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(54) **METHOD FOR PRODUCTION OF SORGHUM HYBRIDS WITH SELECTED FLOWERING TIMES**

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**A01H 1/02** (2006.01)  
**A01H 1/04** (2006.01)  
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CPC ..... **C12N 15/827** (2013.01); **A01H 1/02** (2013.01); **A01H 1/04** (2013.01); **A01H 5/10** (2013.01); **C07K 14/415** (2013.01); **C12Q 1/68** (2013.01)

(58) **Field of Classification Search**

USPC ..... 800/290  
See application file for complete search history.

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(57) **ABSTRACT**

Methods and composition for the production of sorghum hybrids with selected and different flowering times are provided. In accordance with the invention, a substantially continual and high-yield harvest of sorghum is provided. Improved methods of seed production are also provided.

**4 Claims, 7 Drawing Sheets**

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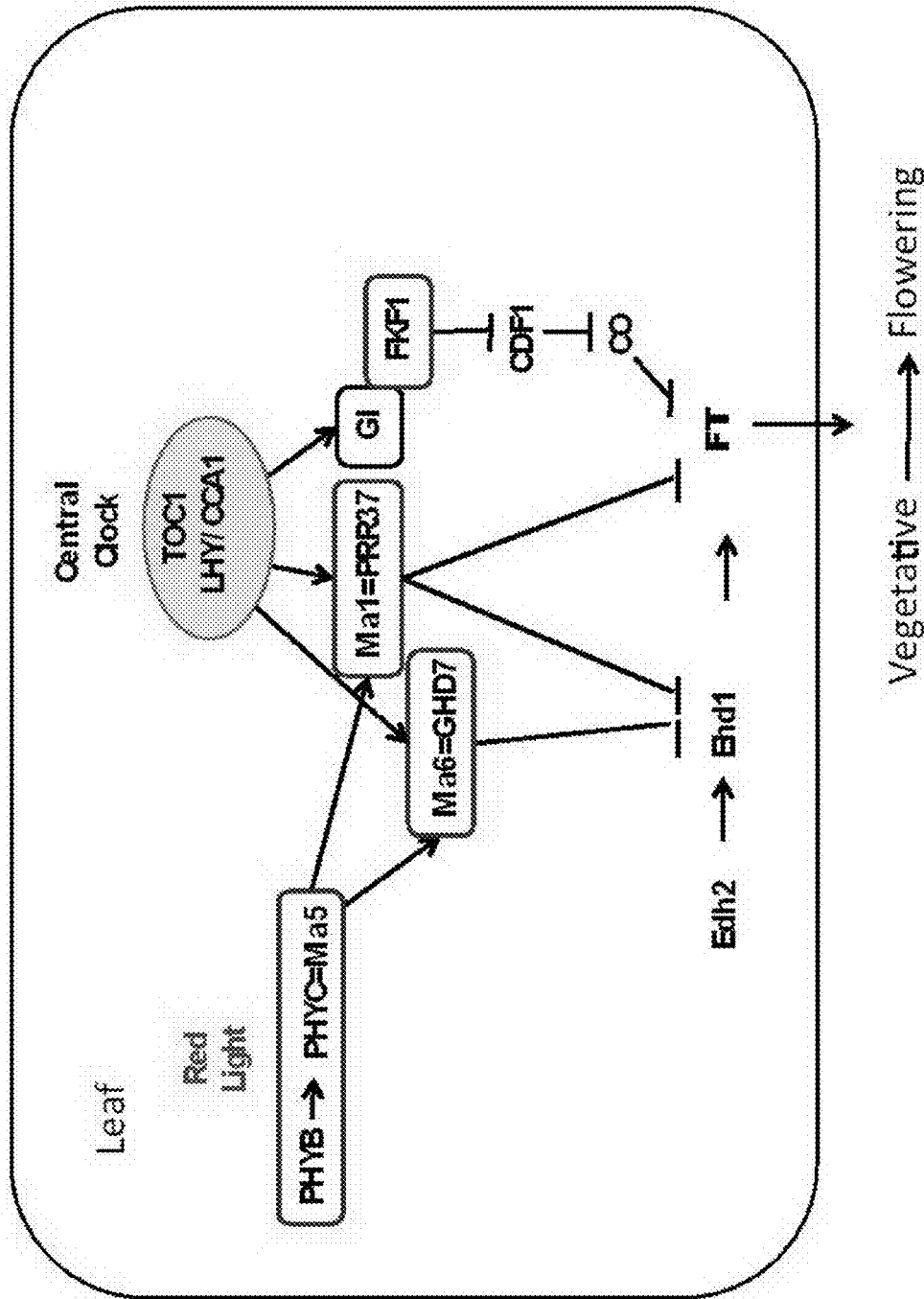


FIG. 1

ATGATGCTTCGGAATAACAACAATAATCTGAGGAGCAATGGCCCATCAGATGGCTT  
GCTCAGCAGGCCAACCCCTGCAGTACTCCAGGATGATGACGATGGTGGTATGATG  
ATACGGAAAACCAGCAGCAGGAGGCGGTCTACTGGGAGCGCTTCTCCAGAAGAAG  
ACCATCAACGTCTTGCTCGTGGAGAGTGACACTGCACTAGGCGGGTCGTCAGTGCC  
CTTCTTCGTCAGTGCATGTACCAA(x2)GTTATCTCTGCTGAAAATGGCCAGCAAGCAT  
GGAATTATCTTGAAGATAAGCAGAACAACATAGATATTGTTTTGATTGAGGTTTTTA  
TGCCCGGTGTGTCTGGAATTTCTCTGCTGAGTAGGATCATGAGCCACAATATTTGCA  
AGAATATTCCAGTGATT(x3)ATGATGCTTCCGAATGATGCTAGGAATACAGTCTTTAA  
ATGTTTGTCGAAAGGTGCTGTTGACTTTTTAGTCAA7CCTATACGTAAGAATGAACTT  
AAGAATCTTTGGCAGCATGTATGGAGACGGTGTACAGC(x4)TCAAGTGGTAGTGGA  
AGTGAAGTGGCATTTCAGACGCAGAAGTGTGGCAAATCAAAGGTGGAAGAAT  
CTGGTAATAATAGTGGTAGCAATGACAGTCACGACAACGAAGCAGACATGGGACTT  
AATGCAAGGGATGACAGTGATAATGGCAGTGGCACTCAA(x5)GCGCAGAGCTCATG  
GACTAAGTGTGCTGTGGAGATGGACAGCCACAGGCAATGTCTCTGGATCAGTTAG  
CCGATTCACCTGATAGCACTTGTGCGTAAAGTAATCCACCCAAAGTCAGAGATATGTA  
GCAACAGACGGCTACCA(x6)GACGACTTCAAGGAAAAGGACTTGGAGATAGGTGGC  
CCTGGAAATTTATATATAGATCACCAATCTTCCCCAAATGAGAGGCCTATCAAAGCA  
ACAGATGGACGTTGTGAGTACCCACCAAAAAACAATTCGAAGGAGTCAATGATGCA  
AAATCTAGAGGACCCAACCTGTTTCGAGCTGCTGATCTAATTGGTTCAATGGCCAAAA  
CATGGATAACCCAGGAGGCAGCGAGAGCTGCAGATACCCCTAATCTCCCTTCCAAAG  
TGCCAGAAGGGAAAAGATAAGAACAAGCATGACAAAATTTGCCATCACTGAGTTG  
AGTTTGAAGAGGTTCGAGATCATGTGGA7ATGGTGCCAATACAGTCAAAGTGAATGA  
ACAACAGAATGTATTAAGACAGTCAAATCTCTCAGCTTTTACAAGG(x7/1)TACCATA  
CATCTACGGCTTCCAATCAAGGTGGGACTGGATTAGTAGGGAGCTGTTCCGCCACATG  
ACAACAGCTCAGAGGCTATGAAAACAGATTCTACTTACAACATGAAGTCAAATTCA  
GATGCTGCTCCAATAAAACAAGGCTCCAACGGAAGTAGCAATAACAATGACATGGG  
TTCCACTACAAAGAATGTTGTGACAAAGCCACTACAAATAATAAGGACAGGGTAA  
TGTTGCCCTCATCAGCTATTAATAAGGCTAATGGACACACATCAGCATTCCACCCTG  
TGCAGCATTGGACGATGGTTCCAGCTAATGCAGCAGGAGGGACAGCGAAGGCTGAT  
GAAGTGGCCAACATTGCAGGTTACCTTTCAGGTGACATGCAGTGTAACCTGATGCAA  
TGGTACCCTCGTCCAACCCTTCAATTACGTCCAGTTTGATGGTGCACGGGAGAATGGT  
GGATCGGGAGCCCTGGAATGTGGTTCCTCCAACGTAFTTTGATCCTCCAGTTGAAGGT  
CAAGCTACTAACTATGGTGTGAACAGGAGCAACTCAGGCAGTAACAATGCAACCAA  
GGGGCAGAATGGAAGTAATACAGTTGGTGAAGCATGGCTGGTCCAAATGCAAATG  
CAAATGGTAATGCTGGACGAACAACATGGAGATTGCTAATGAGGTGATCGACAAA  
AGTGGACATGCAGGAGGTGGCAATGGGAGTGGCAGTGGCAGTGGCAATGACACATA  
TGTCAAACGGCTTGCAGCGGGCTTGACACCAGACAAGCACAACATAAAGAAATATA  
GAGAGAAAAAGAAAGATCGAAACTTTGGGAAAAAG(x8)GTGCGGTACCAGAGCAGA  
AAGAGGCTGGCCGACCAGCGGCCGCGTTTCGTGGGCAGTTCGTGAAGCAAGCCTT  
GCAAGATCAGGGCGAACAGGACGGAAGTGGAGAGAGATGA

