008	2008	2008	2007 2008		2007			
A.B05042-1-4	2007 2008			2007			2007		
A.B05043-2-4-2	2007 2008		2008	2007 2008	2007 2008	2007			
A.B05043-2-4-4	2008	2008							
Pollen Parent Cultivars		2008	2008	2007 2008	2007	2007 2008	2007 2008	2007	2007

Statistical Analysis

The data was analyzed using SAS Proc mixed considering genotype as a fixed effect and replication and environment as random effects. Data was analyzed separately by environment and data from environments with homogeneous error variance was combined for multi-environment analysis. Orthogonal contrasts were used to detect significant differences between groups of hybrids and parental lines.

Results and Discussion

Genotype and environment effects as well as their interaction were highly significant effects for glucan, xylan, lignin, and soluble components of sweet sorghum biomass (Table 4.2). The year effect was significant for glucan and lignin concentration and highly significant for xylan concentration, but did not have a significant effect on the concentration of solubles. The effect of harvest, comparing primary and ratoon crops, also had a highly significant effect on biomass composition. While genotype effects were highly significant, orthogonal contrasts comparing the elite hybrids to their parental lines revealed no significant differences in biomass composition across years and locations.

Genotype had a significant effect on the glucan concentration in the whole plant biomass from the primary harvest across locations in 2007, but did not have a significant effect on concentration of xylan, lignin, and solubles (Table 4.3). Environmental effects were not significant for glucan, but were significant for the three other components. The genotype by environment interaction effect was significant for the concentration of all four biomass components in the whole plant samples from the primary harvest.

Table 4.2. ANOVA mean squares for sources of variance affecting whole plant biomass composition across locations and years

Source	DF	Glucan	Xylan	Lignin	Solubles
genotype	99	62.15**	6.20**	3.72**	87.35**
loc(year)	4	74.64**	26.00**	30.78**	608.23**
year	1	348.00*	523.28**	141.63*	32.37^{ns}
rep	2	19.40^{ns}	0.60^{ns}	5.79**	11.99^{ns}
loc*genotype(year)	231	9.63**	2.99**	1.44**	17.29**
harvest	2	1530.06**	82.07**	26.85**	1012.38**
residual	949	7.07	1.82	1.08	12.64

Table 4.3. ANOVA mean squares for sources of variance affecting whole plant biomass components in the 2007 primary harvest across locations

Source	df	Glucan	Xylan	Lignin	Solubles
Genotype	48	37.01**	5.14^{ns}	3.01^{ns}	58.34^{ns}
Environment	2	27.26^{ns}	19.50*	30.58**	475.80**
Rep	2	24.02^{ns}	15.94**	14.44**	199.98**
Genotype*Env	54	14.12*	4.37**	2.69**	40.29**
Residual	207	9.99	2.53	1.16	14.63

Orthogonal contrasts revealed that the experimental hybrids contain a significantly lower glucan concentration than the seed parents in Halfway and all three harvests in Weslaco in 2007 (Table 4.4). The hybrids had a greater glucan concentration than the pollen parent cultivars in Halfway and the first ratoon in Weslaco, but the hybrids and cultivars had a similar glucan concentration in the other two Weslaco harvests. The pollen parent cultivar samples were not analyzed from the College Station location due to an error in sample handling. Few significant differences in xylan concentration were detected among the hybrids and parental types. No clear trends were detected in lignin concentration among the three plant types tested. The differences are small and of little practical value. All three sorghum types were significantly different for percent solubles in Halfway and Weslaco with the hybrids intermediate to the parent types. This was consistent with observations of the juice research in Chapter III.

Table 4.4. Whole plant composition of sweet sorghum hybrids and parental lines in each location and harvest in 2007

		Glucan (%)			Xylan (%)		
Location	Harvest	Hybrids	Pollen Parents	Seed Parents	Hybrids	Pollen Parents	Seed Parents
College Station	Primary	28.75^{a}	.	33.14^{a}	13.84^{a}	.	12.68^{a}
College Station	Ratoon	25.04^{a}	.	27.04^{a}	14.76^{b}	.	15.17^{a}
Halfway	Primary	28.84^{b}	25.96^{c}	34.20^{a}	13.54^{b}	13.89^{b}	15.16^{a}
Weslaco	Primary	30.72^{b}	29.64^{b}	32.21^{a}	13.85^{a}	14.25^{a}	12.76^{b}
Weslaco	Ratoon	24.52^{b}	23.25^{c}	27.08^{a}	14.28^{b}	14.22^{b}	15.08^{a}
Weslaco	Ratoon 2	25.98^{b}	25.58^{b}	27.14^{a}	13.63^{a}	12.38^{b}	13.90^{a}

		Lignin (%)			Solubles (%)		
Location	Harvest	Hybrids	Pollen Parents	Seed Parents	Hybrids	Pollen Parents	Seed Parents
College Station	Primary	12.31^{a}	.	11.61^{a}	31.76^{a}	.	27.67^{a}
College Station	Ratoon	13.16^{a}	.	13.52^{a}	33.20^{a}	.	29.44^{a}
Halfway	Primary	10.65^{b}	10.57^{b}	12.66^{a}	36.01^{b}	38.62^{a}	24.81^{c}
Weslaco	Primary	12.84^{a}	12.68^{a}	11.93^{b}	28.01^{ab}	29.37^{a}	27.78^{b}
Weslaco	Ratoon	12.07^{b}	11.34^{c}	13.16^{a}	35.90^{b}	38.24^{a}	30.22^{c}
Weslaco	Ratoon 2	11.79^{b}	10.48^{c}	12.30^{a}	33.64^{b}	36.87^{a}	31.23^{c}

The 2008 field trials included more entries than the 2007 trials. Genotype was a highly significant effect for all four biomass components in 2008 (Table 4.5), while it was only significant for glucan concentration in the 2007 trials. Environment effects were also significant for glucan, xylan, lignin, and solubles and had a greater effect than genotype. Genotype by environment interaction was significant for all components except glucan.

Table 4.5. ANOVA mean squares for sources of variance affecting whole plant biomass components in the primary harvest in 2008 across locations

Source	df	Glucan	Xylan	Lignin	Solubles
Genotype	79	53.95**	6.48**	2.83**	51.95**
Environment	2	135.87**	32.64**	40.18**	885.17**
Rep	2	146.29**	6.71*	1.31^{ns}	116.82**
Genotype*Env	148	6.83^{ns}	2.39**	0.96*	10.54*
Residual	413	6.59	1.70	0.76	8.05

Table 4.6. Whole plant composition of sweet sorghum hybrids and parental lines by location in 2008

		Glucan (%)			Xylan (%)		
		Mean (sd)	Min	Max	Mean (sd)	Min	Max
College Station	Hybrid	29.81 (1.97)	25.95	35.25	12.46 (0.73)	11.13	13.94
	Pollen Parents	27.12 (1.85)	24.77	29.05	12.39 (0.74)	11.10	12.96
	Seed Parents	35.34 (1.56)	31.67	38.50	11.38 (0.80)	9.11	13.28
Halfway	Hybrid	32.04 (1.27)	29.91	35.19	12.80 (1.24)	9.59	15.28
	Pollen Parents	30.25 (1.05)	29.38	31.54	13.24 (0.74)	12.48	14.46
	Seed Parents	35.96 (1.15)	34.07	38.36	10.62 (1.09)	8.52	12.63
Weslaco	Hybrid	31.75 (1.53)	29.16	36.04	11.67 (0.80)	9.48	13.29
	Pollen Parents	27.93 (1.81)	26.09	30.81	12.26 (0.64)	11.62	13.16
	Seed Parents	35.43 (1.64)	32.20	38.23	10.76 (1.03)	9.07	12.56
		Lignin (%)			Solubles (%)		
		Mean (sd)	Min	Max	Mean (sd)	Min	Max
College Station	Hybrid	11.48 (0.59)	10.29	13.00	31.85 (2.74)	25.00	37.03
	Pollen Parents	10.50 (0.53)	9.72	11.12	35.64 (1.89)	33.06	38.36
	Seed Parents	10.87 (0.51)	9.76	12.19	26.22 (1.83)	22.43	31.09
Halfway	Hybrid	11.97 (0.81)	10.26	13.91	26.94 (1.71)	23.47	30.56
	Pollen Parents	12.09 (0.49)	11.45	12.61	28.76 (1.76)	26.70	30.19
	Seed Parents	10.79 (0.77)	9.50	12.31	24.78 (0.98)	22.97	26.88
Weslaco	Hybrid	10.98 (0.47)	10.04	12.22	31.10 (1.95)	26.55	34.56
	Pollen Parents	10.13 (0.61)	9.42	10.89	36.28 (2.71)	32.47	38.46
	Seed Parents	10.36 (0.66)	9.26	11.35	27.87 (1.47)	24.03	30.55

The biomass composition in the 2008 trial was similar to the 2007 trial (Table 4.6) with slightly more variation for each component due to the greater number of entries in the 2008 trials.

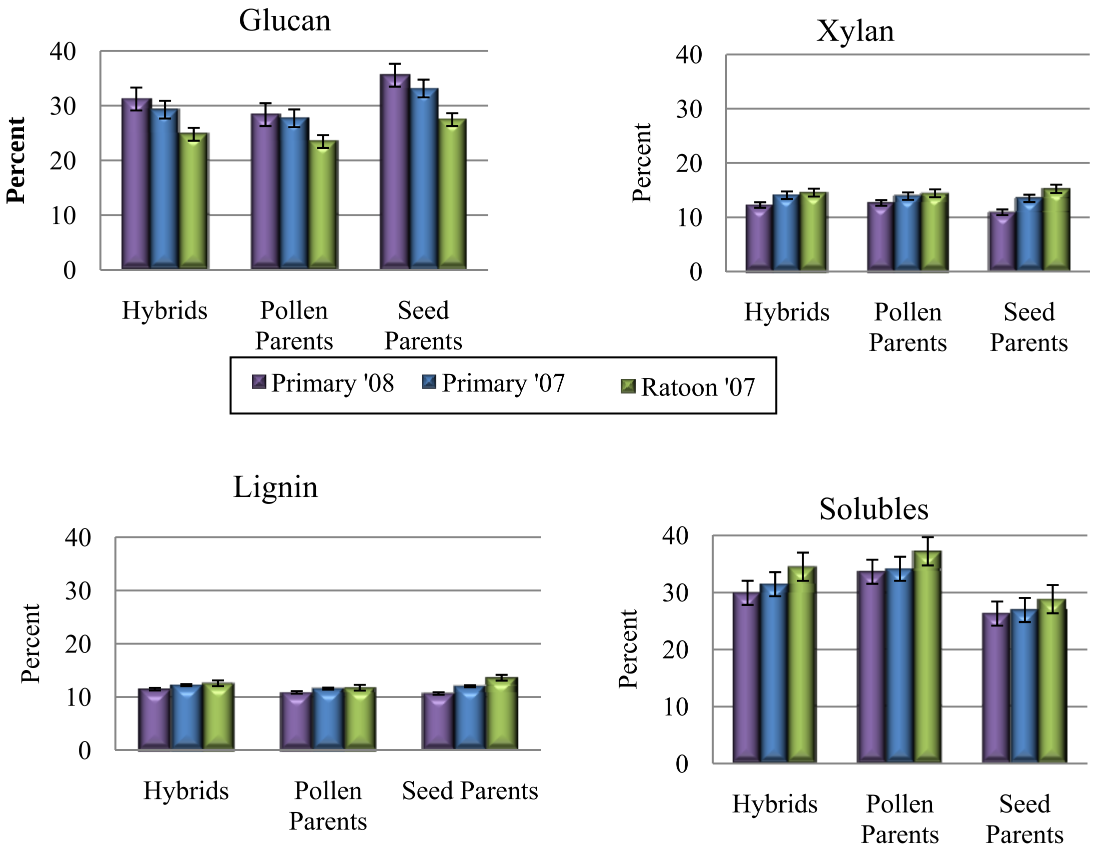

Figure 4.1. Mean percent glucan, xylan, lignin, and solubles content by plant type and harvest across environments

Conclusions

The environment had a much larger effect than genotype on the biomass composition of sweet sorghum. The genotype effect was significant for all biomass components in 2008, but was not significant for concentration of xylan, lignin, and soluble in 2007. Biomass from ratoon harvests in 2007 had reduced glucans and increased xylans and solubles compared to the primary harvest. Breeding for increased biomass yield should be a much higher priority than breeding for improved plant composition for conversion to ethanol.

CHAPTER V

CONCLUSIONS

Sweet sorghum has several advantages for use as a bioethanol feedstock. While the development of sweet sorghum as a crop lags behind maize, it is far ahead of other potential bioenergy crops like switchgrass and miscanthus in breeding for important traits as well as understanding of production and management of the crop. Production of sweet sorghum hybrids to replace traditional cultivars will overcome the seed limitation issues so adequate seed can be produced for planting on a large scale. Elite first generation sweet sorghum hybrids are similar to the traditional cultivars in biomass and sugar yield as well as sugar concentration in the stalk juice. Experimental hybrids also express high parent heterosis for these traits of interest. Higher yielding hybrids can be developed through additional selection for yield and combining ability. Agronomic traits can also be improved in future hybrids.

The traditional cultivars have higher sugar concentrations in the stalk juice than the majority of hybrids although one hybrid tested was superior to the pollen parent cultivars as well as the seed parent. The sugar profile was similar among the hybrids and pollen parent cultivars while the seed parent tested accumulated a significantly greater percentage of the monosaccharides glucose and fructose. The environment had a greater effect than genotype on sweet sorghum juice composition. The sugar in the sweet sorghum juice deteriorated rapidly and composition was greatly affected by adding a chemical biocide to control microbial growth in the juice samples in 2008, but not in 2007.

There was little variation in biomass composition among genotypes included in this trial. Environment had a greater effect than genotype on biomass composition. Breeding efforts should focus on biomass yield before selecting for altered biomass composition which may require the addition of genetic diversity from other sorghum types to introduce adequate variation.

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APPENDIX

Table A.1. Field management information

Year	Location			
2007	Weslaco			
		Soil Type	Raymondville Clay Loam	
		Previous Crop	Cotton	
		Planting Date	20-Feb	
		Fertilization	29-Jan	50 gal/A 4-10-10 + 2 qt/A Quick Boost + Awaken
			26-Mar	100-0-0 as 32-0-0
		Herbicide	21-Feb	2 pt/A Atrazine 4E
		Rainfall	Jan-June	9.75"
		Irrigation	Mar-May	12"
		Harvest	Primary	13-Jun
			Ratoon	4-Sep
			2nd Ratoon	15-Dec
2007	College Station			
		Soil Type	Ships Clay Loam	
		Previous Crop	Cotton	
		Planting Date	22-Mar	
		Fertilization	8-Feb	158 lbs 10-34-0 + 4Zn/A
			29-Apr	120 lbs N2/A
		Pesticide	22-Mar	8 lb Counter CR 20/A
			22-Mar	3 pts Atrazine 4L + 1.3 pts Dual Mag II/A
			7-May	2..5 pts Prowl H2O/A
			22-Jun	7.6 oz Asana XL/A
			10-Jul	7.6 oz Asana XL/A
		Rainfall	Mar-July	19.96"
		Irrigation	15-Jun	~3"
		Harvest	Primary	23-Jul
			Ratoon	22-Oct
2007	Halfway			
		Soil Type	Pullman Silty Clay Loam	
		Previous Crop	Cotton	
		Planting Date	12-Jun	
		Fertilization	25-Jun	120-60-0
		Pesticide	14-May	1.2 qt/A MiloPro
			14-May	1 qt/A Glystar
		Rainfall	May-Sept	13.40"
		Irrigation	4.47"	
		Harvest	18-Sep	
2008	Weslaco			
		Soil Type	Raymondville Clay Loam	
		Previous Crop	Cotton	
		Planting Date	13-Feb	
		Fertilization	9-Jan	50 gal/A 4-10-10 + 2 qt/A Quick Boost + Awaken
			17-Mar	100-0-0 as 32-0-0

Table A.1. Cont.