FIG. 2A

MMLRNNNNNLRNSGPSDGLLSRPTPAVLQDDDDGGDDDTENQQQEAVYWERFLQKK  
TINVLLVESDDCTRRVVSALLRHC MYQVISAENGQQA WNYLEDKQNNIDIVLIEVFMPG  
VSGISLLSRIMSHNICKNIPVIMMSSNDARNTVFKCLSKGAVDFLVNPIRKNELKNLWQH  
VWRRCHSSSGSGSESGIQTQKCGKSKGGKESGNNSGSNDSHDNEADMGLNARDSDN  
GSGTQAQSSWTKCAVEMDSPQAMSLDQLADSPDSTCA.VIHPKSEICSNRRLPDDFKEK  
DLEIGGPGNLYIDHQSSPNERPIKATDGRCEYPPKNNSKESMMQNLEDPTVRAADLIGS  
MAKNMDTQEAAARAADTPNLPSKVPEGKDKNKHDKILPSLELSLKRSRSCGYGANTVKA  
DEQQNVLQRSNLSAFTRYHTSTASNQGGTGLVGSCSPHDNSSEAMKTDSTYNMKSNSD  
AAPIKQGSNGSSNNNDMGSTTKNVVTKPTTNNKDRVMLPSSAINKANGHTSAFHPVQH  
WTMVPANAAGGTAKADEVANIAGYPSGDMQC NLMQWYPRPTLHYVQFDGARENGGS  
GALECGSSNVFDPPVEGQATNYGVNRSNSGSNNA TKGQNGSNTVGASMAGPNANANG  
NAGRTNMEIANEVIDKSGHAGGGNGSGSGSNDTYVKRLAAGLTPRQAQLK KYREKK  
KDRNFGKKVRYQSRKRLADQRPRFRGQFVKQALQDQGEQDGTGER.

FIG. 2B

ATGTCAGGGCCAGCATGCGGTGTGTGCGGTGCAGCCGCCTGCTGCCGGCACCTCTTC  
CACACCGGCGACGAGAACGACGACTTCAACAGCCGGCGGGCCTTGTTCTCTGTCTTC  
CCTGCGGCGGTTACCATCATGAGCCCAGCCCAGCAGCATGCAGCAGCAGCCTCC  
GGCGGGGTGCCTGCACGAGTTCAGTTCTTTGGCCATCAGGACAACGATGACCACC  
AAGAAAGCATCGCCTGGCTCTTCGACCACCCGCCGCCACCTGCGCATGATGTCGACG  
ACGACGACCGGTCCCCAGCTGAGAACCAGCAGCCTCATCACCGGGCGTTTGACCCG  
TTTGGGACGGAGGGAAACGGGCTCACCTTTGAGGTTGATGCCCGGCTGGGCCTCGG  
CAGCGGGGGCGCCGCCCGGCAAACAGCAGAGACAGCAGCAGCAAGCGCCACCATC  
ATGTCATTCTGTGGGAGCACATTCACAGACGCCGCAAGCTCGAGGCTCAAGGAGCC  
AACCTGACTGACGACAGTCAGCTGCAAATGCCGGTAGGTCAGTCAACGGAGAGG  
**GAGGCTAAGTTGATGAGGTACAAGGAGAAGAGGATGATGAGGTGTTATGAGAA**  
**GCAGATAAGATATGCATCCAGGAAAGCCTATGCGCAGGTGAGACCCCGGGTGA**  
**AAGGTCGCTTTGCCAAGGTAACCGAAGCCTGCTCCGCCACAGCAGACAATGTTGG**  
CAACGACCACCTGCTCTGA

FIG. 3A

ATGTCAGGGCCAGCATGCGGTGTGTGCGGTGCAGCCGCCTGCTGCCGGCACCTCTTC  
CACACCGGCGACGAGAACGACGACTTCAACAGCCGGCGGGCCTTGTTCTCTGTCTTC  
CCTGCGGCGGTTACCATCATGAGCCCAGCCCCAGCAGCATGCAGCAGCAGCCTCC  
GGCGGGGTGCCTGCACGAGTTCCAGTTCTTTGGCCATCAGGACAACGATGACCACC  
AAGAAAGCATCGCCTGGCTCTTCGACCACCCGCGCCACCTGCGCATGATGTCGAG  
TCGACGACGACGACGACCGGTCCCAGCTGAGAACCAGCAGCCTCATCACCGGCGTT  
GACCCGTTTGGGACGGAGGGAAACGGGCTCACCTTTGAGGTTGATGCCCGGCTGGG  
CCTCGGCAGCGGGGCGCCGCCCGGCAAACAGCAGAGACAGCAGCAGCAAGCGCC  
ACCATC/ATGTCATTCTGTGGGAGCACATTACAGACGCCGCAAGCTCGAGGCTCAA  
GGAGCCAACCCTGACTGACGACAGTCAGCTGCAAATGCCGGTAGGTCAGTCAACGG  
AGAGGGAGGCTAAGTTGATGAGGTACAAGGAGAAGAGGATGAGGAGGTGTTA  
TGAGAAGCAGATAAGATATGCATCCAGGAAAGCCTATGCGCAGGTGAGACCCC  
GGGTGAAAGGTGCGTTTGCCAAGGTAACCGAAGCCTGCTCCGCCACAGCAGACAA  
TGTTGGCAACGACCACCTGCTCTGA

FIG. 3B

ATGTCGTCGCCGTTGAACAACCGGGGGACGTGCTCCCGGAGCAGCTCTGCGCGG  
TCCAGGCACAGCGCGCGGGTGGTGGCGCAGACGCCCGTGGACGCGCAGCTGCA  
CGCCGAGTTCGAGAGCTCCCAGCGCAACTTCGACTACTCCTCGTCGGTGAGCGC  
CGCCATCCGACCGTCGGTCAGCACCAGCACCGTCTCCACCTACCACCAGACCAT  
GCAGCGGGGCCTCTACATCCAGCCCTTCGGCTGCCTGCTCGCCGTCCACCCGGA  
CACCTTCACGTTGCTCGCCTACAGCGAGAACGCGCCCCGAGATGCTCGACCTCAC  
GCCACACGCGGTCCCCACCATCGACCAGCGGGACGCGCTCGCCGTGCTCGCCGA  
CGTGCGCACGCTCTTCCGCTCGCAGAGCTCCGTCGCGCTGCACAAGGCCGCCAC  
CTTCGGGGAGGTCAACCTGCTCAACCCCATCCTCGTGCATGCCAGGACGTGCGAG  
GAAGCCCTTCTACGCCATATTGCACCGGATCGACGTCGGCCTTGTATCGACCTT  
GAGCCGGTCAACCCAGTTGACGTGCCAGCCACTGCTGCGGGTGCCTTAAGTCG  
TACAAGCTCGCCGCCAAGGCCATCTCCAGGCTGCAGTCGCTGCCAGCGGGAAC  
CTGTGCTGCTGTGCGATGTGCTTGTCCGTGAGGTGAGCGAGCTCACGGGCTAT  
GACCGGGTCATGGCGTACAAGTTCATGAGGATGAGCATGGTGAGGTCATTTCC  
GAGTGCAGGAGGTCTGATCTGGAGCCGTATCTTGGCCTGCACTACCCAGCCACC  
GACATCCCGCAGGCGTCCAGGTTCTTGTATGAAGAACAAGTGAGGATGATA  
TGTGATTGCTCTGCCACTCTGGTGAAGATCATTGAGGATGATAGCCTAGCACAG  
CCTCTCAGCCTCTGTGGTCCACCCTCAGGGCTTCCCATGGTTGCCATGCACAGT  
ACATGGCAAACATGGGTTCTGTTGCATCGCTTGTGATGTCAGTGACTATAAGCA  
ATGATGAGGAGGAAGATGTTGATACCGGGAGTGACCAACAACCGAAAGGCAGG  
AACTGTGGGGGCTGGTTCGTCTGCCATCATAAAGCCCGAGGTTTCGTCCCTTTC  
CCACTAAGGTACGCTTGCGAGTTTCTCTTGCAAGTATTTGGCATAACAGCTAAAC  
AAGGAGGTGGAATTGGCTGCTCAGGCAAAGGAGAGGCACATCCTCAGAACGCA  
AACCTTCTTTGTGATATGCTCCTGCGGGATGCTCCTGTTGGGATATTTACCCAG  
TCACCTAATGTGATGGATCTAGTAAAGTGCGATGGAGCTGCATTGTATTACCAG  
AACCAGCTTTTGTGCTCGGATCAACACCCTCCGAGTCAGAGATAAAGAGCATT  
GCCACATGGCTGCAGGAGAACCATGATGGTTCAACTGGGCTGAGTACTGACAGC  
TTAGTGGAAGCAGGTTATCCTGGTGCCTGCTGCACTTCGTGAAGTTGTGTGTGGC  
ATGGCGGCTATAAAGATCTCTTCCAAAGATTTTATCTTCTGGTTCCGATCGCACA  
CAACAAGGAGATCAAGTGGGGTGGGGCTAAGCATGAACCGGTTGACGCAGAT  
GACAATGGCAGGAAGATGCATCCACGATCTTCATTCAAGGCCTTCTTGGAGGTG  
GTTAAATGGAGAAGTGTTCCTGGGAGGATGTTGAAATGGATGCTATTCATTCT  
TTGCAGTTAATATTACGTGGCTCCCTGCAAGATGAAGATGCCAACAGAAACAAT  
GTAAGGTCCATTGTAAGAGCTCCACCTGATGATACGAAGAAGATACAGGGGCT  
ACTTGAAC TAAGAACAGTTACAAACGAGATGGTCCGCTTAATTGAGACAGCAAC  
CGCCCCTGTCTTGGCTGTCGACATTGCCGGTAACATAAATGGATGGAACAATAA  
AGCTGCAGAACTAACAGGGTTACCTGTAATGGAAGCCATAGGGAGGCCTCTGAT  
AGATCTTGTGTTGTTGATTCTATTGAAGTGGTTAAGCGGATTTTGGACTCAGCT  
TTACAAG(\*2)GAATTGAAGAGCAAAATCTGGAATCAAGCTTAAAGCATTCCAT  
GAACAGGAATGCAATGGTCCAATAATCTTGATGGTTAACTCCTGCTGTAGTCGG  
GACCTTTCAGAGAAAGTCATTGGAGTTTGCCTTGTAGGACAAGATTTGACCACG  
CAGAAGATGATTATGGATAAGTATACTAGGATACAAGGAGACTATGTTGCCATA  
GTAAAGAACCCAGTGAGCTCATCCCTCCCATATTTATGATCAATGATCTTGGTT  
CCTGCTTAGAGTGGAATAAAGCTATGCAGAAGATTACCGGTATACAGAGGGAA

FIG. 4A



GATGTGATAGATAAGTTGTTAATTGGGGAGGTCTTCACCCTTCATGATTATGGCT  
GTAGGGTGAAAGATCATGCTACTCTAACGAACTTAGCATACTGATGAATGCAG  
TGATTTCTGGTCAGGATCCTGAGAAGCTCCTTTTTGGTTTCTTCGACACAGATGG  
GAAGTATATTGAATCCTTGCTGACAGTGAACAAGAGAATAAATGCTGAGGGTA  
AGATCACTGGCGCTATTTGCTTTCTGCATGTGGCCAGTCCAGAGCTTCAGCATGC  
TCTCCAGGTGCAGAAAATGTCTGAACAAGCTGCCACAAACAGTTTTAAGGAATT  
AACTTACATTCATCAAGAATTAAGGAACCCACTCAATGGCATGCAATTTACTTG  
CAACTTATTGGATCCTTCCGAATTGACAGAGGAGCAGAGGAACTTCTTTCATC  
TAATATTCTCTGTCAGGACCAGCTGAAAAAGATTTTACATGACACTGATCTTGA  
AAGCATTGAACAGTG(\*3)CTATATGGAGATGAACACAGTAGAGTTCAACCTTGA  
GGAAGCTCTTAATACGGTCCTAATGCAAGGCATTCCTTTGGGCAAGGAAAAGCG  
AATTTCTATTGAACGTGATTGGCCGGTGGAAATATCACGCATGTACCTTTACGG  
GGACAATTTAAGGCTTCAGCAGGTCCTAGCAGACTATCTGGCATGCGCCCTTCA  
ATTCACACAACCAGCTGAAGGACCTATCGTGCTCCAGGTCATCCCAAGAAGGA  
AAACATTGGGTCTGGCATGCAGATTGCTCATTTGGAGTTCAG(\*4)GATTGTCCAT  
CCAGCTCCAGGCGTCCCCGAGGCCCTGATACAGGAGATGTTCCGGCACAACCCA  
GAGGTGTCCAGGGAGGGCCTCGGCCTGTACATATGCCAGAAGCTGGTGAAAAC  
GATGAGTGGCACGGTACAGTACCTACGAGAAGCCGATACCTCATCGTTCATCAT  
CCTGATAGAGTTCCAGTCGCCAGCTCAGCAGCAAGCGGTCCAAGCCTTCGAC  
GAGTAAATTCTGA

FIG. 4A continued

## METHOD FOR PRODUCTION OF SORGHUM HYBRIDS WITH SELECTED FLOWERING TIMES

This application claims the priority of U.S. Provisional Appl. Ser. No. 61/643,034 filed May 4, 2012; and of U.S. Provisional Appl. Ser. No. 61/785,616 filed Mar. 14, 2013, the entire disclosures of which are incorporated herein by reference.

### STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

The development of the invention was supported by funding from the US Department of Energy (grant number DE-FG02-06ER64306). The United States government therefore has certain rights in the invention.

### INCORPORATION OF SEQUENCE LISTING

The sequence listing that is contained in the file named "TAMC018US\_ST25.txt," which is 53979 bytes (as measured in Microsoft Windows®) and was created on Mar. 14, 2013, is filed herewith by electronic submission and is incorporated by reference herein.

### BACKGROUND OF THE INVENTION

#### 1. Field of the Invention

The present invention relates generally to the field of agriculture. More particularly, it concerns controlling flowering time in sorghum as well as producing sorghum hybrids with desired flowering times.

#### 2. Description of Related Art

Biomass yield is one of the most important attributes of a biomass or bioenergy crop designed to accumulate lignocellulose and fermentable sugars for conversion to biofuels or bioenergy. Growth duration is a determinant of biomass yield, therefore non-flowering plants or plants that flower late in a growing season accumulate the most biomass assuming environmental conditions allow yield potential to be expressed.

Vegetative growth (e.g. leaves and stems) of the plant ceases once sorghum reaches anthesis (flowering). After flowering, products of photosynthesis (hexoses, sugars) and nitrogen assimilation can be stored or used for grain production. If the storage capacity for and utilization of hexoses for grain filling and respiration is less than the plant's capacity to synthesize hexoses through photosynthesis, the rate of biomass accumulation will decrease limiting yield. Moreover, biomass accumulation is reduced once grain filling has been completed (unless ratooning follows grain production). Stalk sugar yield in sweet sorghum generally peaks at grain maturity so flowering helps maximize yield. Therefore, there is a need to produce bioenergy sweet sorghum hybrids with optimal flowering times for each growing environment and to meet the needs of sugar mills and to enable mill operation for a longer duration each year.

A non-flowering or late flowering bioenergy sorghum crop grown for biomass production will continue to accumulate biomass in the form of larger vegetative plants until adverse environmental conditions (e.g., drought, cold) inhibit photosynthesis. It is estimated that late/non-flowering biomass sorghum will generate more than two times the biomass accumulated by photoperiod insensitive early flowering grain sorghum per acre assuming reasonable growth

conditions throughout the growing season. Therefore, there is a need for producing late or non-flowering sorghum.

### SUMMARY OF THE INVENTION

In one aspect of the invention, a method is provided for producing a plurality of sorghum hybrids with differing flowering times, comprising obtaining a set of at least three different sorghum parent lines, the parent lines each comprising a different genotype for loci contributing to flowering time phenotype, and crossing the parent lines to produce at least two hybrids differing in flowering time. In certain embodiments, the method comprises obtaining at least four different parent lines, the parent lines each comprising a different genotype for loci contributing to flowering time phenotype, and crossing the parent lines to produce at least two hybrids differing in flowering time. In particular embodiments, the loci contributing to flowering time phenotype are selected from the group consisting of SbPRR37 (Ma1), Sbpr37-1, Sbpr37-2, Sbpr37-3 (ma1), GHD7 (Ma6), Sbghd7-1 (ma6), PHYC (Ma5), and SbphyC-1 (ma5). In further embodiments, the set of at least three different sorghum parent lines comprises at least one A/B parent line and at least one R parent line, wherein the A/B parent line comprises a genotype of ma1Ma5ma6; and wherein the R parent lines comprises a genotype of Ma1ma5Ma6, Ma1ma5ma6, ma1ma5Ma6, or ma1Ma5ma6. In still further embodiments, the set of at least three different sorghum parent lines comprises at least a first line with a genotype selected from the group consisting of Ma1Ma2Ma3Ma4ma5Ma6, ma1Ma2Ma3Ma4Ma5ma6 and Ma1Ma2M3Ma4Ma5Ma6.

In a method of the invention, including that described herein above, at least two hybrids may be used differing in flowering time comprises at least one hybrid comprising a genotype selected from the group consisting of Ma1ma1, Ma5ma5, Ma6ma6; Ma1ma1, Ma5ma5, ma6ma6; ma1ma1, Ma5ma5, Ma6ma6; and ma1ma1, Ma5ma5, and ma6ma6. The method may comprise use of parent lines exhibiting an earlier flowering time than the at least two hybrids. The parent lines may comprise at least two different alleles contributing to plant height, and the parent lines may exhibit a dwarf phenotype that is absent from the at least two hybrids that exhibit a different flowering time. In certain embodiments, alleles contributing to plant height are selected from the group consisting of Dw1, dw1, Dw2, dw2, Dw3, dw3, Dw4 and dw4.

In still other embodiments of a method of the invention, a set of at least three different sorghum parent lines are used comprising at least one A/B parent line and at least one R parent line, wherein the A/B parent line comprises a genotype of dw1Dw2dw3dw4, dw1Dw2Dw3dw4 or Dw1Dw2dw3dw4; and wherein the R parent lines comprises a genotype of Dw1dw2Dw3dw4, Dw1dw2dw3Dw4 or dw1Dw2Dw3dw4. In still other embodiments, the set of at least three different sorghum parent lines comprises at least one line comprising a genotype selected from the group consisting of dw1Dw2dw3dw4, dw1Dw2Dw3dw4, Dw1dw2Dw3dw4, Dw1Dw2dw3Dw4, Dw1Dw2dw3dw4, dw1Dw2dw3Dw4, dw1Dw2Dw4dw4, Dw1dw2Dw3dw4 and Dw1Dw2Dw3dw4. In yet another embodiment, the set of at least three different sorghum parent lines comprises at least two sorghum parent lines that are substantially of the same genotype other than with respect to the genotype for loci contributing to flowering time phenotype. In other embodiments of the invention, at least one hybrid is produced with a genotype selected from the group consisting of

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Dw1dw1, Dw2dw2, Dw3dw3, dw4dw4; Dw1dw1, Dw1dw2, dw3dw3, Dw4dw4; Dw1dw1, Dw2dw2, Dw3dw3, dw4dw4; and Dw1dw1, Dw1dw2, Dw3dw3, Dw4dw4

In another aspect, a system is provided for the production of biofuel comprising harvesting biomass from a plurality of sorghum hybrids produced according to a method of the invention and producing biofuel from the biomass, comprised of lignocellulose and fermentable sugars, wherein harvesting is staggered to provide a substantially continuous supply of the biomass. In the system, the plurality of sorghum hybrids may be planted substantially simultaneously with one another. In one embodiment, the plurality of sorghum hybrids comprises hybrids with at least 3, 4 or 5 different dates of maturity.