Year	Location			
2008	Weslaco	Pesticide	20-Mar	2 pt/A Atrazine 4E
		Rainfall	Feb-June	1.26"
		Irrigation	Feb-Mar	~18.00"
		Harvest	3-Jun	
2008	College Station			
		Soil Type	Ships Clay Loam	
		Previous Crop	Sorghum	
		Planting Date	26-Mar	
		Fertilization	8-Feb	150 lbs 10-34-0 + 4lbs Zn/A
			29-Apr	100 lbs N/A
		Pesticide	26-Mar	8 lb Counter CR 20/A
			27-Mar	2.55 pts Atrazine 4L + 1.1 pt Cinch/A
			13-May	2.66 pt Prowl H2O/A
		Rainfall	Jan-July	13.97"
		Irrigation	11-Jun	~3"
		Harvest	2-Jul	
2008	Halfway			
		Soil Type	Pullman Clay Loam	
		Previous Crop	Cotton	
		Planting Date	3-Jun	
		Fertilization	3-Jul	100-0-0
		Pesticide	1.2 qt/A MiloPro	
		Rainfall	May-Sept	10.34"
		Irrigation	May-Aug	10.5"
		Harvest	16-Sep	

Table A.2. Best linear unbiased estimator of yield traits for sweet sorghum hybrids and parental lines across years and locations

Genotype	Fresh Biomass	Dry Biomass	Brix	Sugar
	Mg ha^{-1}	Mg ha^{-1}	%	Mg ha^{-1}
Hybrids				
A.B05034-1-1/R.07003	49.93	17.50	14.68	3.53
A.B05034-1-1/R.07005	47.59	16.86	15.38	3.54
A.B05034-1-1-4/R.07002	50.74	17.04	13.84	3.32
A.B05034-1-3-3/R.07003	50.52	16.72	13.45	3.33
A.B05034-1-3-4/R.07001	49.80	16.31	13.93	3.40
A.B05034-1-3-4/R.07003	54.43	19.52	13.06	3.37
A.B05034-1-4-2/R.07002	46.55	16.06	14.55	2.97
A.B05034-1-4-2/R.07003	43.36	15.15	13.60	2.68
A.B05034-1-4-2/R.07003	56.07	21.09	13.06	2.99
A.B05034-1-4-4/R.07002	47.24	16.62	14.78	2.74
A.B05034-1-4-4/R.07003	42.95	15.15	13.08	2.51
A.B05034-1-4-4/R.07004	40.32	14.53	14.16	2.48
A.B05034-1-4-4/R.07005	52.12	18.03	14.80	3.58
A.B05035-2-1/R.07006	48.06	17.12	15.52	3.62
A.B05035-2-1/R.07010R	50.83	17.65	15.05	3.87
A.B05035-2-1-4/R.07002	53.80	19.12	14.49	3.68
A.B05035-2-1-4/R.70703	46.98	16.17	14.41	3.04
A.B05035-2-2/R.07003	44.71	15.15	13.37	3.04
A.B05035-2-2/R.07005	51.63	18.03	14.41	3.69
A.B05035-2-2/R.07005	47.28	16.69	14.70	3.27
A.B05035-2-2/R.07006	72.89	26.31	12.26	3.74
A.B05035-2-2/R.07011R	64.32	18.90	14.19	4.69
A.B05035-2-2-1/R.07001	44.17	14.53	14.47	2.87
A.B05035-2-2-1/R.07002	51.09	17.20	13.75	3.37
A.B05035-2-2-1/R.07003	49.24	17.61	12.90	3.13
A.B05035-2-2-3/R.07001	59.51	19.25	14.19	4.69
A.B05035-2-2-3/R.07002	53.02	18.25	14.59	3.67
A.B05035-2-2-3/R.07003	46.98	17.46	13.31	3.04
A.B05035-2-2-4/R.07001	54.09	18.91	14.61	3.74
A.B05035-2-2-4/R.07002	50.30	17.32	14.30	3.27
A.B05035-4-2/R.07006	60.12	22.11	15.96	5.04
A.B05036-4-2-4/R.07003	45.45	16.15	13.15	2.70
A.B05036-4-3/R.07010R	51.45	18.46	16.91	4.43
A.B05036-4-3-4/R.07001	44.16	16.19	14.56	2.71
A.B05036-4-3-4/R.07002	50.31	17.58	14.15	3.19
A.B05036-4-3-4/R.07003	45.49	16.00	14.43	2.98
A.B05037-3-1/R.07005	53.45	19.70	14.53	3.82
A.B05037-3-1/R.07011R	101.37	33.22	15.09	7.29
A.B05037-3-4/R.07005	56.59	20.13	14.67	3.23
A.B05037-3-4/R.07010R	57.23	18.79	14.09	3.69
A.B05037-3-4-1/R.07003	38.26	11.47	15.48	2.78
A.B05038-4-1/R.07010R	73.34	24.43	14.14	4.64
A.B05038-4-1-3/R.07001	41.12	14.76	16.06	2.79
A.B05039-3-4/R.07001	40.04	14.45	14.98	2.67
A.B05039-3-4/R.07002	45.10	15.87	15.66	3.32
A.B05040-3/R.07004	59.67	22.31	14.63	4.46
A.B05040-3/R.07005	66.48	20.88	14.44	4.42

Table A.2. Cont.

Genotype	Fresh Biomass Mg ha^{-1}	Dry Biomass Mg ha^{-1}	Brix %	Sugar Mg ha^{-1}
A.B05040-3-2-1/R.07001	49.68	18.10	15.61	3.36
A.B05040-3-2-1/R.07002	59.58	21.21	15.33	4.86
A.B05040-3-2-1/R.07003	47.53	16.48	13.74	3.04
A.B05042-1-3/R.07005	49.65	14.89	12.79	3.03
A.B05042-1-3-4/R.07003	53.14	17.49	13.22	3.64
A.B05042-1-4/R.07003	45.70	15.83	14.70	3.33
A.B05042-1-4/R.07006	60.65	19.52	14.81	4.10
A.B05043-2-4/R.07003	64.32	22.15	16.36	4.95
A.B05043-2-4/R.07006	60.43	23.03	14.79	3.72
A.B05043-2-4-2/R.07002	42.70	15.37	16.06	2.94
A.B05043-2-4-2/R.07003	47.05	17.53	15.13	3.29
A.B05043-2-4-2/R.07005	55.76	18.88	13.73	3.85
Pollen Parent Cultivars				
R.07004	56.86	19.29	13.31	4.11
R.07001	47.27	16.74	15.30	3.54
R.07002	47.69	15.02	15.30	3.59
R.07003	53.40	17.58	15.30	4.40
R.07005	58.65	21.42	16.92	4.85
R.07006	63.31	20.35	16.51	5.86
R.07010R	59.30	20.72	16.78	5.08
R.07011R	88.23	32.74	15.30	5.50
Seed Parents				
B.05034-1-3-4-1	23.30	9.77	12.92	1.13
B.05034-1-1-4-4	26.26	10.45	12.32	1.41
B.05034-1-3-4-2	26.05	9.77	12.27	1.31
B.05034-1-4-2-3	27.99	10.87	13.83	1.54
B.05034-1-4-2-4	20.98	8.27	12.99	1.04
B.05034-1-4-4-1	26.34	10.39	12.81	1.30
B.05034-1-4-4-2	23.80	9.48	13.26	1.15
B.05035-1-3-4-2	23.52	9.14	12.51	1.37
B.05035-2-1-4-1	33.70	12.76	13.89	2.10
B.05035-2-2-1-1	35.03	12.27	14.07	2.17
B.05035-2-2-1-2	33.61	13.10	14.22	1.98
B.05035-2-2-3-1	31.87	12.41	13.23	1.84
B.05035-2-2-3-2	34.16	12.01	12.36	1.81
B.05035-2-2-4-3	30.69	11.15	13.76	1.88
B.05036-4-2-4-2	20.62	8.36	13.58	1.03
B.05036-4-2-4-3	19.57	7.92	13.74	0.95
B.05036-4-2-4-3	19.48	7.52	13.55	0.99
B.05036-4-3-4-2	24.10	9.33	12.33	1.29
B.05036-4-3-4-3	26.24	10.79	12.76	1.32
B.05037-3-1	31.34	11.74	11.08	1.55
B.05037-3-4-1-4	30.53	11.96	12.69	1.73
B.05038-4-1-3-2	35.66	13.88	11.71	1.77
B.05038-4-1-3-3	32.60	12.30	12.24	1.76
B.05039	35.88	12.94	11.28	1.98
B.05040-3-2-1-1	31.46	11.41	11.72	1.72
B.05040-3-2-1-2	32.97	12.13	11.53	1.75
B.05042-1-3-4-2	31.09	15.77	12.49	1.61
B.05042-1-4	31.48	12.30	13.00	1.78
B.05043-2-4-4	26.54	10.63	11.98	1.39
Minimum	19.48	7.52	11.08	0.95
Maximum	101.37	33.22	16.92	7.29
Mean	45.71	16.19	14.03	3.03
Standard Deviation	14.61	4.67	1.29	1.24

Table A.3. BLUE of yield traits of sweet sorghum hybrids and parental lines across locations in 2007

Genotype	Fresh Biomass Mg ha^{-1}	Dry Biomass Mg ha^{-1}	Brix %	Sugar Mg ha^{-1}
Hybrids				
A.B05034/1-4/R.07003	32.71	11.18	12.37	2.19
A.B05034-1-1/R.07003	55.70	20.74	14.50	4.18
A.B05034-1-1/R.07005	48.19	17.93	14.97	3.80
A.B05034-1-4/R.07003	53.16	20.56	12.19	3.23
A.B05034-1-4/R.07005	46.10	17.39	13.28	3.15
A.B05035-2-1/R.07006	51.10	18.98	14.96	3.81
A.B05035-2-1/R.07010R	53.87	19.51	14.49	4.06
A.B05035-2-2/R.07003	44.51	15.04	14.26	3.35
A.B05035-2-2/R.07005	51.54	18.98	13.27	3.56
A.B05035-2-2/R.07005	45.72	16.71	13.62	3.24
A.B05035-2-2/R.07006	66.23	23.10	12.54	4.09
A.B05035-2-2/R.07011R	57.66	15.69	14.47	5.05
A.B05036-4-2/R.07003	48.67	15.86	12.70	3.20
A.B05036-4-2/R.07006	63.16	23.96	15.40	5.23
A.B05036-4-3/R.07003	34.75	11.64	12.00	2.30
A.B05036-4-3/R.07010R	54.49	20.31	16.34	4.62
A.B05037-3-1/R.70705	56.49	21.55	13.97	4.01
A.B05037-3-4/R.07005	53.69	19.59	13.81	3.47
A.B05037-3-4/R.07010R	54.33	18.26	13.23	3.93
A.B05037-3-4/R.07011R	94.71	30.01	15.37	7.64
A.B05038-4-1/R.07010R	70.44	23.89	13.28	4.88
A.B05040-3/R.07004	62.71	24.16	14.07	4.65
A.B05040-3/R.07005	63.58	20.35	13.58	4.66
A.B05042-1-3/R.07003	56.18	19.35	12.66	3.83
A.B05042-1-3/R.07005	42.99	11.68	13.07	3.38
A.B05042-1-4/R.07003	48.74	17.68	14.13	3.52
A.B05042-1-4/R.07006	57.75	18.99	13.94	4.34
A.B05043-2-4/R.07003	64.55	24.87	15.03	4.75
A.B05043-2-4/R.07003	57.66	18.94	16.64	5.30
A.B05043-2-4/R.07005	51.13	13.71	14.57	4.24
A.B05043-2-4/R.07006	57.53	22.49	13.93	3.96
Pollen Parent Cultivars				
R.07003	56.32	19.87	16.19	4.80
R.07004	56.47	19.71	13.20	4.04
R.07005	59.83	24.13	16.81	4.93
R.07006	51.90	18.73	16.78	4.63
R.07010R	58.92	21.14	16.67	5.00
Seed Parents				
B.005037-3-1-4	29.98	11.61	11.74	1.80
B.05034-1-1-4	24.56	9.77	11.92	1.47
B.05034-1-4-4	20.59	8.56	12.59	1.43
B.05035-2-1-4	31.69	11.48	14.00	2.24
B.05035-2-2-3	30.94	12.58	13.01	1.96
B.05035-2-2-4	29.41	10.87	13.51	1.99
B.05036-4-2-4	22.96	8.66	11.99	1.43
B.05036-4-3-4	19.74	6.93	11.52	1.18
B.05038-4-1-3	34.50	12.14	11.88	2.25
B.05040-3-2-1	30.74	10.53	10.77	1.83
B.05042-1-3-4	31.48	12.86	11.22	1.75
B.05042-1-4-4	31.31	12.42	12.77	1.95
B.05043-2-4-4	26.12	11.01	11.40	1.43

Table A.3. Cont.

Genotype	Fresh Biomass	Dry Biomass	Brix	Sugar
	Mg ha^{-1}	Mg ha^{-1}	%	Mg ha^{-1}
Minimum	19.74	6.93	10.77	1.18
Maximum	94.71	30.01	16.81	7.64
Mean	47.91	17.06	13.69	3.50
SD	15.20	5.20	1.56	1.36

Table A.4. BLUE of yield traits of sweet sorghum hybrids and parental lines in 2007 at Weslaco

Genotype	Fresh Biomass Mg ha^{-1}	Dry Biomass Mg ha^{-1}	Brix %	Sugar Mg ha^{-1}	Immature Grain kg ha^{-1}
Hybrids					
A.B05034-1-1/R.07003	40.03	15.08	14.93	3.00	4373.60
A.B05034-1-1/R.07005	26.69	9.13	14.77	2.09	3256.00
A.B05034-1-4/R.07003	43.82	14.94	13.33	3.09	4903.00
A.B05034-1-4/R.07005	31.30	9.99	13.70	2.36	3796.79
A.B05035-2-1/R.07006	31.63	12.50	15.43	2.37	3228.34
A.B05035-2-1/R.07010R	37.56	13.74	14.57	2.79	3465.77
A.B05035-2-2/R.07003	35.91	12.08	15.27	2.94	3777.71
A.B05035-2-2/R.07005	36.74	13.49	14.70	2.77	4302.62
A.B05035-2-2/R.07005	36.57	12.64	14.60	2.81	4500.43
A.B05036-4-2/R.07006	31.46	11.26	14.43	2.34	2971.81
A.B05036-4-3/R.07010R	35.75	12.71	13.87	2.58	3786.16
A.B05037-3-1/R.70705	39.37	13.48	14.37	3.00	4431.15
A.B05037-3-4/R.07005	38.55	14.61	15.00	2.33	3445.15
A.B05037-3-4/R.07010R	42.50	12.35	14.40	3.47	2808.74
A.B05038-4-1/R.07010R	46.46	16.66	14.10	3.38	3959.05
A.B05040-3/R.07004	38.38	14.12	13.77	2.71	5274.90
A.B05040-3/R.07005	47.94	14.75	15.07	4.07	4569.59
A.B05042-1-3/R.07003	47.11	14.88	13.83	3.59	3898.49
A.B05042-1-4/R.07003	37.89	15.56	14.43	2.60	3661.84
A.B05042-1-4/R.07006	38.22	13.67	14.77	2.94	3620.44
A.B05043-2-4/R.07003	47.11	15.20	15.20	3.90	4677.71
A.B05043-2-4/R.07006	41.84	13.26	14.83	3.41	3514.26
Pollen Parent Cultivars					
R.07003	42.01	13.35	15.83	3.66	3017.09
R.07004	34.10	12.06	13.70	2.44	2639.65
R.07005	36.74	13.21	16.47	3.11	2539.54
R.07006	33.77	11.57	16.33	2.95	1772.82
R.07010R	43.00	13.57	16.40	3.89	2886.75
Seed Parents					
B.005037-3-1-4	31.46	9.75	14.03	2.45	2750.95
B.05034-1-1-4	23.23	9.02	14.63	1.68	2967.85
B.05034-1-4-4	22.57	8.53	14.30	1.62	3212.59
B.05035-2-1-4	31.63	11.01	14.73	2.45	4219.99
B.05035-2-2-3	28.50	9.65	15.10	2.29	4405.19
B.05035-2-2-4	24.22	9.02	15.27	1.87	2947.60
B.05036-4-2-4	16.47	5.91	13.53	1.14	2964.45
B.05036-4-3-4	21.09	8.26	14.53	1.50	3828.52
B.05038-4-1-3	32.62	10.71	12.97	2.28	3262.99
B.05040-3-2-1	31.79	9.80	13.93	2.48	2419.49
B.05042-1-3-4	29.65	10.17	14.37	2.25	3391.83
B.05042-1-4-4	27.84	9.45	13.73	2.04	3383.02
B.05043-2-4-4	24.22	10.13	14.03	1.59	3069.80

Table A.4. Cont.

Genotype	Fresh Biomass Mg ha^{-1}	Dry Biomass Mg ha^{-1}	Brix %	Sugar Mg ha^{-1}	Immature Grain kg ha^{-1}
Minimum	16.47	5.91	12.97	1.14	1772.82
Maximum	47.94	16.66	16.47	4.07	5274.90
Mean	34.69	12.03	14.58	2.65	3547.59
Standard Deviation	7.71	2.45	0.81	0.69	751.75

Table A.5. BLUE of yield traits of sweet sorghum hybrids and parental lines in 2007 at College Station

Genotype	Fresh Biomass Mg ha^{-1}	Dry Biomass Mg ha^{-1}	Brix %	Sugar Mg ha^{-1}	Immature Grain kg ha^{-1}
Hybrids					
A.B05034/1-4/R.07003	48.94	18.78	10.60	2.60	2686.24
A.B05034-1-1/R.07003	74.74	28.82	12.40	4.60	5361.62
A.B05034-1-1/R.07005	63.82	25.75	12.57	4.00	3401.85
A.B05034-1-4/R.07003	67.03	28.75	10.17	3.12	4356.30
A.B05034-1-4/R.07005	65.43	27.36	11.97	3.69	4861.10
A.B05035-2-1/R.07006	76.24	28.53	12.60	4.76	2950.83
A.B05035-2-1/R.07010R	72.39	26.70	13.60	5.03	3607.75
A.B05035-2-2/R.07003	48.19	15.74	9.37	2.34	3257.46
A.B05035-2-2/R.07005	62.75	24.14	10.93	3.48	4470.95
A.B05035-2-2/R.07005	53.75	21.09	10.10	2.63	3884.24
A.B05035-2-2/R.07006	82.45	30.70	10.77	4.50	3012.59
A.B05035-2-2/R.07011R	73.88	23.29	12.70	5.46	443.40
A.B05036-4-2/R.07003	64.89	23.46	10.93	3.60	3623.31
A.B05036-4-2/R.07006	83.95	34.71	14.00	5.64	5083.71
A.B05036-4-3/R.07003	50.97	19.23	10.23	2.71	2522.60
A.B05036-4-3/R.07010R	74.96	29.76	13.83	5.03	4541.12
A.B05037-3-1/R.70705	71.96	30.82	13.00	4.32	3601.58
A.B05037-3-4/R.07005	73.35	27.14	11.73	4.36	3295.65
A.B05037-3-4/R.07010R	70.67	26.73	11.17	4.13	1923.09
A.B05037-3-4/R.07011R	110.93	37.61	13.60	8.05	1254.80
A.B05038-4-1/R.07010R	98.94	33.69	11.57	6.12	3721.20
A.B05040-3/R.07004	86.95	36.39	13.27	5.88	3642.76
A.B05040-3/R.07005	83.74	28.52	11.20	4.99	3623.41
A.B05042-1-3/R.07003	77.31	27.73	10.77	4.58	5537.91
A.B05042-1-3/R.07005	59.21	19.28	11.30	3.79	1492.60
A.B05042-1-4/R.07003	67.89	23.33	11.70	4.30	4114.56
A.B05042-1-4/R.07006	81.81	26.87	12.23	5.49	2543.62
A.B05043-2-4/R.07003	102.15	43.88	13.67	6.40	5931.45
A.B05043-2-4/R.07003	73.88	26.54	14.87	5.71	4410.32
A.B05043-2-4/R.07005	67.35	21.31	12.80	4.65	3199.54
A.B05043-2-4/R.07006	77.74	34.29	12.13	4.25	1748.75
Pollen Parent Cultivars					
R.07003	81.81	30.45	14.83	6.17	2757.88
R.07004	70.46	24.39	11.60	4.30	1369.82
R.07005	95.09	42.50	15.63	6.93	1645.71
R.07006	67.67	25.65	14.33	4.90	578.75
R.07010R	91.45	35.03	14.07	6.46	3218.10
R.07011R	99.16	38.23	12.70	6.25	1029.05
Seed Parents					
B.005037-3-1-4	39.62	18.49	11.33	1.94	3475.62
B.05034-1-1-4	30.20	13.19	11.43	1.57	3136.31

Table A.5. Cont.

Genotype	Fresh Biomass Mg ha^{-1}	Dry Biomass Mg ha^{-1}	Brix %	Sugar Mg ha^{-1}	Immature Grain kg ha^{-1}
B.05034-1-4-4	23.13	11.16	10.00	0.99	2507.95
B.05035-2-1-4	40.90	15.55	11.70	2.40	5021.95
B.05035-2-2-3	41.12	19.96	11.23	1.93	4957.60
B.05035-2-2-4	40.90	15.51	11.80	2.45	3235.14
B.05036-4-2-4	29.77	12.15	10.00	1.41	3143.14
B.05036-4-3-4	26.23	8.37	9.50	1.39	3039.28
B.05038-4-1-3	40.90	16.14	9.90	1.97	3013.72
B.05040-3-2-1	37.26	13.69	10.87	2.04	3909.24
B.05042-1-3-4	44.12	21.18	10.43	1.93	4693.90
B.05042-1-4-4	44.44	20.24	11.10	2.18	2894.51
B.05043-2-4-4	36.41	16.69	10.40	1.65	2494.45
Minimum	23.13	8.37	9.37	0.99	443.40
Maximum	110.93	43.88	15.63	8.05	5931.45
Mean	64.98	24.99	11.89	3.98	3284.57
Standard Deviation	21.45	8.14	1.52	1.71	1273.48

Table A.6. BLUE of yield traits of sweet sorghum hybrids and parental lines in 2007 at Halfway

Genotype	Fresh Biomass Mg ha^{-1}	Dry Biomass Mg ha^{-1}	Brix %	Sugar Mg ha^{-1}	Immature Grain kg ha^{-1}
Hybrids					
A.B05034-1-1/R.07003	52.34	18.32	16.17	4.93	3774.53
A.B05034-1-1/R.07005	54.06	18.92	17.57	5.33	2762.97
A.B05035-2-1/R.07006	45.42	15.90	16.83	4.30	1513.96
A.B05035-2-1/R.07010R	51.66	18.08	15.30	4.38	2073.86
A.B05035-2-2/R.07003	49.44	17.30	18.13	4.77	2769.31
A.B05035-2-2/R.07005	55.15	19.30	14.17	4.44	2116.99
A.B05035-2-2/R.07005	46.84	16.39	16.17	4.29	1822.35
A.B05036-4-2/R.07006	74.07	25.93	17.77	7.72	2404.06
A.B05036-4-3/R.07010R	52.75	18.46	21.33	6.25	2168.02
A.B05037-3-1/R.70705	58.14	20.35	14.53	4.72	3466.46
A.B05040-3/R.07004	62.79	21.98	15.17	5.36	2336.54
A.B05042-1-3/R.07003	44.10	15.44	13.37	3.32	2068.36
A.B05042-1-4/R.07003	40.44	14.15	16.27	3.68	3094.95
A.B05043-2-4/R.07003	44.37	15.53	16.23	3.95	3381.63
Pollen Parent Cultivars					
R.07003	45.15	15.80	17.90	4.57	1128.05
R.07004	64.85	22.70	14.30	5.37	1262.38
R.07005	47.66	16.68	18.33	4.76	325.41
R.07006	54.25	18.99	19.67	6.05	279.74
R.07010R	42.31	14.81	19.53	4.66	1470.27
Seed Parents					
B.005037-3-1-4	18.87	6.60	9.87	1.02	1707.50
B.05034-1-1-4	20.26	7.09	9.70	1.15	2429.64
B.05035-2-1-4	22.54	7.89	15.57	1.87	2779.58
B.05035-2-2-3	23.21	8.12	12.70	1.66	2371.58
B.05035-2-2-4	23.10	8.09	13.47	1.67	2309.27
B.05036-4-2-4	22.63	7.92	12.43	1.73	2440.06
B.05036-4-3-4	11.91	4.17	10.53	0.64	1422.36
B.05040-3-2-1	23.18	8.11	7.50	0.98	1589.14
B.05042-1-3-4	20.67	7.23	8.87	1.05	2762.98
B.05042-1-4-4	21.64	7.57	13.47	1.63	1162.90
B.05043-2-4-4	17.75	6.21	9.77	1.05	1917.90
Minimum	40.44	14.15	13.37	3.32	279.74
Maximum	74.07	25.93	21.33	7.72	3774.53
Mean	51.88	18.16	16.78	4.89	2116.83
Standard Deviation	16.90	5.92	3.47	1.94	836.67

Table A.7. BLUE of yield traits of sweet sorghum hybrids and parental lines across locations in 2008

Genotype	Fresh Biomass Mg ha^{-1}	Dry Biomass Mg ha^{-1}	Brix %	Sugar Mg ha^{-1}
Hybrids				
A.B05034-1-1-4/R.07002	44.86	14.29	14.41	2.89
A.B05034-1-1-4/R.07003	43.20	14.49	14.74	2.81
A.B05034-1-1-4/R.07005	43.96	14.30	15.38	2.95
A.B05034-1-3-3/R.07003	44.36	13.79	14.14	2.86
A.B05034-1-3-4/R.07001	44.03	13.69	14.47	2.93
A.B05034-1-3-4/R.07003	48.28	16.54	13.87	3.00
A.B05034-1-4-2/R.07002	43.21	14.88	14.91	2.78
A.B05034-1-4-2/R.07003	40.48	13.90	14.25	2.54
A.B05034-1-4-4/R.07002	42.75	14.37	15.07	2.53
A.B05034-1-4-4/R.07003	41.53	14.51	14.11	2.63
A.B05034-1-4-4/R.07004	37.65	12.91	14.64	2.34
A.B05034-1-4-4/R.07005	48.51	16.03	15.39	3.48
A.B05035-2-1-4/R.07002	47.28	15.79	14.87	3.15
A.B05035-2-1-4/R.07003	42.59	14.11	14.81	2.74
A.B05035-2-2-1/R.07001	40.42	12.95	14.85	2.61
A.B05035-2-2-1/R.07002	44.73	14.05	14.35	2.89
A.B05035-2-2-1/R.07003	44.23	15.03	13.76	2.80
A.B05035-2-2-1/R.07005	47.44	15.22	15.21	3.33
A.B05035-2-2-3/R.07001	51.84	16.33	14.66	3.88
A.B05035-2-2-3/R.07002	46.57	15.11	14.93	3.13
A.B05035-2-2-3/R.07003	43.60	15.81	14.05	2.76
A.B05035-2-2-4/R.07001	46.10	14.42	14.95	3.06
A.B05035-2-2-4/R.07002	43.74	13.74	14.73	2.78
A.B05035-2-2-4/R.07003	42.84	14.30	13.07	2.62
A.B05035-2-2-4/R.07005	45.54	15.08	15.37	2.99
A.B05036-4-2-4/R.07003	36.22	12.77	14.11	2.21
A.B05036-4-3-4/R.07001	43.91	14.94	14.30	2.95
A.B05036-4-3-4/R.07002	40.58	14.12	14.91	2.52
A.B05036-4-3-4/R.07003	45.20	15.21	14.63	2.87
A.B05037-3-1-4/R.07002	41.66	13.48	15.45	2.85
A.B05037-3-4-1/R.07003	36.27	11.10	15.56	2.55
A.B05038-4-1-3/R.07002	38.05	12.90	15.96	2.53
A.B05039-3-4/R.07001	37.94	13.30	15.21	2.51
A.B05039-3-4/R.07002	41.24	13.71	15.88	2.95
A.B05039-3-4/R.07003	37.96	12.86	14.82	2.50
A.B05040-3-2-1/R.07001	43.90	14.76	15.65	2.89
A.B05040-3-2-1/R.07002	50.32	16.13	15.45	3.84
A.B05040-3-2-1/R.07003	42.34	13.73	14.34	2.68
A.B05043-2-4-2/R.07002	38.82	12.96	15.96	2.60
A.B05043-2-4-2/R.07003	40.49	14.27	14.97	2.69
A.B05043-2-4-2/R.07005	47.65	15.56	14.21	3.20
A.B05043-2-4-4/R.07001	36.50	12.56	14.37	2.32
Pollen Parent Cultivars				
R.07001	43.58	13.86	16.15	3.09
R.07002	42.80	11.84	15.32	3.02
R.07003	44.92	12.64	16.10	3.29
R.07005	48.74	13.71	16.47	3.70
R.07006	60.69	15.46	15.66	5.22
Seed Parents				
B.05034-1-1-4-4	31.21	12.12	13.24	1.72
B.05034-1-3-4-1	29.48	12.63	13.74	1.65
B.05034-1-3-4-2	31.31	12.52	13.29	1.76

Table A.7. Cont.

Genotype	Fresh Biomass Mg ha^{-1}	Dry Biomass Mg ha^{-1}	Brix %	Sugar Mg ha^{-1}
B.05034-1-4-2-3	32.25	12.81	14.38	1.88
B.05034-1-4-2-4	28.29	12.12	13.80	1.64
B.05034-1-4-4-1	32.06	12.67	13.78	1.88
B.05034-1-4-4-2	30.47	13.03	13.99	1.73
B.05035-2-1-4-1	37.08	14.24	13.98	2.17
B.05035-2-2-1-1	37.61	14.00	14.55	2.34
B.05035-2-2-1-2	36.15	14.10	14.65	2.16
B.05035-2-2-3-1	35.68	13.73	13.75	2.08
B.05035-2-2-3-2	37.78	14.55	13.36	2.17
B.05035-2-2-4-3	34.57	12.76	14.14	2.05
B.05036-4-2-4-2	27.30	11.52	14.21	1.56
B.05036-4-2-4-3	27.44	12.04	14.32	1.59
B.05036-4-2-4-3	27.10	11.56	14.19	1.59
B.05036-4-3-4-2	32.31	13.16	13.54	1.83
B.05036-4-3-4-3	31.87	13.54	13.64	1.81
B.05037-3-4-1-4	33.08	12.54	13.89	1.90
B.05038-4-1-3-2	34.97	13.38	12.83	1.89
B.05038-4-1-3-3	34.53	12.79	13.27	1.93
B.05039	36.78	13.12	12.60	2.07
B.05040-3-2-1-1	33.71	12.38	13.20	1.86
B.05040-3-2-1-2	35.26	13.11	12.77	1.97
B.05042-1-3-4-2	34.35	17.83	13.98	1.93
B05037-3-1	35.23	13.89	12.47	1.94
B05042-1-4	34.07	12.97	13.60	1.93
B05043-2-4-4	30.52	11.60	13.14	1.74
Minimum	27.10	11.10	12.47	1.56
Maximum	60.69	17.83	16.47	5.22
Mean	39.63	13.79	14.44	2.54
SD	6.56	1.31	0.90	0.65

Table A.8. BLUE of yield traits of sweet sorghum hybrids and parental lines in Weslaco in 2008

Genotype	Fresh Biomass Mg ha^{-1}	Dry Biomass Mg ha^{-1}	Brix %	Sugar Mg ha^{-1}
Hybrids				
A.B05034-1-1-4/R.07002	38.47	11.78	13.21	2.86
A.B05034-1-1-4/R.07003	34.58	11.20	13.78	2.48
A.B05034-1-1-4/R.07005	30.32	10.66	13.76	2.39
A.B05034-1-3-3/R.07003	33.31	10.98	13.16	2.53
A.B05034-1-3-4/R.07001	29.62	10.43	12.82	2.07
A.B05034-1-3-4/R.07003	34.25	11.43	13.18	2.26
A.B05034-1-4-2/R.07002	33.44	11.51	13.72	2.08
A.B05034-1-4-2/R.07003	31.64	11.37	13.84	2.14
A.B05034-1-4-4/R.07002	34.37	12.00	13.88	1.91
A.B05034-1-4-4/R.07003	34.32	11.03	13.52	2.18
A.B05034-1-4-4/R.07004	26.33	9.65	13.11	1.83
A.B05034-1-4-4/R.07005	34.08	8.80	14.01	2.63
A.B05035-2-1-4/R.07002	35.47	11.58	14.13	2.73
A.B05035-2-1-4/R.07003	34.15	11.25	14.07	2.51
A.B05035-2-2-1/R.07001	29.81	10.14	14.00	2.39
A.B05035-2-2-1/R.07002	38.60	13.00	13.11	2.81
A.B05035-2-2-1/R.07003	36.66	13.80	13.64	2.45
A.B05035-2-2-1/R.07005	34.53	11.93	13.83	2.59
A.B05035-2-2-3/R.07001	31.90	11.37	13.69	2.08
A.B05035-2-2-3/R.07002	37.06	12.38	13.69	2.76
A.B05035-2-2-3/R.07003	38.37	13.28	13.42	2.18
A.B05035-2-2-4/R.07001	31.59	11.89	13.12	2.38
A.B05035-2-2-4/R.07002	38.63	12.44	12.97	2.87
A.B05035-2-2-4/R.07003	38.50	11.82	13.15	2.79
A.B05035-2-2-4/R.07005	32.44	11.61	13.97	2.50
A.B05036-4-2-4/R.07003	29.34	9.93	12.96	1.90
A.B05036-4-3-4/R.07001	20.80	8.67	13.26	1.15
A.B05036-4-3-4/R.07002	33.34	11.67	14.05	2.45
A.B05036-4-3-4/R.07003	34.46	11.38	14.08	2.52
A.B05037-3-1-4/R.07002	36.85	12.43	14.60	3.18
A.B05037-3-4-1/R.07003	35.91	9.06	14.14	3.22
A.B05038-4-1-3/R.07002	31.83	11.20	14.45	2.72
A.B05039-3-4/R.07001	27.52	9.96	13.86	2.02
A.B05039-3-4/R.07002	31.77	11.01	14.56	2.66
A.B05039-3-4/R.07003	26.70	8.89	14.03	2.19
A.B05040-3-2-1/R.07001	31.36	11.51	13.23	2.29
A.B05040-3-2-1/R.07002	39.22	13.68	14.35	3.26
A.B05040-3-2-1/R.07003	34.78	11.72	13.38	2.56
A.B05043-2-4-2/R.07002	33.16	11.39	14.76	3.00
A.B05043-2-4-2/R.07003	32.50	11.04	14.08	2.37
A.B05043-2-4-2/R.07005	36.79	12.09	14.11	2.88
A.B05043-2-4-4/R.07001	23.84	8.38	13.43	1.86
Pollen Parent Cultivars				
R.07001	31.15	11.13	14.89	2.86

Table A.8. Cont.