In yet another aspect, an assemblage is provided of seed of at least two sorghum hybrids with differing flowering times, the hybrids being produced by a method of the invention. In one embodiment, the assemblage is defined as comprising at least three sorghum hybrids with differing flowering times, the hybrids being produced by a method of the invention.

In still yet another aspect, the invention provides a method of producing an inbred sorghum plant comprising: a) crossing a first parent sorghum plant which is homozygous dominant for the Ma6 allele with a second parent sorghum plant which is homozygous recessive for the Ma6 allele; b) selfing an F1 progeny; and c) selecting for an F2 plant homozygous dominant for the Ma6 allele. Thus, in certain embodiments, the first parent sorghum may be of variety R.07007 or a plant related by lineage to R.07007. In a specific embodiment, the first parent sorghum is of variety R.07007. In certain embodiments the method is further defined as selecting for an F2 plant by assaying the F2 plant for a genetic marker genetically linked to Ma6.

Another aspect of the invention provides sorghum seed produced by the method of a) crossing a first parent sorghum plant which is homozygous dominant for the Ma6 allele with a second parent sorghum plant which is homozygous recessive for the Ma6 allele; b) selfing an F1 progeny; and c) selecting for an F2 plant homozygous dominant for the Ma6 allele.

In another aspect, the invention provides a method of identifying the genotype of a sorghum plant for an Ma6 allele comprising: a) obtaining a sorghum plant; and b) assaying the sorghum plant for a genetic marker genetically linked to the Ma6 allele. In one embodiment the genetic marker genetically linked to the Ma6 allele is a nucleic acid encoding a Ghd7 polypeptide. In certain embodiments the genetic marker is selected from the group consisting of sequence variants revealed by direct sequence analysis, restriction fragment length polymorphisms (RFLP), isozyme markers, allele specific hybridization (ASH), amplified variable sequences of plant genome, self-sustained sequence replication, simple sequence repeat (SSR) and arbitrary fragment length polymorphisms (AFLP).

#### BRIEF DESCRIPTION OF THE DRAWINGS

The following drawings form part of the present specification and are included to further demonstrate certain aspects of the present invention. The invention may be better understood by reference to one or more of these drawings in

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combination with the detailed description of specific embodiments presented herein.

FIG. 1: Model for regulation of flowering time.

FIG. 2A-B: PRR37 allele sequences. 2A. ATx623 cDNA sequence (SEQ ID NO:3): the sequence differences from SEQ ID NO:1 from R.07007 are italicized and underlined, the nonsense mutation is bolded and underlined, and the first base of each exon in the genomic sequence is underlined. 2B. ATx623 protein sequence (SEQ ID NO:4): the bolded and underlined period is the non-sense mutation Q270→stop codon.

FIG. 3A-B: GHD7 allele sequences. 3A. SEQ ID NO:5 GHD7 cDNA sequence; this GHD7 dominant allele is found in R.07007. 3B. SEQ ID NO:7 GHD7 ATx623 cDNA sequence; this recessive ghd7-1 allele sequence, present in ATx623, contains a GTCGA insertion (282-286) which results in a stop codon.

FIG. 4A-B: PhyC allele sequences. 4A. R.07007 phyC-1 recessive allele cDNA sequence (SEQ ID NO:11): the nonsynonymous mutations that distinguish this sequence from the ATx623 PHYC cDNA sequence (SEQ ID NO:9) are italicized and underlined, and the first base of each exon in the genomic sequence is underlined; 4B. R.07007 phyC-1 recessive allele protein sequence (SEQ ID NO:12): the nonsynonymous mutations that distinguish this sequence from the PhyC protein sequence present in ATx623 are italicized and underlined.

#### DESCRIPTION OF THE SEQUENCE LISTING

SEQ ID NO:1 PRR37 R.07007 cDNA sequence.  
 SEQ ID NO:2 PRR37 R.07007 protein sequence.  
 SEQ ID NO:3 PRR37 ATx623 cDNA sequence.  
 SEQ ID NO:4 PRR37 ATx623 protein sequence.  
 SEQ ID NO:5 GHD7 R.07007 cDNA sequence.  
 SEQ ID NO:6 GHD7 R.07007 Protein sequence.  
 SEQ ID NO:7 GHD7 ATx623 cDNA sequence.  
 SEQ ID NO:8 GHD7 ATx623 protein sequence.  
 SEQ ID NO:9 PhyC BTx623 cDNA sequence.  
 SEQ ID NO:10 PHYC BTx623 protein sequence.  
 SEQ ID NO:11 PhyC R.07007 cDNA sequence.  
 SEQ ID NO:12 PHYC R.07007 protein sequence.

#### DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

The instant invention overcomes problems with current sorghum production technologies in providing inbred varieties that flower early and at nearly the same time capable of producing multiple hybrids having selected desired maturation times. By manipulation of maturation times in accordance with the invention, hybrids providing a substantially high-yield harvest can be designed for harvest throughout a growing season. In one embodiment of the invention, such methods permit the efficient delivery of biofuel sorghum to a biofuel biorefinery without substantial interruption of availability of feedstock for biofuel production between harvests. By providing multiple inbreds having selected genetic contributions for maturity, the seed of such hybrids can be produced, and numerous different desired maturation times may be incorporated into selected hybrid germplasm.

In accordance with specific embodiments of the invention, hybrids that have long duration of vegetative growth due to late flowering or lack of flowering may be produced from inbreds that flower sufficiently early in regions optimal for hybrid seed production. Such inbreds may be generated with the allelic combinations described herein, thereby

manipulating pathways that regulate photoperiod sensitivity and flowering time in sorghum. In specific embodiments, methods to generate sorghum genotypes with the genetic potential for improved biomass production are provided.

Energy crops such as sweet sorghum or high biomass sorghum that are tall and have delayed flowering accumulate more biomass and sugar than plants that are short and flower early. However, plants that flower at different times (or not at all) during a growing season have different utilities. Non-flowering hybrids may yield maximal potential for sugar and biomass accumulation. Use of non flowering plants also prevents propagation of seed from elite hybrids (genotype protection) and blocks transgene flow in cases where transgenic plants are used commercially. Further, the production, from inbreds that flower early, of sweet sorghum hybrids that flower and accumulate elevated amounts of sugar at different times in the growing season may find use in industry since these hybrids allow staggered harvest times during the season. This maximizes yield across the growing season, allows for improved planning of harvest time and extends the duration of biorefinery operation. The present invention thus, in one embodiment, describes the breeding of sorghum inbreds capable of providing such staggered harvest. In particular embodiments, R-line (males) and A/B-lines (females) are provided that, when crossed, will produce hybrids that are tall and flower at different times or not at all during a growing season.

#### I. Engineering Photoperiod Sensitivity in Accordance with the Invention

Methods are provided in accordance with the invention for modulating photoperiod sensitivity and flowering time in sorghum, for example, to provide for high and/or staggered biomass production and other utilities. Photoperiod sensitivity refers to the fact that some plants will not flower until they are exposed to day lengths that are less than a critical photoperiod (short day plants) or greater than a critical photoperiod (long day plants). Long day (LD) and short day (SD) plant designations refer to the day length required to induce flowering. Facultative LD or SD plants are those that show accelerated flowering in LD or SD but will eventually flower regardless of photoperiod. Most plants including sorghum must pass through a juvenile stage (lasting ~14-21 days for sorghum) before they become sensitive to photoperiod.