Genotype	Fresh Biomass Mg ha^{-1}	Dry Biomass Mg ha^{-1}	Brix %	Sugar Mg ha^{-1}
R.07002	38.85	11.25	13.41	3.69
R.07003	40.54	11.43	14.35	4.17
R.07005	39.25	12.08	14.43	4.22
R.07006	44.45	13.30	13.54	4.55
Seed Parents				
B.05034-1-1-4-4	23.17	9.18	12.75	1.40
B.05034-1-3-4-1	17.33	7.80	13.66	0.87
B.05034-1-3-4-2	21.76	8.82	12.87	1.08
B.05034-1-4-2-3	24.11	8.59	13.66	1.60
B.05034-1-4-2-4	14.46	6.64	13.80	0.64
B.05034-1-4-4-1	22.47	9.05	13.52	1.19
B.05034-1-4-4-2	15.39	7.17	14.67	0.69
B.05035-2-1-4-1	23.70	9.60	13.79	1.50
B.05035-2-2-1-1	25.22	10.49	14.19	1.44
B.05035-2-2-1-2	27.27	10.56	13.98	1.77
B.05035-2-2-3-1	23.94	9.72	13.01	1.16
B.05035-2-2-3-2	24.50	9.44	13.65	1.22
B.05035-2-2-4-3	27.38	10.23	13.73	1.78
B.05036-4-2-4-2	10.57	5.25	14.47	0.65
B.05036-4-2-4-3	14.64	6.84	14.10	0.64
B.05036-4-2-4-3	12.05	5.79	14.22	0.58
B.05036-4-3-4-2	20.27	9.21	13.52	1.07
B.05036-4-3-4-3	15.97	7.84	14.15	0.71
B.05037-3-4-1-4	25.34	10.19	14.04	1.79
B.05038-4-1-3-2	26.76	10.34	12.83	1.67
B.05038-4-1-3-3	26.05	8.98	12.83	1.85
B.05039	26.72	9.77	13.06	1.83
B.05040-3-2-1-1	26.79	10.14	12.80	1.81
B.05040-3-2-1-2	26.54	9.80	13.19	1.65
B.05042-1-3-4-2	23.34	9.75	14.23	1.27
B05037-3-1	29.49	10.94	13.21	1.46
B05042-1-4	23.72	9.51	13.51	1.43
B05043-2-4-4	22.03	8.35	13.53	1.52
Minimum	10.57	5.25	12.75	0.58
Maximum	44.45	13.80	14.89	4.55
Mean	29.44	10.41	13.70	2.11
SD	7.34	1.76	0.53	0.85

Table A.9. BLUE of yield traits of sweet sorghum hybrids and parental lines in College Station in 2008

Genotype	Fresh Biomass Mg ha^{-1}	Dry Biomass Mg ha^{-1}	Brix %	Sugar Mg ha^{-1}
Hybrids				
A.B05034-1-1-4/R.07002	44.25	14.07	13.72	3.27
A.B05034-1-1-4/R.07003	43.23	13.07	14.69	3.52
A.B05034-1-1-4/R.07005	43.74	13.89	15.72	3.79
A.B05034-1-3-3/R.07003	48.18	15.20	13.62	3.46
A.B05034-1-3-4/R.07001	36.60	12.44	14.41	2.84
A.B05034-1-3-4/R.07003	54.90	16.56	13.46	3.91
A.B05034-1-4-2/R.07002	41.92	12.05	14.63	3.53
A.B05034-1-4-2/R.07003	47.91	13.76	14.15	3.82
A.B05034-1-4-4/R.07002	45.10	13.85	13.89	3.45
A.B05034-1-4-4/R.07003	50.67	14.77	14.20	4.04
A.B05034-1-4-4/R.07004	35.69	12.03	15.40	3.01
A.B05034-1-4-4/R.07005	42.86	13.58	15.52	3.61
A.B05035-2-1-4/R.07002	47.96	15.16	13.70	3.50
A.B05035-2-1-4/R.07003	46.45	13.61	14.25	3.68
A.B05035-2-2-1/R.07001	38.17	12.19	14.00	3.01
A.B05035-2-2-1/R.07002	43.21	13.29	14.41	3.47
A.B05035-2-2-1/R.07003	45.12	13.57	14.52	3.66
A.B05035-2-2-1/R.07005	41.39	13.83	14.99	3.30
A.B05035-2-2-3/R.07001	48.74	14.43	14.62	3.91
A.B05035-2-2-3/R.07002	42.25	13.90	14.04	3.12
A.B05035-2-2-3/R.07003	46.86	14.46	13.58	3.48
A.B05035-2-2-4/R.07001	46.35	14.73	14.68	3.70
A.B05035-2-2-4/R.07002	38.63	13.08	14.47	3.01
A.B05035-2-2-4/R.07003	51.55	16.91	13.90	3.69
A.B05035-2-2-4/R.07005	46.05	16.11	15.04	3.51
A.B05036-4-2-4/R.07003	34.76	11.16	14.63	2.88
A.B05036-4-3-4/R.07002	36.25	12.68	13.65	2.62
A.B05036-4-3-4/R.07003	51.88	16.12	13.82	3.79
A.B05037-3-1-4/R.07002	50.59	15.39	15.71	4.37
A.B05037-3-4-1/R.07003	43.54	13.73	15.57	3.74
A.B05038-4-1-3/R.07002	40.60	13.50	16.38	3.49
A.B05039-3-4/R.07001	41.23	12.90	15.32	3.61
A.B05039-3-4/R.07002	32.71	11.53	15.37	2.88
A.B05040-3-2-1/R.07001	42.62	14.63	16.07	3.64
A.B05040-3-2-1/R.07002	51.55	16.49	15.83	4.39
A.B05040-3-2-1/R.07003	39.66	12.92	14.12	3.11
A.B05043-2-4-2/R.07002	41.85	13.80	15.70	3.58
A.B05043-2-4-2/R.07003	39.21	13.31	15.54	3.27
A.B05043-2-4-2/R.07005	48.95	15.95	15.25	3.90
Pollen Parent Cultivars				
R.07001	39.26	14.47	16.94	3.50
R.07002	38.43	13.22	16.39	3.55
R.07003	42.88	13.89	16.38	4.01
R.07005	42.76	15.68	17.11	3.98
R.07006	56.48	17.64	15.94	5.08
Seed Parents				
B.05034-1-1-4-4	26.55	10.53	14.05	2.00
B.05034-1-3-4-1	25.41	9.77	14.39	2.03
B.05034-1-3-4-2	30.14	10.56	14.06	2.35
B.05034-1-4-2-3	32.31	12.91	14.75	2.37
B.05034-1-4-2-4	25.42	9.35	15.26	2.16

Table A.9. Cont.

Genotype	Fresh Biomass Mg ha^{-1}	Dry Biomass Mg ha^{-1}	Brix %	Sugar Mg ha^{-1}
B.05034-1-4-4-1	29.55	10.87	14.16	2.27
B.05034-1-4-4-2	26.54	9.13	14.39	2.12
B.05035-2-1-4-1	35.55	12.47	14.52	2.74
B.05035-2-2-1-1	37.50	11.67	15.15	3.22
B.05035-2-2-1-2	34.99	11.66	15.10	2.91
B.05035-2-2-3-1	34.56	11.36	14.81	2.80
B.05035-2-2-3-2	42.15	13.60	13.11	2.94
B.05035-2-2-4-3	35.56	12.09	13.89	2.70
B.05036-4-2-4-2	25.03	9.30	14.37	2.04
B.05036-4-2-4-3	25.03	9.40	15.05	2.09
B.05036-4-2-4-3	28.99	10.18	14.06	2.29
B.05036-4-3-4-2	29.65	11.33	14.73	2.29
B.05036-4-3-4-3	30.01	10.64	14.24	2.40
B.05037-3-4-1-4	31.51	11.32	13.73	2.37
B.05038-4-1-3-2	39.38	13.89	12.77	2.58
B.05038-4-1-3-3	38.06	13.18	12.98	2.57
B.05039	36.97	13.03	13.08	2.52
B.05040-3-2-1-1	32.02	12.72	13.41	2.13
B.05040-3-2-1-2	37.87	12.86	12.45	2.58
B.05042-1-3-4-2	35.82	22.16	14.23	2.59
B05037-3-1	34.53	11.28	12.45	2.45
B05042-1-4	36.48	12.51	13.45	2.64
B05043-2-4-4	30.38	11.24	13.22	2.17
Minimum	25.03	9.13	12.45	2.00
Maximum	56.48	22.16	17.11	5.08
Mean	39.46	13.20	14.54	3.12
SD	7.65	2.19	1.01	0.68

Table A.10. BLUE of yield traits of sweet sorghum hybrids and parental lines in Halfway in 2008

Genotype	Fresh Biomass Mg ha^{-1}	Dry Biomass Mg ha^{-1}	Brix %	Sugar Mg ha^{-1}
Hybrids				
A.B05034-1-1-4/R.07002	56.92	18.56	16.16	3.01
A.B05034-1-1-4/R.07003	56.90	19.26	15.83	2.79
A.B05034-1-1-4/R.07005	60.07	20.15	16.52	3.08
A.B05034-1-3-3/R.07003	54.87	16.80	15.32	3.01
A.B05034-1-3-4/R.07001	69.49	19.89	16.16	4.38
A.B05034-1-3-4/R.07003	63.87	22.05	14.99	3.33
A.B05034-1-4-2/R.07002	58.05	19.73	17.20	2.82
A.B05034-1-4-2/R.07003	44.50	16.25	14.73	1.74
A.B05034-1-4-4/R.07002	52.72	18.20	17.43	2.38
A.B05034-1-4-4/R.07003	42.52	15.90	15.18	1.63
A.B05034-1-4-4/R.07004	50.56	17.72	15.45	2.18
A.B05034-1-4-4/R.07005	75.45	24.22	17.44	4.87
A.B05035-2-1-4/R.07002	63.46	21.31	16.79	3.75
A.B05035-2-1-4/R.07003	47.66	16.83	16.52	1.98
A.B05035-2-2-1/R.07001	56.39	17.73	16.11	2.78
A.B05035-2-2-1/R.07002	56.81	18.32	15.17	2.87
A.B05035-2-2-1/R.07003	56.37	19.16	12.62	2.70
A.B05035-2-2-1/R.07005	69.61	21.06	17.05	4.65
A.B05035-2-2-3/R.07001	82.69	22.87	16.15	6.62
A.B05035-2-2-3/R.07002	66.23	20.61	17.02	4.15
A.B05035-2-2-3/R.07003	48.65	17.80	16.12	2.39
A.B05035-2-2-4/R.07001	62.16	19.61	16.84	3.56
A.B05035-2-2-4/R.07002	55.42	18.08	16.77	2.73
A.B05035-2-2-4/R.07003	40.22	14.70	11.80	1.45
A.B05035-2-2-4/R.07005	62.40	19.08	16.93	3.45
A.B05036-4-2-4/R.07003	44.25	16.92	15.00	1.68
A.B05036-4-3-4/R.07001	69.37	21.50	15.80	4.32
A.B05036-4-3-4/R.07002	54.08	18.61	17.05	2.59
A.B05036-4-3-4/R.07003	53.21	17.64	16.18	2.50
A.B05037-3-1-4/R.07002	39.05	14.53	15.38	1.37
A.B05037-3-4-1/R.07003	29.34	10.41	16.82	0.90
A.B05038-4-1-3/R.07002	44.62	16.24	16.29	1.86
A.B05039-3-4/R.07001	47.49	17.61	16.27	2.18
A.B05039-3-4/R.07002	61.96	20.27	17.41	3.89
A.B05040-3-2-1/R.07001	62.91	20.77	17.47	3.38
A.B05040-3-2-1/R.07002	65.96	21.18	15.63	4.98
A.B05040-3-2-1/R.07003	54.03	17.93	15.39	2.54
A.B05043-2-4-2/R.07002	43.71	16.31	16.50	1.67
A.B05043-2-4-2/R.07005	59.96	19.50	13.00	3.21
Pollen Parent Cultivars				
R.07001	58.96	18.30	16.15	3.29
R.07002	50.01	15.73	15.23	2.40
R.07003	53.99	17.39	16.37	2.63
R.07005	66.00	19.88	16.43	4.08
R.07006	92.58	23.91	15.64	8.67
Seed Parents				
B.05034-1-1-4-4	37.76	16.09	13.08	1.09
B.05034-1-3-4-1	39.31	17.39	13.80	1.19
B.05034-1-3-4-2	37.52	15.77	13.59	1.14
B.05034-1-4-2-3	36.51	15.31	15.05	1.15
B.05034-1-4-2-4	38.45	16.37	13.07	1.22
B.05034-1-4-4-1	40.25	15.25	14.34	1.55
B.05034-1-4-4-2	43.78	18.44	13.57	1.46

Table A.10. Cont.

Genotype	Fresh Biomass Mg ha^{-1}	Dry Biomass Mg ha^{-1}	Brix %	Sugar Mg ha^{-1}
B.05035-2-1-4-1	49.87	19.77	13.78	1.90
B.05035-2-2-1-1	48.46	17.57	14.95	1.93
B.05035-2-2-1-2	44.42	19.24	15.19	1.45
B.05035-2-2-3-1	45.47	17.51	14.41	1.65
B.05035-2-2-3-2	47.18	17.01	14.05	1.89
B.05035-2-2-4-3	38.37	14.87	15.02	1.28
B.05036-4-2-4-2	38.35	17.31	13.89	1.14
B.05036-4-2-4-3	35.85	15.60	14.69	1.11
B.05036-4-2-4-3	32.79	14.66	14.91	0.99
B.05036-4-3-4-2	42.28	17.10	12.66	1.45
B.05036-4-3-4-3	45.10	18.81	12.98	1.56
B.05037-3-4-1-4	36.04	15.96	13.71	0.93
B.05038-4-1-3-2	33.97	15.80	12.85	0.81
B.05038-4-1-3-3	36.32	16.82	13.71	1.01
B.05039	43.11	16.79	11.28	1.45
B.05040-3-2-1-1	39.18	15.42	12.94	1.29
B.05040-3-2-1-2	36.68	15.48	12.81	1.04
B.05042-1-3-4-2	39.83	18.27	14.13	1.14
B05037-3-1	37.77	16.15	12.58	1.05
B05042-1-4	36.15	15.20	14.26	0.96
B05043-2-4-4	32.58	14.31	12.43	0.85
Minimum	29.34	10.41	11.28	0.81
Maximum	92.58	24.22	17.47	8.67
Mean	50.26	17.84	15.08	2.39
SD	12.71	2.41	1.57	1.43

Table A.11. Ratoon efficiency for yield traits in 2007 across locations

Genotype	Fresh Biomass	Dry Biomass	Brix	Sugar
Hybrids				
A.B05034/1-4/R.07003	0.77	1.01	1.31	0.75
A.B05034-1-1/R.07003	0.90	1.10	0.94	0.74
A.B05034-1-1/R.07005	0.93	1.20	1.06	0.79
A.B05034-1-4/R.07003	0.84	1.10	1.10	0.72
A.B05034-1-4/R.07005	0.99	1.33	1.15	0.92
A.B05035-2-1/R.07006	1.20	1.20	1.06	1.20
A.B05035-2-1/R.07010R	0.87	1.04	0.95	0.74
A.B05035-2-2/R.07003	0.79	0.96	1.14	0.72
A.B05035-2-2/R.07005	0.93	1.14	1.16	0.81
A.B05035-2-2/R.07005	0.68	0.89	1.14	0.59
A.B05035-2-2/R.07006	0.77	1.01	1.13	0.64
A.B05035-2-2/R.07011R	0.94	1.29	0.92	0.70
A.B05036-4-2/R.07003	0.84	1.10	0.94	0.72
A.B05036-4-2/R.07006	1.21	1.55	1.05	1.03
A.B05036-4-3/R.07003	0.84	1.03	1.41	0.88
A.B05036-4-3/R.07010R	0.86	1.09	0.87	0.62
A.B05037-3-1/R.70705	0.80	0.97	0.96	0.66
A.B05037-3-4/R.07005	0.64	0.84	0.89	0.51
A.B05037-3-4/R.07010R	0.77	1.20	1.06	0.65
A.B05037-3-4/R.07011R	0.84	1.15	0.91	0.67
A.B05038-4-1/R.07010R	0.80	0.95	0.96	0.68
A.B05040-3/R.07004	0.91	1.18	1.01	0.74
A.B05040-3/R.07005	0.78	1.09	1.09	0.64
A.B05042-1-3/R.07003	0.55	0.74	1.13	0.64
A.B05042-1-3/R.07005	0.71	0.99	1.07	0.46
A.B05042-1-4/R.07003	0.78	0.94	0.93	0.60
A.B05042-1-4/R.07006	0.85	1.04	0.91	0.65
A.B05043-2-4/R.07003	0.79	1.04	0.78	0.54
A.B05043-2-4/R.07003	0.71	0.88	0.84	0.43
A.B05043-2-4/R.07005	0.84	1.11	0.97	0.59
A.B05043-2-4/R.07006	0.89	1.11	1.01	0.77
Pollen Parent Cultivars				
R.07003	0.60	0.74	0.86	0.43
R.07004	1.00	1.27	1.08	0.89
R.07005	0.91	1.18	0.96	0.71
R.07006	0.86	1.01	0.93	0.68
R.07010R	0.65	0.85	0.80	0.42
R.07011R	0.87	1.12	0.88	0.59
Seed Parents				
B.005037-3-1-4	0.56	0.68	0.82	0.42
B.05034-1-1-4	0.72	0.84	1.23	0.65
B.05034-1-4-4	1.05	1.12	1.12	1.20
B.05035-2-1-4	0.72	0.86	1.05	0.60
B.05035-2-2-3	0.99	1.06	1.03	0.95
B.05035-2-2-4	0.94	1.21	0.97	0.75
B.05036-4-2-4	0.94	1.32	1.08	0.65
B.05036-4-3-4	0.89	1.08	0.98	0.72
B.05038-4-1-3	0.39	0.56	0.95	0.27
B.05040-3-2-1	0.59	0.82	0.91	0.39
B.05042-1-3-4	0.59	0.64	1.02	0.53
B.05042-1-4-4	0.64	0.75	0.88	0.49
B.05043-2-4-4	0.58	0.75	0.92	0.37
Minimum	0.39	0.56	0.78	0.27
Maximum	1.21	1.55	1.41	1.20
Mean	0.81	1.02	1.01	0.67
Standard Deviation	0.16	0.20	0.13	0.19

Table A.12. BLUE of sugar concentration in the juice of the primary harvest sweet sorghum hybrids and parental lines in Weslaco in 2007

Genotype	Total Sugar g/L	Sucrose g/L	Glucose g/L	Fructose g/L	Sucrose %	Glucose %	Fructose %
Hybrids							
A.B05035-1-1/R.07003	128.95	82.81	25.33	20.81	65.65	18.90	15.45
A.B05035-1-1/R.07005	122.32	69.40	29.48	23.44	55.83	24.55	19.62
A.B05035-2-2/R.07003	144.00	91.99	28.04	23.97	64.04	19.39	16.57
A.B05035-2-2/R.07005	110.52	64.22	25.23	21.08	59.74	21.99	18.27
A.B05036-4-2/R.07006	123.20	40.73	43.35	39.11	35.70	33.86	30.44
A.B05036-4-3/R.07010R	121.06	48.96	38.30	33.80	40.99	31.37	27.63
A.B05037-3-1/R.07005	96.91	38.23	31.30	27.37	42.35	30.83	26.82
A.B05038-4-1/R.07010R	109.16	31.35	41.86	35.95	28.77	38.32	32.91
A.B05040-3/R.07005	110.14	69.85	22.61	17.68	63.58	20.45	15.97
A.B05042-1-3/R.07003	117.28	53.78	35.39	28.11	46.46	29.88	23.66
A.B05042-1-4/R.07003	136.38	83.44	30.29	22.65	61.33	22.13	16.53
A.B05043-2-4/R.07003	129.77	73.65	31.86	24.26	56.92	24.45	18.63
Pollen Parent Cultivars							
R.07003	123.59	68.89	30.53	24.17	55.76	24.64	19.59
R.07005	151.37	119.95	18.97	12.45	79.25	12.53	8.22
Seed Parent							
B.05037-3-1-4	118.92	60.14	33.19	25.59	51.02	27.71	21.27
Minimum	96.91	31.35	18.97	12.45	28.77	12.53	8.22
Maximum	151.37	119.95	43.35	39.11	79.25	38.32	32.91
Mean	122.90	66.49	31.05	25.36	53.83	25.40	20.77
SD	14.02	22.91	6.77	6.89	13.12	6.67	6.50

Table A.13. BLUE of sugar concentration in the juice of the first ratoon harvest of sweet sorghum hybrids and parental lines in Weslaco in 2007

Genotype	Total Sugar g/L	Fructose %	Sucrose g/L	Glucose g/L	Fructose g/L	Sucrose %	Glucose %
Hybrids							
A.B05035-1-1/R.07003	103.34	23.18	50.99	28.46	23.88	49.17	27.64
A.B05035-1-1/R.07005	119.54	21.54	63.04	30.84	25.65	52.61	25.85
A.B05035-2-2/R.07003	109.49	31.66	33.99	40.73	34.77	31.24	37.10
A.B05035-2-2/R.07005	104.79	29.47	35.71	37.73	31.35	35.01	35.52
A.B05036-4-2/R.07006	78.62	38.07	16.32	33.41	28.89	17.88	44.05
A.B05036-4-3/R.07010R	95.60	32.43	28.48	35.99	31.13	30.06	37.51
A.B05037-3-1/R.07005	94.18	37.94	16.05	41.85	36.27	18.16	43.90
A.B05038-4-1/R.07010R	108.55	18.94	64.88	23.84	19.83	58.26	22.80
A.B05040-3/R.07005	111.15	16.73	70.48	22.01	18.65	63.53	19.74
A.B05042-1-3/R.07003	85.61	44.95	2.82	44.30	38.49	3.32	51.72
A.B05042-1-4/R.07003	86.03	42.96	2.97	46.16	36.91	3.51	53.54
A.B05043-2-4/R.07003	90.08	32.34	36.12	28.89	25.07	30.67	36.99
Pollen Parent Cultivars							
R.07003	104.31	37.91	19.20	45.68	39.42	18.10	43.99
R.07005	106.90	40.56	11.72	51.89	43.28	10.80	48.63
Seed Parent							
B.05037-3-1-4	106.88	30.88	38.51	37.26	31.10	32.24	36.88
Minimum	78.62	16.73	2.82	22.01	18.65	3.32	19.74
Maximum	119.54	44.95	70.48	51.89	43.28	63.53	53.54
Mean	100.34	31.97	32.75	36.60	30.98	30.30	37.72
SD	11.42	8.73	21.94	8.69	7.32	18.98	10.27

Table A.14. BLUE of sugar concentration in the juice of the second ratoon harvest of sweet sorghum hybrids and parental lines in Weslaco in 2007

Genotype	Total Sugar g/L	Sucrose g/L	Glucose g/L	Fructose g/L	Sucrose %	Glucose %	Fructose %
Hybrids							
A.B05035-1-1/R.07003	138.98	123.83	9.43	5.72	89.07	6.81	4.12
A.B05035-1-1/R.07005	144.87	125.70	12.47	6.71	86.73	8.63	4.64
A.B05035-2-2/R.07003	131.03	111.74	12.85	6.44	85.21	9.85	4.93
A.B05035-2-2/R.07005	129.06	112.54	10.52	6.01	86.89	8.32	4.80
A.B05036-4-2/R.07006	150.83	129.51	14.43	6.90	85.79	9.62	4.59
A.B05036-4-3/R.07010R	166.26	144.43	13.89	7.94	86.81	8.38	4.80
A.B05037-3-1/R.07005	137.38	121.10	10.81	5.48	88.12	7.88	3.99
A.B05038-4-1/R.07010R	154.22	108.63	29.62	15.97	70.46	19.19	10.35
A.B05040-3/R.07005	113.23	95.93	11.26	6.04	84.70	9.97	5.33
A.B05042-1-3/R.07003	119.72	90.67	19.18	9.88	75.73	16.02	8.25
A.B05042-1-4/R.07003	120.35	80.37	24.87	15.11	66.76	20.68	12.56
A.B05043-2-4/R.07003	130.42	97.03	21.00	12.39	74.28	16.10	9.62
Pollen Parent Cultivars							
R.07003	178.60	138.84	24.83	14.93	77.62	13.98	8.40
R.07005	153.89	138.21	10.51	5.18	89.78	6.84	3.38
Seed Parent							
B.05037-3-1-4	117.56	82.63	21.26	13.68	70.30	18.07	11.63
Minimum	113.23	80.37	9.43	5.18	66.76	6.81	3.38
Maximum	178.60	144.43	29.62	15.97	89.78	20.68	12.56
Mean	139.09	113.41	16.46	9.23	81.22	12.02	6.76
SD	18.94	20.63	6.46	4.03	7.84	4.81	3.07

Table A.15. BLUE of sugar concentration in the juice of the primary harvest of sweet sorghum hybrids and parental lines in College Station in 2007

Genotype	Total Sugar g/L	Sucrose g/L	Glucose g/L	Fructose g/L	Sucrose %	Glucose %	Fructose %
Hybrids							
A.B05035-1-1/R.07003	102.45	64.04	21.60	16.82	60.42	22.22	17.35
A.B05035-1-1/R.07005	95.55	38.34	31.38	25.83	43.10	31.73	25.17
A.B05035-2-2/R.07005	88.42	55.78	18.08	14.56	63.81	20.12	16.07
A.B05035-2-2/R.07003	63.19	33.09	17.42	12.68	51.99	27.73	20.28
A.B05036-4-2/R.07006	112.32	83.15	16.22	12.95	72.33	15.37	12.29
A.B05036-4-3/R.07010R	119.09	80.71	21.19	17.20	67.78	17.78	14.44
A.B05037-3-1/R.07005	93.18	62.35	17.40	13.44	66.08	19.09	14.82
A.B05042-1-3/R.07003	107.43	48.98	31.88	26.57	44.66	30.16	25.18
A.B05042-1-4/R.07003	121.86	61.46	33.74	26.66	50.37	27.72	21.91
A.B05043-2-4/R.07003	132.53	79.73	29.68	23.11	60.27	22.34	17.39
A.B05038-4-1/R.07010R	96.81	49.83	27.20	19.78	51.48	28.09	20.43
A.B05040-3/R.07005	91.66	71.00	11.95	8.71	77.02	13.35	9.63
Pollen Parent Cultivars							
R.07005	135.70	100.23	20.47	15.01	70.71	16.72	12.57
R.07003	142.01	78.29	35.65	28.07	54.46	25.46	20.08
Seed Parent							
B.05037-3-1-4	95.08	18.57	41.19	35.32	22.12	42.08	35.80
Minimum	63.19	18.57	11.95	8.71	22.12	13.35	9.63
Maximum	142.01	100.23	41.19	35.32	77.02	42.08	35.80
Mean	106.49	61.70	25.00	19.78	57.11	24.00	18.90
SD	21.01	21.65	8.55	7.45	14.04	7.54	6.53

Table A.16. BLUE of juice composition of ratoon harvest of sweet sorghum hybrids and parent lines in College Station in 2007

Genotype	Total Sugar g/L	Sucrose g/L	Glucose g/L	Fructose g/L	Sucrose %	Glucose %	Fructose %
Hybrids							
A.B05035-1-1/R.07003	120.57	101.77	12.04	6.45	84.76	10.02	5.26
A.B05035-1-1/R.07005	124.46	109.33	8.68	6.32	86.79	7.50	5.66
A.B05035-2-2/R.07003	120.93	101.48	12.30	6.82	84.65	9.98	5.41
A.B05035-2-2/R.07005	134.04	118.32	9.85	5.55	88.78	7.30	3.96
A.B05036-4-2/R.07006	130.81	110.59	13.03	6.86	85.20	9.88	4.96
A.B05036-4-3/R.07010R	84.87	62.54	12.84	9.16	72.95	15.74	11.35
A.B05037-3-1/R.07005	120.24	101.45	12.29	6.19	84.87	10.19	4.98
A.B05038-4-1/R.07010R	83.85	41.92	25.52	16.08	50.69	30.26	19.09
A.B05040-3/R.07005	123.22	110.20	8.02	4.68	90.00	6.47	3.58
A.B05042-1-3/R.07003	105.11	80.09	16.20	8.50	76.91	15.28	7.85
A.B05042-1-4/R.07003	98.04	58.36	24.29	16.03	57.99	25.15	16.78
A.B05043-2-4/R.07003	97.27	59.27	23.33	14.35	61.38	24.03	14.62
Pollen Parent Cultivars							
R.07003	116.92	77.37	25.19	14.03	66.88	21.46	11.69
R.07005	142.64	127.18	10.16	4.99	89.59	7.11	3.34
Seed Parents							
B.05037-3-1-4	87.84	57.34	18.95	12.00	62.97	22.47	14.57
Minimum	83.85	41.92	8.02	4.68	50.69	6.47	3.34
Maximum	142.64	127.18	25.52	16.08	90.00	30.26	19.09
Mean	112.72	87.81	15.51	9.20	76.29	14.85	8.87
SD	18.65	26.80	6.29	4.14	13.13	7.86	5.32

Table A.17. BLUE of juice composition of primary harvest of sweet sorghum hybrids and parent lines in Halfway in 2007

Genotype	Total Sugar g/L	Sucrose g/L	Glucose g/L	Fructose g/L	Sucrose %	Glucose %	Fructose %
Hybrids							
A.B05035-1-1/R.07003	135.00	113.12	11.92	10.14	83.35	9.00	7.65
A.B05035-1-1/R.07005	161.44	144.40	9.06	8.15	89.34	5.61	5.05
A.B05035-2-2/R.07003	138.03	108.97	17.52	11.71	78.84	12.68	8.48
A.B05035-2-2/R.07005	147.41	126.13	12.42	9.03	85.50	8.31	6.19
A.B05036-4-2/R.07006	148.89	125.12	14.07	9.87	83.93	9.44	6.63
A.B05036-4-3/R.07010R	155.90	133.27	13.01	9.78	85.02	8.57	6.41
A.B05037-3-1/R.07005	96.37	67.04	17.17	12.33	69.20	17.95	12.85
A.B05042-1-3/R.07003	137.76	112.65	14.89	10.39	81.39	10.98	7.63
A.B05042-1-4/R.07003	154.64	113.86	23.88	17.07	73.21	15.62	11.17
A.B05043-2-4/R.07003	173.28	132.20	23.93	17.33	76.13	13.85	10.02
Pollen Parent Cultivars							
R.07003	165.21	102.74	36.40	26.24	62.06	22.04	15.90
R.07005	178.76	150.14	17.37	11.42	83.61	9.88	6.51
Seed Parent							
B.05037-3-1-4	54.12	21.20	18.14	14.95	35.25	35.40	29.35
Minimum	54.12	21.20	9.06	8.15	35.25	5.61	5.05
Maximum	178.76	150.14	36.40	26.24	89.34	35.40	29.35
Mean	142.06	111.60	17.68	12.96	75.91	13.80	10.29
SD	33.62	34.28	7.11	4.95	14.35	7.88	6.50

Table A.18. BLUE of sugar composition of primary harvest of sweet sorghum hybrids and parents across locations in 2008

Genotype	Sucrose g/L	Glucose g/L	Fructose g/L	Total Sugar g/L	Sucrose %	Glucose %	Fructose %
Hybrids							
A.B05034-1-1-4/R.07003	79.27	10.60	4.83	94.70	82.87	11.74	5.39
A.B05034-1-1-4/R.07005	105.69	12.93	6.35	124.96	84.31	10.42	5.27
A.B05035-2-2-1/R.07003	89.48	13.56	6.22	109.94	81.54	12.44	5.55
A.B05035-2-2-1/R.07005	93.12	11.89	5.97	111.19	84.45	10.44	4.69
A.B05036-4-2-4/R.07003	86.80	11.80	4.99	103.59	82.94	11.93	5.13
A.B05036-4-3-4/R.07002	96.41	15.48	6.80	115.69	81.84	12.65	4.53
A.B05037-3-1-4/R.07002	96.52	23.15	10.84	130.28	75.96	16.33	6.73
A.B05038-4-1-3/R.07002	90.89	20.41	8.14	119.77	78.06	14.89	6.05
A.B05040-3-2-1/R.07002	102.39	12.92	6.76	122.08	83.85	10.48	5.67
A.B05042-1-3-4/R.07003	97.11	13.06	10.41	117.40	82.86	11.49	4.84
A.B05043-2-4-2/R.07003	105.69	31.43	9.28	155.57	72.73	16.74	9.53
Pollen Parent Cultivars							
R.07003	97.31	25.47	9.28	133.67	72.08	19.49	7.87
R.07005	118.54	18.76	9.28	144.33	81.80	13.17	5.03
Seed Parent							
B05037-3-1	35.72	15.99	9.28	64.63	54.20	25.83	19.38
Minimum	35.72	10.60	4.83	64.63	54.20	10.42	4.53
Maximum	118.54	31.43	10.84	155.57	84.45	25.83	19.38
Mean	92.50	16.96	7.74	117.70	78.54	14.15	6.83
SD	18.90	6.14	1.99	21.99	8.13	4.31	3.86