Alleles of genes that regulate flowering time that may be used in accordance with the invention have been described, for example, in US 2010/0024065 A1. In US 2010/0024065 A1, alleles of a gene encoding PRR37 were described where the dominant or active forms of PRR37 increase photoperiod sensitivity and delay flowering in long days. In US 2010/0024065 A1, the locus encoding PRR37 was labeled as Ma6. Additional research revealed that PRR37 should be named Ma1 to be consistent with historical work on this maturity locus, and this designation was published (Murphy et al., *PNAS* 108:16469-16474, 2011). Additional Ma1 alleles have been identified, including null alleles of PRR37 (Murphy et al., 2011). In US Patent Pub. No US 2010/0024065 A1, a locus on sorghum LG-02 that enhances photoperiod sensitivity was tentatively identified as Ma5. More recent research has shown that this locus historically had been designated as Ma2. This application (US 2010/0024065) also proposed that alleles of the gene encoding PHYC modified photoperiod sensitivity and designated this locus Ma7. More recent studies confirmed the critical role of PHYC in repression of flowering in long days and alleles of this gene have been identified and characterized. Herein, the locus encoding PHYC has been redesignated Ma5 to be

consistent with the current knowledge of this gene's action and prior literature (Rooney and Aydin, *Crop Science*, 39:397-400, 1999). Alleles of an additional gene in the long day floral repressing pathway, GHD7, were identified that enhanced photoperiod sensitivity in sorghum. The locus encoding GHD7 (Sb06g000570) was named Ma6 consistent with prior analysis of Ma6 (Rooney and Aydin, *Crop Science*, 39:397-400, 1999) Active and null alleles of GHD7 have been identified and are reported in this disclosure.

In one embodiment of the invention, complementary dominant/recessive alleles of genes that control photoperiod sensitivity are present in R-lines (male) and A/B-lines (female). In this way parental R- and A/B lines may be bred to produce plants that are photoperiod insensitive and flower early. Such parental lines can be crossed to produce hybrids and progeny may be propagated easily, including for production of hybrid seed, for instance wherein hybrid plants derived from crossing R- and A/B-lines are photoperiod sensitive and flower later than the inbred parental lines.

Some sorghum genotypes, including most grain sorghums, are photoperiod insensitive or have reduced photoperiod sensitivity, meaning that the number of days to flowering in these genotypes is not significantly delayed in long days vs. short days under normal growing conditions. Other sorghum genotypes are photoperiod sensitive and flowering is delayed when day lengths exceed a critical photoperiod. These genotypes flower when day lengths are shorter than a critical photoperiod specific for different genotypes, consistent with their designation as short day (SD) plants. Because different sorghum genotypes can be constructed that vary in their critical photoperiods (photoperiod sensitivity), it is possible to design hybrids that flower at different times during a growing season.

Sorghum is a facultative SD plant where long days inhibit flowering and short days accelerate flowering. The degree of photoperiod sensitivity in sorghum refers to the length of the short days that are required to induce flowering. A highly photoperiod sensitive sorghum will exhibit delayed flowering in photoperiods that are 11-12 h or greater whereas plants with low photoperiod sensitivity only show delayed flowering in photoperiods that are 13-14 h or longer. Different sorghum genotypes vary in their degree of photoperiod sensitivity. Sorghum inbreds have been identified with critical photoperiods ranging from ~10.5 to ~14 hours and still others that are nearly completely insensitive to photoperiod. Thus, in College Station, Tex., most photoperiod insensitive sorghum planted in April will flower in approximately 48-60 days. In contrast, highly photoperiod sensitive sorghum hybrids with the Ma1-Ma6 genotype flower in mid to late September in College Station, Tex. (~175-180 days) or later.

Sorghum genotypes with varying photoperiod sensitivity, planted between April 1 and April 20 in College Station, Tex. will flower between 50-200 days after plant emergence or not at all. The number of days to flowering will depend on the planting date and latitude where a sorghum genotype is planted because these factors determine when the plants are exposed to days that are sufficiently short to induce flowering. In general, late flowering photoperiod sensitive plants such as sorghum with the genotype Ma1\_Ma2\_Ma3\_Ma4\_Ma5\_Ma6\_ will not flower until day lengths are less than 12 hrs and 20 mins, whereas less photoperiod-sensitive sorghum with recessive forms of Ma5 and Ma6 (or Ma1, Ma2, Ma3, Ma4, etc.) will flower when exposed to day lengths (photoperiods) of ~12-14 hr or longer depending on genotype.

In certain aspects of this invention, method and compositions are provided for producing inbreds which, when crossed, generate high biomass bioenergy sorghum hybrid seed that can be planted at any time of the year suitable for substantially continual production. Such hybrid plants may have long growth duration (i.e., late flowering or non-flowering) at all latitudes from ~40° N/S of the equator (40° N being the upper mid-west in N. America, where sorghum growth is limited by cold). In another aspect, this system can be used to produce sweet sorghum hybrids that grow for a specified number of days prior to flowering at different latitudes, from early flowering inbreds suitable for hybrid seed production.

Table 1 below describes the relationship between latitude and daylength at planting and harvest for biomass/bioenergy production regions from ~40° N/S to the equator. At higher latitudes, planting date is later in the year and harvesting occurs earlier due to longer duration of winter and low temperatures (shorter season). At lower latitudes, planting can be done earlier in the year, or virtually at any time in some locations, and harvesting may occur later in the year or multiple times during the year, including times of the year when daylength is less than 12 hours (Table 1).

TABLE 1

Relationship between latitude of crop production and daylength					
City	Latitude	Planting date	Daylength hours	Harvest date	Daylength hours
Des Moines, IA	41.35 N	15-May	14.3	1-October	11.6
New York, NY	40.42 N	30-May	14.6	1-October	11.6
Amarillo, TX	35.05 N	15-May	13.8	15-October	11.1
College Station, TX	30.37 N	20-March	11.7	15-November	10.4
Beaumont, TX	30.05 N	20-March	11.8	15-November	10.5
Weslaco, TX	26.09 N	20-March	11.8	1-December	10.5
Puerto Rico	18.57 N	monthly	10.8-13.2	monthly	10.8-13.2
Panama City	08.57 N	monthly	11.4-12.6	monthly	11.4-12.6
Equator	0	monthly	12	monthly	12
Brazilia, Brazil	16.12 S	monthly	11.1-12.9	monthly	11.1-12.9
Brisbane, AU	27.30 S	20-September	11.9	15-March	12.2
Piracicaba, Brazil	22.43 S	monthly	10.6-13.6	monthly	10.6-13.6

Sorghum is insensitive to photoperiod and cannot be induced to flower during the juvenile phase which lasts for ~14-21 days post planting, depending on genotype. Therefore, bioenergy sorghum hybrids must have sufficient photoperiod sensitivity to prevent flowering at the daylengths that occur ~14-21 days post-planting at all latitudes used for bioenergy crop production. In addition, bioenergy sorghum hybrids which are planted during a season of long days that block flowering may also require increased photoperiod sensitivity in order to block flowering prior to frost or harvest if daylengths decrease significantly during the growing season.