Table A.19. BLUE of sugar composition of juice of primary harvest of sweet sorghum hybrids and parental lines in College Station in 2008

Genotype	Sucrose g/L	Glucose g/L	Fructose g/L	Total Sugar g/L	Sucrose %	Glucose %	Fructose %
Hybrids							
A.B05034-1-1-4/R.07003	96.68	11.62	4.45	112.75	85.61	10.50	3.88
A.B05034-1-1-4/R.07005	120.01	13.67	6.75	140.43	85.52	9.67	4.81
A.B05035-2-2-1/R.07003	119.06	14.95	6.48	140.49	84.66	10.71	4.63
A.B05035-2-2-1/R.07005	114.87	12.27	6.35	133.49	85.97	9.23	4.80
A.B05036-4-2-4/R.07003	105.31	11.77	4.66	121.74	86.19	9.91	3.90
A.B05036-4-3-4/R.07002	101.74	14.68	6.54	122.42	82.85	11.82	5.35
A.B05037-3-1-4/R.07002	112.13	25.95	10.64	148.71	75.43	17.42	7.16
A.B05038-4-1-3/R.07002	124.06	24.94	10.19	159.19	77.86	15.71	6.43
A.B05040-3-2-1/R.07002	139.32	14.90	5.18	159.39	87.45	9.32	3.23
A.B05042-1-3-4/R.07003	114.47	13.61	4.75	132.82	86.23	10.21	3.56
A.B05043-2-4-2/R.07003	127.91	35.91	24.59	188.41	70.80	17.47	11.73
Pollen Parent Cultivars							
R.07003	120.36	29.44	11.01	160.80	74.99	18.21	6.80
R.07005	140.43	21.41	7.20	169.04	82.89	12.78	4.34
Seed Parent							
B05037-3-1	53.77	15.59	9.78	79.13	68.04	19.61	12.35
Minimum	53.77	11.62	4.45	79.13	68.04	9.23	3.23
Maximum	140.43	35.91	24.59	188.41	87.45	19.61	12.35
Mean	113.58	18.62	8.47	140.63	81.04	13.04	5.93
SD	21.29	7.62	5.17	27.20	6.39	3.79	2.85

Table A.20. BLUE of sugar composition of juice of primary harvest of sweet sorghum hybrids and parental lines in Halfway in 2008

Genotype	Sucrose g/L	Glucose g/L	Fructose g/L	Total Sugar g/L	Sucrose %	Glucose %	Fructose %
Hybrids							
A.B05034-1-1-4/R.07003	56.38	9.26	4.20	69.84	79.68	13.88	6.45
A.B05034-1-1-4/R.07005	102.60	12.61	5.08	120.28	84.95	10.39	4.66
A.B05035-2-2-1/R.07003	39.31	8.25	5.06	55.11	76.21	14.77	8.97
A.B05035-2-2-1/R.07005	83.89	13.24	5.84	102.96	81.25	12.98	5.77
A.B05036-4-2-4/R.07003	101.61	13.33	5.56	120.49	84.49	10.90	4.61
A.B05036-4-3-4/R.07002	133.97	16.74	6.48	159.69	85.46	10.46	4.03
A.B05037-3-1-4/R.07002	89.88	21.11	13.52	126.99	73.34	16.30	10.31
A.B05038-4-1-3/R.07002	37.13	8.35	6.77	54.72	73.17	15.01	11.77
A.B05040-3-2-1/R.07002	74.01	13.31	7.18	94.50	80.21	12.82	6.97
Pollen Parent Cultivars							
R.07003	80.20	22.78	11.62	114.59	66.65	21.66	11.69
R.07005	90.81	19.03	9.08	118.92	76.83	15.76	7.41
Seed Parent							
B05037-3-1	21.26	16.44	14.73	52.43	40.41	31.50	28.09
Minimum	21.26	8.25	4.20	52.43	40.41	10.39	4.03
Maximum	133.97	22.78	14.73	159.69	85.46	31.50	28.09
Mean	75.92	14.54	7.93	99.21	75.22	15.54	9.23
SD	32.27	4.80	3.53	34.33	12.30	5.91	6.51

Table A.21. BLUE of whole plant composition of primary harvest across locations in 2007

Genotype	Glucan %	Xylan %	Lignin %	Solubles %
Hybrids				
A.B05034/1-4/R.07003	26.73	13.91	12.15	34.72
A.B05034-1-1/R.07003	29.15	13.24	11.74	32.67
A.B05034-1-1/R.07005	29.95	13.56	11.01	33.42
A.B05034-1-4/R.07003	30.81	13.70	12.05	29.91
A.B05034-1-4/R.07005	29.32	14.05	12.23	31.62
A.B05035-2-1/R.07006	31.53	12.66	10.65	32.31
A.B05035-2-1/R.07010R	28.60	13.53	11.28	34.07
A.B05035-2-2/R.07003	29.67	13.83	12.29	30.88
A.B05035-2-2/R.07005	30.64	13.68	11.78	31.39
A.B05035-2-2/R.07005	29.42	13.71	11.86	32.02
A.B05035-2-2/R.07006	28.84	15.02	12.40	30.78
A.B05035-2-2/R.07011R	27.17	15.07	12.98	32.21
A.B05036-4-2/R.07003	30.74	13.86	12.51	29.01
A.B05036-4-2/R.07006	32.46	12.43	11.18	29.98
A.B05036-4-3/R.07003	31.06	14.71	13.16	26.81
A.B05036-4-3/R.07010R	29.64	13.60	11.60	32.78
A.B05037-3-1/R.70705	29.25	14.55	12.66	30.84
A.B05037-3-4/R.07005	29.32	15.38	13.50	28.58
A.B05037-3-4/R.07010R	29.24	13.87	12.13	31.60
A.B05037-3-4/R.07011R	26.38	14.87	12.99	33.84
A.B05038-4-1/R.07010R	29.64	13.93	12.31	30.73
A.B05040-3/R.07004	29.60	13.75	12.43	31.28
A.B05040-3/R.07005	27.04	14.44	12.54	33.37
A.B05042-1-3/R.07003	30.09	14.38	12.28	30.09
A.B05042-1-3/R.07005	28.51	15.48	13.24	31.52
A.B05042-1-4/R.07003	26.89	13.16	11.97	34.63
A.B05042-1-4/R.07006	30.19	13.87	11.53	31.41
A.B05043-2-4/R.07003	28.91	13.25	12.03	32.02
A.B05043-2-4/R.07003	29.61	15.03	13.06	28.96
A.B05043-2-4/R.07005	28.32	15.55	13.43	30.02
A.B05043-2-4/R.07006	29.05	14.27	12.16	31.49
Pollen Parent Cultivars				
R.07003	26.92	13.55	11.47	34.86
R.07004	29.03	13.82	12.39	32.04
R.07005	30.14	15.35	11.76	31.38
R.07006	26.68	12.94	10.78	36.79
R.07010R	25.82	13.85	11.56	35.66
Seed Parents				
B.005037-3-1-4	34.04	14.55	12.69	24.17
B.05034-1-1-4	38.36	10.67	10.49	24.55
B.05034-1-4-4	32.42	12.51	11.07	29.71
B.05035-2-1-4	30.96	13.88	11.95	29.00
B.05035-2-2-3	33.57	12.35	11.30	28.38
B.05035-2-2-4	32.96	13.01	11.55	27.94
B.05036-4-2-4	34.40	14.27	12.79	24.22
B.05036-4-3-4	33.30	14.77	12.87	25.18
B.05038-4-1-3	32.48	12.99	11.40	28.57
B.05040-3-2-1	31.66	14.77	12.74	27.04
B.05042-1-3-4	31.05	14.84	13.03	27.48
B.05042-1-4-4	32.80	13.32	12.00	27.11
B.05043-2-4-4	32.99	13.41	12.30	26.63

Table A.21. Cont.

Genotype	Glucan	Xylan	Lignin	Solubles
	%	%	%	%
Minimum	25.82	10.67	10.49	24.17
Maximum	38.36	15.55	13.50	36.79
Mean	30.15	13.90	12.11	30.52
Standard Deviation	2.44	0.94	0.73	2.97

Table A.22. BLUE of whole plant composition of primary harvest in Weslaco in 2007

Genotype	Glucan %	Xylan %	Lignin %	Solubles %
Hybrids				
A.B05034-1-1/R.07003	31.20	12.30	11.87	29.27
A.B05034-1-1/R.07005	30.71	12.87	11.84	29.80
A.B05034-1-4/R.07003	33.07	13.86	12.58	25.90
A.B05034-1-4/R.07005	29.91	15.34	13.70	27.19
A.B05035-2-1/R.07006	33.65	11.73	11.45	28.17
A.B05035-2-1/R.07010R	29.94	13.26	12.45	29.35
A.B05035-2-2/R.07003	29.67	13.94	12.72	29.52
A.B05035-2-2/R.07005	33.43	13.05	12.85	25.68
A.B05035-2-2/R.07005	31.07	13.71	12.87	27.70
A.B05036-4-2/R.07006	31.49	13.34	12.12	28.16
A.B05036-4-3/R.07010R	30.07	14.61	13.58	27.35
A.B05037-3-1/R.70705	29.90	14.75	13.59	27.38
A.B05037-3-4/R.07005	31.06	14.50	13.45	26.28
A.B05037-3-4/R.07010R	30.72	14.34	13.29	27.07
A.B05038-4-1/R.07010R	32.39	13.68	12.99	25.89
A.B05040-3/R.07004	30.08	13.68	13.14	28.50
A.B05040-3/R.07005	28.71	14.48	13.07	29.63
A.B05042-1-3/R.07003	30.36	15.46	13.91	25.94
A.B05042-1-4/R.07003	29.78	12.92	12.53	29.93
A.B05042-1-4/R.07006	32.85	13.48	12.25	26.53
A.B05043-2-4/R.07003	28.16	14.87	13.46	29.61
A.B05043-2-4/R.07006	27.67	14.52	12.77	31.29
Pollen Parent Cultivars				
R.07003	29.56	14.72	13.00	28.62
R.07004	30.75	13.47	12.78	28.77
R.07005	29.43	15.01	12.91	28.73
R.07006	30.32	13.43	11.92	30.26
R.07010R	28.12	14.63	12.81	30.49
Seed Parents				
B.005037-3-1-4	30.99	13.46	12.22	28.34
B.05034-1-1-4	34.33	11.25	10.92	27.71
B.05034-1-4-4	31.69	12.14	11.54	29.21
B.05035-2-1-4	29.97	11.69	11.00	32.12
B.05035-2-2-3	32.72	11.85	11.51	28.68
B.05035-2-2-4	32.04	12.11	11.51	29.13
B.05036-4-2-4	33.13	12.66	11.84	27.02
B.05036-4-3-4	32.31	13.22	12.48	26.98
B.05038-4-1-3	31.11	13.57	12.46	27.46
B.05040-3-2-1	31.21	14.43	12.87	26.61
B.05042-1-3-4	31.85	14.20	12.98	26.14
B.05042-1-4-4	33.81	13.66	12.41	24.20
B.05043-2-4-4	33.62	11.67	11.39	27.53
Minimum	27.67	11.25	10.92	24.20
Maximum	34.33	15.46	13.91	32.12
Mean	31.07	13.55	12.53	28.10
SD	1.66	1.10	0.76	1.68

Table A.23. BLUE of whole plant composition of primary harvest in College Station in 2007

Genotype	Glucan %	Xylan %	Lignin %	Solubles %
Hybrids				
A.B05034/1-4/R.07003	26.58	13.58	12.08	34.53
A.B05034-1-4/R.07003	28.80	13.06	12.02	31.44
A.B05034-1-4/R.07005	28.96	12.29	11.27	33.58
A.B05035-2-1/R.07006	32.98	12.24	10.43	29.72
A.B05035-2-1/R.07010R	26.41	12.92	11.12	36.12
A.B05035-2-2/R.07003	30.51	14.99	13.61	26.33
A.B05035-2-2/R.07005	28.11	13.20	11.70	33.86
A.B05035-2-2/R.07005	28.44	13.95	12.24	31.61
A.B05035-2-2/R.07006	28.68	14.68	12.33	30.58
A.B05035-2-2/R.07011R	27.01	14.73	12.91	32.01
A.B05036-4-2/R.07003	30.59	13.52	12.44	28.82
A.B05036-4-2/R.07006	33.74	12.76	11.62	26.85
A.B05036-4-3/R.07003	30.90	14.37	13.09	26.62
A.B05037-3-4/R.07005	27.82	15.79	14.04	28.41
A.B05037-3-4/R.07010R	28.01	12.93	11.48	33.67
A.B05037-3-4/R.07011R	26.23	14.53	12.92	33.65
A.B05038-4-1/R.07010R	27.14	13.71	12.13	33.11
A.B05040-3/R.07004	30.66	13.62	13.00	28.32
A.B05040-3/R.07005	25.61	13.93	12.52	34.64
A.B05042-1-3/R.07005	28.35	15.14	13.17	31.32
A.B05042-1-4/R.07003	25.13	14.02	12.31	35.55
A.B05042-1-4/R.07006	27.78	13.78	11.31	33.82
A.B05043-2-4/R.07003	30.76	12.56	11.86	30.38
A.B05043-2-4/R.07003	29.45	14.69	12.99	28.76
A.B05043-2-4/R.07005	28.17	15.21	13.36	29.82
A.B05043-2-4/R.07006	30.68	13.55	12.06	29.21
Seed Parents				
B.05034-1-4-4	33.40	12.41	11.11	27.74
B.05035-2-1-4	31.30	13.19	11.55	29.05
B.05035-2-2-3	34.93	10.85	10.69	27.51
B.05035-2-2-4	33.52	12.55	11.22	27.32
B.05036-4-2-4	34.02	13.66	12.73	24.38
B.05036-4-3-4	30.56	13.30	12.07	29.31
B.05038-4-1-3	34.09	11.95	10.85	27.21
B.05042-1-4-4	33.49	12.75	11.85	26.11
B.05043-2-4-4	32.91	13.50	12.38	25.88
Minimum	25.13	10.85	10.43	24.38
Maximum	34.93	15.79	14.04	36.12
Mean	29.88	13.54	12.13	30.21
SD	2.76	1.05	0.86	3.13

Table A.24. BLUE of whole plant composition of primary harvest in Halfway in 2007

Genotype	Glucan %	Xylan %	Lignin %	Solubles %
Hybrids				
A.B05034-1-1/R.07003	27.25	14.52	11.68	35.77
A.B05034-1-1/R.07005	29.35	14.59	10.25	36.74
A.B05035-2-1/R.07006	27.97	14.01	10.07	38.54
A.B05035-2-1/R.07010R	29.43	14.41	10.26	36.24
A.B05035-2-2/R.07003	28.84	12.57	10.54	36.31
A.B05035-2-2/R.07005	30.37	14.77	10.78	34.12
A.B05035-2-2/R.07005	28.75	13.47	10.48	36.25
A.B05036-4-2/R.07006	32.14	11.20	9.81	34.43
A.B05036-4-3/R.07010R	29.36	12.93	9.68	37.91
A.B05037-3-1/R.70705	28.74	14.69	11.81	33.99
A.B05040-3/R.07004	28.07	13.95	11.15	36.52
A.B05042-1-3/R.07003	29.97	13.65	10.73	33.93
A.B05042-1-4/R.07003	25.76	12.52	11.07	37.90
A.B05043-2-4/R.07003	27.80	12.33	10.78	35.56
Pollen Parent Cultivars				
R.07003	24.44	12.71	10.01	40.79
R.07004	27.46	14.51	12.07	35.01
R.07005	31.01	16.03	10.67	33.72
R.07006	23.20	12.78	9.72	43.02
R.07010R	23.67	13.41	10.39	40.54
Seed Parents				
B.005037-3-1-4	37.25	15.97	13.24	19.71
B.05034-1-1-4	42.55	10.44	10.14	21.09
B.05035-2-1-4	31.59	16.77	13.31	25.33
B.05035-2-2-3	33.06	14.37	11.70	28.44
B.05035-2-2-4	33.33	14.38	11.91	26.88
B.05036-4-2-4	36.05	16.50	13.81	20.76
B.05036-4-3-4	34.45	16.67	13.33	23.07
B.05040-3-2-1	34.00	17.24	13.85	22.64
B.05042-1-3-4	30.41	15.83	13.15	28.53
B.05042-1-4-4	31.09	13.55	11.75	30.51
B.05043-2-4-4	32.44	15.06	13.13	25.97
Minimum	23.20	10.44	9.68	19.71
Maximum	42.55	17.24	13.85	43.02
Mean	30.33	14.19	11.38	32.34
SD	4.08	1.64	1.32	6.52

Table A.25. BLUE of bagasse composition of primary harvest across locations in 2007

Genotype	Glucan %	Xylan %	Lignin %	Solubles %
Hybrids				
A.B05034/1-4/R.07003	31.38	18.89	17.11	21.33
A.B05034-1-1/R.07003	24.78	15.69	14.62	34.50
A.B05034-1-1/R.07005	27.03	15.37	14.62	33.43
A.B05034-1-4/R.07003	25.27	16.17	15.55	32.98
A.B05034-1-4/R.07005	23.90	13.78	12.48	39.16
A.B05035-2-1/R.07006	26.06	15.71	14.43	33.26
A.B05035-2-1/R.07010R	25.93	14.90	13.78	34.62
A.B05035-2-2/R.07003	27.27	16.72	15.37	30.78
A.B05035-2-2/R.07005	26.62	16.45	15.48	31.05
A.B05035-2-2/R.07005	27.18	16.01	14.88	31.57
A.B05035-2-2/R.07006	30.93	18.48	16.83	22.62
A.B05035-2-2/R.07011R	27.63	17.58	16.57	26.75
A.B05036-4-2/R.07003	27.44	15.83	14.24	30.65
A.B05036-4-2/R.07006	27.28	16.17	14.99	31.59
A.B05036-4-3/R.07003	29.28	18.10	16.50	25.09
A.B05036-4-3/R.07010R	26.57	15.58	14.31	34.08
A.B05037-3-1/R.70705	25.39	15.93	15.34	33.14
A.B05037-3-4/R.07005	28.69	16.79	15.25	28.28
A.B05037-3-4/R.07010R	28.81	16.62	15.17	28.61
A.B05037-3-4/R.07011R	30.30	18.22	16.37	24.15
A.B05038-4-1/R.07010R	22.87	14.80	14.28	37.19
A.B05040-3/R.07004	26.18	16.23	15.85	31.39
A.B05040-3/R.07005	28.07	15.41	13.85	32.94
A.B05042-1-3/R.07003	24.05	15.80	15.10	33.70
A.B05042-1-3/R.07005	27.30	16.40	15.06	29.35
A.B05042-1-4/R.07003	23.00	15.53	15.02	36.00
A.B05042-1-4/R.07006	22.89	14.13	12.91	40.08
A.B05043-2-4/R.07003	25.05	15.50	14.60	34.58
A.B05043-2-4/R.07003	26.51	16.11	15.29	30.48
A.B05043-2-4/R.07005	31.64	18.64	16.77	21.62
A.B05043-2-4/R.07006	29.32	17.57	16.01	26.16
Pollen Parent Cultivars				
R.07003	25.74	16.06	14.26	33.96
R.07004	25.97	17.60	16.12	29.83
R.07005	23.78	16.12	14.95	34.84
R.07006	26.99	14.85	13.50	35.05
R.07010R	28.95	16.74	16.37	28.43
Seed Parents				
B.005037-3-1-4	24.73	14.85	14.02	35.73
B.05034-1-1-4	25.88	15.79	14.81	33.30
B.05034-1-4-4	24.45	14.76	13.14	37.40
B.05035-2-1-4	28.69	16.35	15.06	30.04
B.05035-2-2-3	25.06	16.50	14.95	32.65
B.05035-2-2-4	27.56	17.14	16.44	28.07
B.05036-4-2-4	24.60	15.26	14.36	35.39
B.05036-4-3-4	26.26	15.31	14.51	33.48
B.05038-4-1-3	28.60	17.12	15.58	27.44
B.05040-3-2-1	26.62	17.12	16.30	30.22
B.05042-1-3-4	27.25	17.47	17.32	28.63
B.05042-1-4-4	24.83	16.99	16.49	30.81
B.05043-2-4-4	25.53	16.11	14.30	34.15

Table A.25. Cont.

Genotype	Glucan	Xylan	Lignin	Solubles
	%	%	%	%
Minimum	22.87	13.78	12.48	21.33
Maximum	31.64	18.89	17.32	40.08
Mean	26.66	16.27	15.12	31.44
Standard Deviation	2.13	1.14	1.10	4.22

Table A.26. BLUE of whole plant composition of ratoon harvests of sweet sorghum hybrids and parental lines across locations in 2007

Genotype	Glucan	Xylan	Lignin	Solubles
	%	%	%	%
Hybrids				
A.B05034/1-4/R.07003	28.63	15.80	14.01	26.65
A.B05034-1-1/R.07003	23.70	14.46	12.13	36.45
A.B05034-1-1/R.07005	24.32	14.48	11.90	36.02
A.B05034-1-4/R.07003	25.07	15.14	12.62	33.41
A.B05034-1-4/R.07005	22.26	14.64	11.47	38.15
A.B05035-2-1/R.07006	23.96	13.09	11.01	38.62
A.B05035-2-1/R.07010R	25.40	14.84	13.58	32.34
A.B05035-2-2/R.07003	24.81	14.40	12.58	34.33
A.B05035-2-2/R.07005	24.95	13.97	11.66	36.34
A.B05035-2-2/R.07005	26.26	14.68	11.97	34.26
A.B05035-2-2/R.07006	29.23	16.48	14.89	24.60
A.B05035-2-2/R.07011R	27.31	15.58	14.12	28.00
A.B05036-4-2/R.07003	26.17	14.39	12.61	32.61
A.B05036-4-2/R.07006	25.26	13.96	11.31	36.36
A.B05036-4-3/R.07003	28.17	15.99	14.50	25.81
A.B05036-4-3/R.07010R	25.18	14.62	12.78	33.19
A.B05037-3-1/R.70705	25.63	15.02	13.31	31.92
A.B05037-3-4/R.07005	26.72	14.60	12.50	32.02
A.B05037-3-4/R.07010R	26.54	14.40	12.76	31.88
A.B05037-3-4/R.07011R	27.19	14.97	13.40	28.92
A.B05038-4-1/R.07010R	24.15	14.14	12.28	35.71
A.B05040-3/R.07004	25.23	15.02	13.40	32.75
A.B05040-3/R.07005	25.06	14.48	10.79	38.00
A.B05042-1-3/R.07003	24.87	15.23	13.97	31.89
A.B05042-1-3/R.07005	27.67	15.80	14.55	26.86
A.B05042-1-4/R.07003	23.87	15.16	13.55	34.06
A.B05042-1-4/R.07006	22.05	14.58	11.90	38.27
A.B05043-2-4/R.07003	24.11	15.14	13.58	33.38
A.B05043-2-4/R.07003	26.52	15.56	13.99	29.13
A.B05043-2-4/R.07005	27.75	15.12	13.35	28.80
A.B05043-2-4/R.07006	26.98	14.31	12.89	31.17
Pollen Parent Cultivars				
R.07003	27.21	15.59	14.03	28.57
R.07004	24.17	14.58	12.80	34.88
R.07005	23.25	14.29	12.56	35.40
R.07006	25.51	14.47	12.61	33.79
R.07010R	25.89	13.94	11.45	36.14
Seed Parents				
B.005037-3-1-4	25.31	15.05	13.68	32.05

Table A.26. Cont.

Genotype	Glucan %	Xylan %	Lignin %	Solubles %
B.05034-1-1-4	25.17	14.50	12.91	33.38
B.05034-1-4-4	23.79	14.32	12.32	35.96
B.05035-2-1-4	24.79	14.14	12.21	35.94
B.05035-2-2-3	23.43	15.16	13.57	34.06
B.05035-2-2-4	24.30	14.89	12.66	35.69
B.05036-4-2-4	23.72	15.07	12.63	34.75
B.05036-4-3-4	23.91	13.94	11.74	37.23
B.05038-4-1-3	28.30	15.14	13.45	28.31
B.05040-3-2-1	25.79	14.12	12.40	33.96
B.05042-1-3-4	23.38	13.44	11.00	39.77
B.05042-1-4-4	24.36	14.48	12.40	35.69
B.05043-2-4-4	25.47	14.25	12.46	33.35
Minimum	22.05	13.09	10.79	24.60
Maximum	29.23	16.48	14.89	39.77
Mean	25.36	14.72	12.78	33.28
Standard Deviation	1.64	0.65	0.98	3.56

Table A.27. BLUE of whole plant composition of primary harvest across locations in 2008

Genotype	Glucan %	Xylan %	Lignin %	Solubles %
Hybrids				
A.B05034-1-3-3/R.07003	30.11	12.26	11.32	31.44
A.B05034-1-3-4/R.07001	30.56	12.37	11.49	30.31
A.B05034-1-3-4/R.07003	32.43	11.53	11.24	28.87
A.B05039-3-4/R.07001	31.69	12.67	12.26	28.34
A.B05039-3-4/R.07002	30.45	12.37	11.72	30.69
A.B05039-3-4/R.07003	30.95	13.60	12.63	27.81
A.B05040-3-2-1/R.07001	33.06	12.04	11.44	28.24
A.B05040-3-2-1/R.07002	30.15	13.15	11.97	30.59
A.B05040-3-2-1/R.07003	30.22	12.87	11.92	30.44
A.B05034-1-1-4/R.07002	30.78	13.14	11.90	28.89
A.B05034-1-1-4/R.07005	30.10	11.58	10.77	32.53
A.B05034-1-1-4/R.07003	30.82	12.18	11.20	30.57
A.B05034-1-4-2/R.07002	31.87	11.55	11.00	30.46
A.B05034-1-4-2/R.07003	29.91	11.31	10.71	32.89
A.B05034-1-4-4/R.07004	31.66	12.95	12.08	27.88
A.B05034-1-4-4/R.07002	30.62	12.25	11.48	30.87
A.B05034-1-4-4/R.07005	31.38	11.91	11.24	30.36
A.B05034-1-4-4/R.07003	30.59	11.52	10.69	31.82
A.B05035-2-1-4/R.07002	31.43	11.96	11.06	30.36
A.B05035-2-1-4/R.07003	30.46	11.87	11.21	31.39
A.B05035-2-2-1/R.07001	31.54	13.21	12.09	28.75
A.B05035-2-2-1/R.07002	29.72	12.73	11.49	31.40
A.B05035-2-2-1/R.07005	30.88	12.08	11.44	30.78
A.B05035-2-2-1/R.07003	31.47	11.60	11.17	30.57
A.B05035-2-2-3/R.07001	31.54	12.84	11.97	28.98
A.B05035-2-2-3/R.07002	30.95	11.94	11.05	30.75
A.B05035-2-2-3/R.07003	30.70	12.05	11.58	30.70
A.B05035-2-2-4/R.07001	31.32	11.97	11.30	30.38
A.B05035-2-2-4/R.07002	30.60	12.21	11.25	31.04
A.B05035-2-2-4/R.07005	31.69	12.39	11.52	29.32
A.B05035-2-2-4/R.07003	30.42	11.80	11.05	31.23
A.B05036-4-2-4/R.07003	30.91	11.52	10.79	31.72
A.B05036-4-3-4/R.07001	34.19	12.01	11.61	26.74
A.B05036-4-3-4/R.07002	31.60	12.47	11.44	29.13
A.B05036-4-3-4/R.07003	30.69	12.28	11.41	30.81
A.B05037-3-1-4/R.07002	30.56	12.08	11.54	30.56
A.B05037-3-4-1/R.07003	30.21	12.24	11.26	31.31
A.B05038-4-1-3/R.07001	29.93	12.67	11.83	30.75
A.B05038-4-1-3/R.07002	29.60	12.67	11.85	30.98
A.B05038-4-1-3/R.07003	30.94	11.85	10.95	31.55
A.B05042-1-3-4/R.07001	33.61	13.11	12.37	25.16
A.B05042-1-3-4/R.07002	34.51	11.75	11.60	26.39
A.B05042-1-3-4/R.07003	33.78	12.77	11.78	25.66
A.B05043-2-4-2/R.07002	29.89	12.27	11.73	31.42
A.B05043-2-4-2/R.07005	31.71	13.02	11.60	28.91
A.B05043-2-4-2/R.07003	31.76	11.61	11.19	30.11
A.B05043-2-4-4/R.07001	33.81	11.83	10.96	27.04
Pollen Parent Cultivars				
R.07001	30.47	12.04	10.79	31.82
R.07002	28.20	12.75	11.15	33.30
R.07003	26.86	12.74	10.96	34.65
R.07005	29.30	13.10	11.04	32.72
R.07006	27.07	12.57	10.42	35.66

Table A.27. Cont.

Genotype	Glucan %	Xylan %	Lignin %	Solubles %
Seed Parents				
B.05034-1-1-4-4	36.69	10.52	10.10	25.76
B.05034-1-3-4-1	35.63	10.35	10.27	27.09
B.05034-1-3-4-2	35.67	9.85	9.86	27.74
B.05034-1-4-2-3	35.97	10.73	10.38	26.37
B.05034-1-4-2-4	36.44	10.25	10.07	26.46
B.05034-1-4-4-1	35.90	11.34	10.75	25.74
B.05034-1-4-4-2	35.99	10.15	10.42	26.43
B.05035-2-1-4-1	36.02	10.69	10.47	26.19
B.05035-2-2-1-1	34.93	11.15	10.63	27.02
B.05035-2-2-1-2	34.13	10.61	10.09	29.11
B.05035-2-2-3-1	35.78	10.91	10.49	26.30
B.05035-2-2-3-2	34.66	11.38	10.75	27.06
B.05035-2-2-4-3	34.46	10.98	10.46	27.94
B.05036-4-2-4-2	35.81	10.85	10.83	26.02
B.05036-4-2-4-3	36.60	10.56	10.73	25.66
B.05036-4-2-4-3	35.32	11.07	11.00	26.23
B.05036-4-3-4-2	36.58	10.44	10.47	25.58
B.05036-4-3-4-3	38.02	9.24	9.71	25.80
B.05037-3-4-1-4	34.70	10.67	10.67	27.35
B.05038-4-1-3-2	36.40	11.49	11.05	24.10
B.05038-4-1-3-3	36.08	11.06	10.75	25.20
B.05039	35.34	12.02	11.48	25.13
B.05040-3-2-1-1	35.20	11.69	11.34	25.63
B.05040-3-2-1-2	34.79	12.03	11.45	25.50
B.05042-1-3-4-2	35.06	11.24	11.17	25.76
B05037-3-1	34.76	11.11	11.04	26.61
B05042-1-4	33.97	11.81	11.22	26.91
B05043-2-4-4	34.89	11.73	11.22	25.65
Minimum	26.86	9.24	9.71	24.10
Maximum	38.02	13.60	12.63	35.66
Mean	32.57	11.81	11.16	28.89
SD	2.57	0.88	0.58	2.59

Table A.28. BLUE of whole plant composition of primary harvest in Weslaco in 2008

Genotype	Glucan %	Xylan %	Lignin %	Solubles %
Hybrids				
A.B05034-1-1-4/R.07002	30.33	12.49	11.38	31.41
A.B05034-1-1-4/R.07003	30.44	10.90	10.22	33.46
A.B05034-1-1-4/R.07005	31.12	11.50	10.87	32.32
A.B05034-1-3-3/R.07003	30.35	11.37	10.76	33.72
A.B05034-1-3-4/R.07001	32.54	11.46	11.12	29.77
A.B05034-1-3-4/R.07003	33.07	10.79	10.72	30.30
A.B05034-1-4-2/R.07002	32.86	11.02	10.37	31.67
A.B05034-1-4-2/R.07003	31.76	10.39	10.53	32.06
A.B05034-1-4-4/R.07002	30.31	12.03	11.08	32.37
A.B05034-1-4-4/R.07003	29.57	11.78	10.69	33.27
A.B05034-1-4-4/R.07004	32.57	11.78	11.27	29.65
A.B05034-1-4-4/R.07005	30.98	12.13	11.24	31.63
A.B05035-2-1-4/R.07002	30.67	11.49	10.79	32.52
A.B05035-2-1-4/R.07003	30.14	11.80	10.80	33.20
A.B05035-2-2-1/R.07001	33.90	12.57	11.74	27.85
A.B05035-2-2-1/R.07002	29.16	12.07	10.63	34.56
A.B05035-2-2-1/R.07003	32.31	10.55	10.72	30.96
A.B05035-2-2-1/R.07005	31.93	10.99	10.59	32.17
A.B05035-2-2-3/R.07001	33.13	10.97	10.99	30.44
A.B05035-2-2-3/R.07002	31.88	10.84	10.54	31.79
A.B05035-2-2-3/R.07003	31.41	10.65	10.75	32.17
A.B05035-2-2-4/R.07001	32.55	10.18	10.04	32.62
A.B05035-2-2-4/R.07002	30.66	11.07	10.36	33.64
A.B05035-2-2-4/R.07003	30.36	11.65	10.39	32.51
A.B05035-2-2-4/R.07005	31.30	11.34	10.84	32.28
A.B05036-4-2-4/R.07003	31.60	11.99	11.08	30.95
A.B05036-4-3-4/R.07001	36.04	9.48	10.21	28.96
A.B05036-4-3-4/R.07002	32.58	12.33	11.44	29.08
A.B05036-4-3-4/R.07003	30.49	11.30	10.39	33.59
A.B05037-3-1-4/R.07002	30.51	12.43	11.57	31.31
A.B05037-3-4-1/R.07003	31.36	12.05	10.81	32.04
A.B05038-4-1-3/R.07001	31.77	12.36	11.44	30.01
A.B05038-4-1-3/R.07002	30.69	12.68	11.48	31.07
A.B05038-4-1-3/R.07003	31.73	12.07	11.16	30.57
A.B05039-3-4/R.07001	31.91	11.75	11.34	29.79
A.B05039-3-4/R.07002	30.20	12.46	11.64	31.79
A.B05039-3-4/R.07003	31.45	13.29	12.22	28.39
A.B05040-3-2-1/R.07001	33.86	10.95	10.73	29.08
A.B05040-3-2-1/R.07002	30.42	12.92	11.34	32.20
A.B05040-3-2-1/R.07003	31.73	12.20	11.33	30.54
A.B05042-1-3-4/R.07001	33.84	12.71	11.93	26.55
A.B05042-1-3-4/R.07002	35.41	10.79	10.73	27.98
A.B05042-1-3-4/R.07003	34.04	12.57	11.24	26.88
A.B05043-2-4-2/R.07002	31.59	11.69	11.16	31.44
A.B05043-2-4-2/R.07003	31.68	11.88	11.25	30.76
A.B05043-2-4-2/R.07005	29.49	12.64	11.33	33.44
A.B05043-2-4-4/R.07001	34.67	12.21	10.87	26.87
Pollen Parent Cultivars				
R.07001	30.81	11.75	10.36	32.47
R.07002	28.18	13.16	10.89	34.39
R.07003	26.09	12.62	10.39	37.68
R.07005	27.78	12.15	9.59	38.41
R.07006	26.81	11.62	9.42	38.46

Table A.28. Cont.