Six maturity genes were genetically defined in sorghum that control flowering time, termed Ma1-Ma6. Ma1, Ma2, Ma3 and Ma4 were identified by Quinby and his colleagues (Quinby and Karper, *Amer. J. Botany*, 33(9):716-721, 1946; Quinby, J. R., *Crop Science* 6:516-518, 1966; Quinby, J. R. (1974) *Sorghum Improvement and the Genetics of Growth*. Texas A&M University Press.). These Ma-loci/genes are part of a pathway that inhibits flowering in long days. Therefore in general, sorghum plants with recessive ma1-ma6 genes (with low or no activity) flower earlier than plants with dominant or active Ma1-Ma6 genes that repress flowering when plants are grown in day lengths > 12.2 h. Sor-

ghum plants that are Ma1Ma2Ma3Ma4 but recessive at either Ma5 and/or Ma6 typically flower in ~70-90 days in College Station, Tex. when planted on April 19 (Rooney and Aydin, *Crop Science*, 39:397-400, 1999) or in ~85 days when planted on June 1 in Plainview, Tex. (Quinby, J. R. (1974) *Sorghum Improvement and the Genetics of Growth*. Texas A & M University Press.). Plants with recessive genes at Ma1-Ma4 (and recessive at Ma5 or Ma6) will flower in ~48-60 days post planting in these same locations. Ma5 and Ma6 are an additional pair of maturity loci that delay flowering when sorghum is planted ~April 19 in College Station, Tex. for ~175 days (mid-late September when photoperiods decrease below 12 h 20 min) (Rooney and Aydin, 1999). Based on information described in more detail below, it is predicted that late flowering Ma5/Ma6 plants require an active PhyB gene (Ma3).

Because an active form of PhyB (i.e. Ma3) is required for Ma5/Ma6 genotypes to express photoperiod sensitivity and flower late, complementary dominant/recessive forms of Ma3 could also be used to modulate differential flowering time in certain types of inbreds and hybrids. For instance, an

early flowering inbred sorghum line that has the genotype Ma1Ma1Ma2Ma2ma3ma3Ma4Ma4Ma5Ma5Ma6Ma6 could be crossed to a second early flowering inbred sorghum genotype that has the genotype Ma1Ma1Ma2Ma2-Ma3Ma3Ma5Ma5ma6ma6 in order to produce late flowering sorghum hybrids with the genotype Ma1Ma1Ma2Ma2-Ma3ma3Ma4Ma4Ma5Ma5Ma6ma6.

Certain embodiments of the present invention provide sorghum genotypes that contain Ma-alleles that in combination delay flowering until day lengths are less than 12 hr 20 min. In one embodiment, such alleles comprise one or more of Ma5 and Ma6. In other embodiments, inbreds may be engineered with one or more allele selected from Ma1-Ma4 to modify sorghum photoperiod sensitivity. In addition, different alleles may be chosen, such as of Ma5 and Ma6, for example, which can be used to make bioenergy sorghum hybrids even more photoperiod sensitive (less than 12 hr), increasing their utility for growing regions closer to the equator where bioenergy sorghum will be planted and grown in day lengths shorter than 12 hours (Table 1). For example, Miller et al. (*Crop Science*, 8:499-502, 1968) identified five groups of sorghum that had critical daylength requirements for flowering that ranged from ~13 hr to ~11.1 hr. This

genetic material, and other genotypes identified in accordance with the present invention, flower late when growing at low latitudes in places such as Puerto Rico. Further, Craufurd et al. (*Theor. Appl. Genet.*, 99:900-911, 1999) identified sorghum genotypes with critical photoperiods between 10.2 and 11 hrs. In certain aspects of the invention, these materials allow identification of genes with similar action to Ma5/Ma6 and alleles of Ma5 and Ma6 that would be useful for breeding photoperiod sensitive (“PS”) hybrids for use over the entire range of latitudes from 40° N/S to the equator.

Photoperiod sensitivity and late flowering is mediated in sorghum and rice by genes that repress activation of genes in the FT gene family (flowering locus T) and AP1 and the transition of the apex from vegetative growth to formation of reproductive structures (FIG. 1). The repressors of flowering in sorghum act in a dominant or additive fashion. The repressors are inactivated or less active under short photoperiods (and thermal periods). The vegetative or non-flowering state is maintained in part by light mediated signaling through PHYB and PHYC and possibly from other sources (PHYA, etc.) and partly by output from a circadian clock. The light signaling pathway involves a series of steps and genes modulated by day length such as PRR37, Ghd7, and CO may act directly to repress members of the FT gene family and others of which act downstream from the circadian clock through modulation of homologs of GI to repress FT.

The repressing pathway can be inactivated by disrupting the function of genes that are in the signaling pathway (PhyB, PhyC, or a gene between the photoreceptors and FT, and genes involved in clock function or input/output) that regulate expression of FT repressors such as PRR37, Ghd7 and CO. The disruption of a gene in the flower repression pathway converts a photoperiod sensitive genotype into a less photoperiod sensitive genotype or photoperiod insensitive (“PI”) genotype that will show reduced or no delay in flowering in long days. If genotypes that are PI due to inactivation of different genes in the flowering repression pathway are crossed, then the hybrid may be PS and later flowering because active alleles contributed by gametes from each line complement inactive alleles present in the gametes/genome of the other parental inbred line.

## II. Production of Photoperiod Sensitive Hybrids

In certain aspects of the present invention, early flowering inbred sorghum genotypes with the selected Ma-allelic combinations can be crossed to produce photoperiod sensitive late-flowering sorghum hybrids ideal for biomass/bioenergy production with the use of molecular markers. In one embodiment, the early flowering photoperiod insensitive sorghum inbreds contain complementary pairs of dominant/recessive Ma1/Ma5/Ma6 genes.

Thus, through preparation of a small pool of inbred lines with selected genotypes for flowering time, multiple hybrids may be produced with staggered flowering times, also permitting staggered harvests and a continual supply of biomass with high sugar content. Another advantage of such methodology is the ability to produce sorghum hybrids that have long duration of vegetative growth due to late flowering or lack of flowering, from inbreds that will flower

sufficiently early in regions optimal for hybrid seed production (such as the high plains of Texas).

The production of bioenergy sorghum hybrids is highly beneficial in that hybrid vigor will generate greater yield, and the ability to better control seed stocks through hybrid seed production. The increase in biomass yield attributed to hybrid vigor in sorghum is typically ~20% to ~50%. By providing photoperiod sensitive bioenergy sorghum hybrids that flower late or that do not flower, bioenergy production is further enhanced for several reasons: long duration of vegetative growth associated with late/non-flowering genotypes increases biomass yield per acre, high levels of photoperiod sensitivity will allow nearly year round planting of bioenergy sorghum hybrids at lower latitudes, and plants growing vegetatively (non-flowering) are more drought tolerant than plants that are in the reproductive phase of development; this is an important attribute of bioenergy sorghum.

In further aspects of the present invention, naturally occurring alleles of Ma1, Ma5 and Ma6 as well as other maturity genes (e.g., Ma3=PhyB, Ma2, Ma4) that are involved in the photoperiod-sensing pathway can be used to develop early flowering inbreds that can be crossed to produce late flowering hybrids. In one embodiment, sorghum line R.07007 (U.S. Patent Application 20110113505; Murphy et al., *PNAS* 108:16469-16474, 2011) or EBA-3 (Rooney and Aydin, *Crop Sci.* 39:397-400, 1999) is a primary source of ma5 (recessive form) and dominant Ma1 and Ma6, although other versions of Ma6 derived from photoperiod sensitive sorghum accessions may also be utilized. In another embodiment, dominant forms of Ma5 and recessive forms of ma1 and/or ma6 are derived from grain sorghum female lines that may be used for hybrid seed production.