Genotype	Glucan %	Xylan %	Lignin %	Solubles %
Seed Parents				
B.05034-1-1-4-4	38.11	9.59	9.35	26.77
B.05034-1-3-4-1	35.12	10.91	10.18	28.22
B.05034-1-3-4-2	36.86	9.87	9.73	26.97
B.05034-1-4-2-3	36.29	9.99	9.75	28.29
B.05034-1-4-2-4	36.42	9.31	9.30	28.98
B.05034-1-4-4-1	34.98	11.50	10.72	27.75
B.05034-1-4-4-2	37.21	9.77	10.13	26.37
B.05035-2-1-4-1	35.71	10.84	10.39	26.90
B.05035-2-2-1-1	37.03	9.07	9.33	28.63
B.05035-2-2-1-2	35.26	9.51	9.26	30.55
B.05035-2-2-3-1	37.17	9.63	9.66	27.85
B.05035-2-2-3-2	34.05	10.40	10.03	30.30
B.05035-2-2-4-3	34.44	10.33	10.01	30.17
B.05036-4-2-4-2	34.80	11.33	10.83	27.69
B.05036-4-2-4-3	36.06	11.33	10.98	26.33
B.05036-4-2-4-3	35.81	11.13	10.86	26.88
B.05036-4-3-4-2	38.23	9.59	9.84	26.07
B.05036-4-3-4-3	37.19	9.65	9.85	26.84
B.05037-3-4-1-4	34.50	10.81	10.59	28.74
B.05038-4-1-3-2	37.07	11.73	10.87	24.03
B.05038-4-1-3-3	34.47	12.35	11.35	26.48
B.05039	33.93	11.38	10.92	28.63
B.05040-3-2-1-1	35.77	10.90	10.64	27.03
B.05040-3-2-1-2	34.06	11.67	10.80	28.28
B.05042-1-3-4-2	34.31	11.91	11.16	27.60
B05037-3-1	32.62	12.25	11.34	29.10
B05042-1-4	32.36	11.82	11.05	29.73
B05043-2-4-4	32.20	12.56	11.05	29.05
Minimum	26.09	9.07	9.26	24.03
Maximum	38.23	13.29	12.22	38.46
Mean	32.80	11.39	10.71	30.29
SD	2.66	1.00	0.64	2.84

Table A.29. BLUE of whole plant composition of primary harvest in College Station in 2008

Genotype	Glucan %	Xylan %	Lignin %	Solubles %
Hybrids				
A.B05034-1-1-4/R.07002	31.38	13.51	12.16	27.77
A.B05034-1-1-4/R.07003	30.67	13.11	11.75	30.07
A.B05034-1-1-4/R.07005	27.25	11.65	10.84	35.91
A.B05034-1-3-3/R.07003	29.08	12.10	11.00	33.13
A.B05034-1-3-4/R.07001	28.98	12.39	11.66	32.30
A.B05034-1-3-4/R.07003	31.20	11.89	11.07	30.52
A.B05034-1-4-2/R.07002	30.00	11.99	11.16	32.80
A.B05034-1-4-2/R.07003	27.71	11.70	10.29	36.77
A.B05034-1-4-4/R.07002	30.39	12.59	11.85	30.92
A.B05034-1-4-4/R.07003	31.11	11.51	10.65	31.90
A.B05034-1-4-4/R.07004	30.86	13.47	12.01	28.59
A.B05034-1-4-4/R.07005	31.54	11.24	10.89	31.39
A.B05035-2-1-4/R.07002	31.06	12.42	11.16	30.68
A.B05035-2-1-4/R.07003	29.35	12.00	11.04	33.25
A.B05035-2-2-1/R.07001	29.11	13.32	11.91	31.93
A.B05035-2-2-1/R.07002	26.46	13.53	11.81	34.61
A.B05035-2-2-1/R.07003	29.66	12.46	11.28	32.72
A.B05035-2-2-1/R.07005	29.43	12.36	11.45	32.55
A.B05035-2-2-3/R.07001	30.77	13.06	12.15	29.71
A.B05035-2-2-3/R.07002	29.89	12.43	11.21	31.69
A.B05035-2-2-3/R.07003	29.33	13.29	12.02	31.74
A.B05035-2-2-4/R.07001	29.21	12.31	11.43	32.67
A.B05035-2-2-4/R.07002	29.90	12.65	11.44	31.20
A.B05035-2-2-4/R.07003	30.49	11.13	10.69	32.89
A.B05035-2-2-4/R.07005	32.80	11.85	11.45	28.48
A.B05036-4-2-4/R.07003	25.95	13.00	11.03	37.03
A.B05036-4-3-4/R.07001	35.25	12.51	12.08	25.00
A.B05036-4-3-4/R.07002	30.97	12.12	10.94	30.83
A.B05036-4-3-4/R.07003	29.50	12.45	11.37	32.38
A.B05037-3-1-4/R.07002	30.54	11.34	11.11	32.05
A.B05037-3-4-1/R.07003	28.08	12.45	11.26	33.62
A.B05038-4-1-3/R.07001	26.89	12.77	11.74	34.76
A.B05038-4-1-3/R.07002	27.51	11.83	11.18	34.87
A.B05038-4-1-3/R.07003	29.50	11.49	10.35	35.04
A.B05039-3-4/R.07001	28.98	13.94	13.00	30.57
A.B05039-3-4/R.07002	29.49	12.23	11.51	32.55
A.B05039-3-4/R.07003	29.78	13.75	12.64	29.74
A.B05040-3-2-1/R.07001	31.53	12.92	11.90	29.57
A.B05040-3-2-1/R.07002	28.35	13.33	11.90	32.93
A.B05040-3-2-1/R.07003	26.07	13.08	11.54	35.89
A.B05042-1-3-4/R.07002	32.40	13.50	12.81	26.10
A.B05042-1-3-4/R.07003	33.60	12.23	11.99	26.48
A.B05043-2-4-2/R.07002	26.40	12.32	11.44	36.30
A.B05043-2-4-2/R.07003	31.18	11.19	10.73	31.98
A.B05043-2-4-2/R.07005	32.06	12.17	11.49	29.40
Pollen Parent Cultivars				
R.07001	29.05	11.10	9.72	35.98
R.07002	26.90	12.46	10.39	35.53
R.07003	25.98	12.73	10.85	35.29
R.07005	28.89	12.70	11.12	33.06
R.07006	24.77	12.96	10.41	38.36
Seed Parents				
B.05034-1-1-4-4	36.04	11.89	11.08	24.74

Table A.29. Cont.

Genotype	Glucan %	Xylan %	Lignin %	Solubles %
B.05034-1-3-4-1	34.93	10.78	10.44	27.72
B.05034-1-3-4-2	33.39	10.64	10.19	30.06
B.05034-1-4-2-3	35.82	11.23	10.60	26.05
B.05034-1-4-2-4	35.60	11.73	10.90	25.28
B.05034-1-4-4-1	36.29	11.53	10.91	25.15
B.05034-1-4-4-2	34.24	11.63	11.42	26.88
B.05035-2-1-4-1	35.42	11.23	10.87	26.65
B.05035-2-2-1-1	33.70	12.57	11.51	26.04
B.05035-2-2-1-2	31.67	11.46	10.66	31.09
B.05035-2-2-3-1	35.18	11.70	10.85	26.34
B.05035-2-2-3-2	36.41	11.28	10.85	24.91
B.05035-2-2-4-3	34.71	11.04	10.43	27.87
B.05036-4-2-4-2	34.34	12.28	11.73	26.16
B.05036-4-2-4-3	36.66	10.43	10.57	26.17
B.05036-4-2-4-3	35.54	11.44	11.23	25.84
B.05036-4-3-4-2	34.74	11.32	11.01	26.07
B.05036-4-3-4-3	38.50	9.11	9.76	26.04
B.05037-3-4-1-4	33.13	11.33	10.98	28.67
B.05038-4-1-3-2	37.62	11.63	10.65	23.32
B.05038-4-1-3-3	38.07	10.47	10.05	24.51
B.05039	37.47	12.77	11.47	22.43
B.05040-3-2-1-1	35.16	11.53	11.08	26.30
B.05040-3-2-1-2	33.75	13.28	12.19	25.24
B.05042-1-3-4-2	35.49	11.02	10.98	25.01
B05037-3-1	35.12	10.56	10.49	27.03
B05042-1-4	34.02	11.34	10.64	28.00
B05043-2-4-4	36.44	11.43	10.86	24.68
Minimum	24.77	9.11	9.72	22.43
Maximum	38.50	13.94	13.00	38.36
Mean	31.62	12.07	11.20	30.07
SD	3.39	0.91	0.65	3.86

Table A.30. BLUE of whole plant composition of primary harvest in Halfway in 2008

Genotype	Glucan %	Xylan %	Lignin %	Solubles %
Hybrids				
A.B05034-1-1-4/R.07002	30.64	13.54	11.99	27.81
A.B05034-1-1-4/R.07003	31.69	12.66	11.54	28.03
A.B05034-1-1-4/R.07005	32.04	11.47	10.47	29.24
A.B05034-1-3-3/R.07003	31.35	13.79	12.36	26.51
A.B05034-1-3-4/R.07001	30.16	13.26	11.69	28.86
A.B05034-1-3-4/R.07003	33.77	12.39	12.28	24.24
A.B05034-1-4-2/R.07002	32.75	11.64	11.48	26.91
A.B05034-1-4-2/R.07003	30.52	12.08	11.34	29.36
A.B05034-1-4-4/R.07002	31.15	12.14	11.50	29.31
A.B05034-1-4-4/R.07003	31.44	11.11	10.47	30.56
A.B05034-1-4-4/R.07004	31.59	13.88	13.12	25.17
A.B05034-1-4-4/R.07005	31.83	12.55	11.48	27.94
A.B05035-2-1-4/R.07002	32.34	11.88	11.27	28.12
A.B05035-2-1-4/R.07003	34.40	11.47	11.90	24.99
A.B05035-2-2-1/R.07001	31.60	13.75	12.62	26.47
A.B05035-2-2-1/R.07002	33.55	12.59	12.04	25.02
A.B05035-2-2-1/R.07003	32.66	11.78	11.45	28.03
A.B05035-2-2-1/R.07005	31.58	13.24	12.40	27.10
A.B05035-2-2-3/R.07001	30.38	15.28	12.90	26.72
A.B05035-2-2-3/R.07002	31.22	12.83	11.28	28.82
A.B05035-2-2-4/R.07001	32.71	14.11	12.69	24.62
A.B05035-2-2-4/R.07002	31.22	12.90	11.95	28.28
A.B05035-2-2-4/R.07003	30.04	14.01	13.00	27.06
A.B05035-2-2-4/R.07005	30.96	13.98	12.27	27.19
A.B05036-4-2-4/R.07003	35.19	9.59	10.26	27.17
A.B05036-4-3-4/R.07001	29.91	14.99	12.72	27.07
A.B05036-4-3-4/R.07002	31.14	13.18	11.89	27.70
A.B05036-4-3-4/R.07003	32.08	13.08	12.46	26.47
A.B05037-3-1-4/R.07002	30.33	12.99	11.68	28.47
A.B05037-3-4-1/R.07003	32.76	11.92	11.55	26.82
A.B05038-4-1-3/R.07002	32.16	14.94	13.91	23.69
A.B05039-3-4/R.07001	33.33	12.63	12.88	25.23
A.B05039-3-4/R.07002	32.34	12.42	11.85	27.30
A.B05040-3-2-1/R.07001	33.79	12.25	11.69	26.08
A.B05040-3-2-1/R.07002	32.54	13.19	12.75	25.71
A.B05040-3-2-1/R.07003	32.85	13.34	12.88	24.88
A.B05043-2-4-2/R.07002	32.66	13.01	12.74	25.13
A.B05043-2-4-2/R.07005	34.17	13.87	11.87	23.47
A.B05043-2-4-4/R.07001	32.48	9.66	10.39	29.14
Pollen Parent Cultivars				
R.07001	31.54	13.26	12.30	27.00
R.07002	29.38	12.48	12.61	29.76
R.07003	29.44	12.88	11.70	30.19
R.07005	31.23	14.46	12.40	26.70
R.07006	29.63	13.13	11.45	30.16
Seed Parent Cultivars				
B.05034-1-1-4-4	35.91	10.10	9.87	25.78
B.05034-1-3-4-1	36.85	9.37	10.17	25.33
B.05034-1-3-4-2	36.52	8.52	9.50	26.88
B.05034-1-4-2-3	35.82	10.96	10.80	24.75
B.05034-1-4-2-4	37.30	9.71	10.02	25.12
B.05034-1-4-4-1	36.44	10.99	10.60	24.31
B.05034-1-4-4-2	36.52	9.05	9.72	26.03

Table A.30. Cont.

Genotype	Glucan %	Xylan %	Lignin %	Solubles %
B.05035-2-1-4-1	36.94	10.00	10.15	25.03
B.05035-2-2-1-1	34.07	11.81	11.06	26.38
B.05035-2-2-1-2	35.45	10.88	10.34	25.69
B.05035-2-2-3-1	35.00	11.40	10.97	24.71
B.05035-2-2-3-2	34.58	12.32	11.33	24.67
B.05035-2-2-4-3	34.25	11.56	10.95	25.79
B.05036-4-2-4-2	38.28	8.95	9.94	24.21
B.05036-4-2-4-3	37.07	9.92	10.65	24.49
B.05036-4-2-4-3	34.62	10.63	10.91	25.97
B.05036-4-3-4-2	36.76	10.42	10.56	24.58
B.05036-4-3-4-3	38.36	8.98	9.52	24.51
B.05037-3-4-1-4	36.46	9.86	10.45	24.64
B.05038-4-1-3-2	34.53	11.10	11.63	24.96
B.05038-4-1-3-3	35.71	10.34	10.85	24.61
B.05039	34.61	11.92	12.04	24.33
B.05040-3-2-1-1	34.67	12.63	12.31	23.55
B.05040-3-2-1-2	36.56	11.13	11.37	22.97
B.05042-1-3-4-2	35.38	10.78	11.35	24.65
B05037-3-1	36.55	10.51	11.28	23.69
B05042-1-4	35.53	12.25	11.96	23.00
B05043-2-4-4	36.03	11.20	11.75	23.22
Minimum	29.38	8.52	9.50	22.97
Maximum	38.36	15.28	13.91	30.56
Mean	33.44	11.98	11.52	26.23
SD	2.39	1.59	0.97	1.92

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