In addition to working with naturally occurring genetic variants, certain embodiments of the present invention comprise mutagenizing any group of PS genotypes and identify PI lines derived from the parental lines that contain an inactive gene(s) in the pathway that represses flowering. Crossing photoperiod insensitive early flowering genotypes that contain different inactive genes in the pathway that controls flowering time will generate photoperiod sensitive late flowering hybrids.

An exemplary approach involves screening PS (late flowering) sorghum germplasm for accessions that express superior bioenergy traits. These accessions (most likely Ma1-Ma6) are then crossed to R.07007 (Ma1Ma1-ma2ma2ma5ma5Ma6Ma6). F2 progeny from these crosses that flower early (ma5ma5, ma2ma2, or ma2ma2ma5ma5) but that retain Ma1Ma1Ma6Ma6 are selected by phenotyping and/or marker-assisted selection. The resulting early flowering inbreds can then be crossed with, for instance, elite grain female A-lines that have the genotype (ma1ma1Ma2Ma2Ma5Ma5ma6ma6), to produce bioenergy hybrids that are Ma1\_Ma2\_Ma5\_Ma6\_ that will flower late.

In another aspect, mutagenesis of late flowering sorghum genotypes to create early flowering genotypes could be carried out in the following exemplary manner. The seed from a late flowering sorghum inbred would be germinated and treated with a mutagen such as EMS (ethyl methane-sulphonate) or ENU (1-ethyl-1-nitrosourea) or using X-rays

or neutron bombardment to induce changes in DNA sequence throughout the sorghum genomes of thousands of seedlings. The M1 seedlings (M1 refers to the first generation of plants that were exposed to a mutagen) surviving the treatment would be grown to maturity and self-pollinated. M2 seed derived from a large number of M1 plants would be grown out and screened for M2 plants that flower early under conditions where the parental inbred flowers late. An early flowering phenotype would be consistent with mutation in a gene that represses flowering such as Ma1-Ma6.

Marker assisted selection or marker aided selection (MAS) may be used to assist with introduction of one more alleles conferring a selected photoperiod sensitivity into particular germplasm. MAS is a process whereby a marker (morphological, biochemical or one based on DNA/RNA variation) is used for indirect selection of a genetic determinant or determinants of a trait of interest (e.g., productivity, disease resistance, abiotic stress tolerance, and/or quality). For example if MAS is being used to select individuals with disease resistance, then a marker allele which is linked to the gene conferring disease resistance is scored or selected for, rather than disease resistance per se. The assumption is that the marker allele is associated with the gene and/or quantitative trait locus (QTL) of interest that confers the trait under selection. MAS can be useful to select for traits that are difficult to measure, exhibit low heritability, and/or are expressed late in development.

In certain embodiments, a marker may be termed morphological, biochemical, cytological, biological, and/or molecular, as follows:

Morphological—these are loci that have obvious impact on morphology of plant; genes that affect form, coloration, male sterility or resistance among others have been analyzed in many plant species. Examples of this type of marker may include the presence or absence of awn, leaf sheath coloration, height, grain color, aroma, etc.

Biochemical—a gene that encodes a protein that can be extracted and observed; for example, isozymes and storage proteins.

Cytological—for instance results in an alteration in the chromosomal banding produced by different stains; for example, G banding.

Biological—allows for identifying different pathogen races or insect biotypes based on host pathogen or host parasite interaction; may be used as a marker since the

genetic constitution of an organism can affect its susceptibility to pathogens or parasites.

DNA-based and/or molecular—A unique (DNA sequence), occurring in proximity to or within the gene or locus of interest and sometimes corresponding to a mutation causing gene inactivation can be identified by a range of molecular techniques such as direct sequencing, RFLPs, RAPDs, AFLP, DAF, SCARs, microsatellites, Taqman™ assays, etc. DNA markers detect variation in DNA sequence, or DNA polymorphisms, that distinguish the genomes of different individuals. DNA polymorphisms include differences in single nucleotide sequences (SNPs), simple sequence repeats (SSRs), inversions or deletions (INDELS). DNA markers are designed to identify DNA sequence differences by one of several methods including; direct sequence analysis, electrophoretic separation of DNA fragment sizes following digestion of genomic DNA with restriction enzymes (RFLP) or after DNA amplification using PCR (AFLP, SSRs), or based on differences in amplification or probe hybridization (microarrays, Taqman probes, etc.).

As used herein, an “inherited genetic marker” is an allele at a single locus. A locus is a position on a chromosome, and allele refers to a DNA sequence variant of a gene; that is, different nucleotide sequences, at those loci. The marker allelic composition of each locus can be either homozygous or heterozygous.

In specific embodiments of the invention, genetic markers linked to alleles conferring photoperiod sensitivity may thus be used, for example, for producing an inbred line as described herein, or the hybrid progeny thereof. In other instances, genetic markers may be designed to detect mutations that cause functional differences in genes. Table 2 shows that information about the genetic map location of Ma1 and Ma3 that has been published (Klein et al., *Plant Genome*, 48: S12-22, 2008; Murphy et al., *Proc Natl Acad Sci USA*, 108: 16469-74, 2011; Childs et al., *Plant Physiol.*, 113:611-619, 1997). Ma3 encodes the red light photoreceptor phytochrome B that is known to mediate repression of flowering in short day and long day plants (Childs et al., *Plant Physiol.*, 116(3):1003-1011, 1998). In addition, the inventors have genetically mapped the locations of Ma5 and Ma2, loci required in combination with Ma6 to delay flowering ~175 days in College Station. Ma6 has also been mapped, as well as a modifier of Ma6 activity.

TABLE 2

<i>Sorghum</i> maturity (Ma) genes.			
Locus	Map Location	Gene	Reference
Ma1	SBI06, 11-19 cM	PRR37, (SBI06: 40,280,414-40,290,602 Mbp)	Murphy et al. ( <i>PNAS</i> 108: 16459-74, 2011)
Ma2	SBI02, 145-148 cM	Unknown	
Ma3	SBI01, ~166 cM	PHYB, (SBI01: 60,910,479-60,917,763 Mbp)	Childs et al., ( <i>Plant Physiol.</i> , 116: 1003-1011, 1998)
Ma4	Unknown		
Ma5	SBI01, ~23-26 cM	PHYC (SBI01: 6,762-743-6,767,650 Mbp)	This work
Ma6	SBI06, ~11-19 cM	GHD7	This work

Information on various other QTL for flowering time in sorghum is listed in Table 3.

TABLE 3

<i>Sorghum</i> flowering time QTL		
Lin et al., <i>Genetics</i> , 141(1): 391-411, 1995; Paterson et al., <i>Proc. Natl. Acad. Sci. USA</i> , 92(13): 6127-6131, 1995; BTx623 X <i>S. propinquum</i>		
Locus	Map location	Marker
FlrAvgB1	SBI02, ~102-119 cM	UMC5, UMC139
FlrAvgD1	SBI06, ~9-21 cM	QTL overlaps Ma1
FlrFstG1	SBI09, ~129-150 cM	UMC132
Crasta et al., <i>Mol. Gen. Genet.</i> , 262(3): 579-588, 1999; B35 X RTx430		
Locus	Map location	Gene
FltQTL-DFG	SBI10, ~70-74 cM	UMC21
FltQTL-DFB	SBI01, ~45 cM	UMC27
Hart et al., <i>Theor. Appl. Genet.</i> , 103: 1222-1242, 2001 (see map positions in Feltus et al., <i>Theor. Appl. Genet.</i> , 112(7): 1295-1305, 2006 below)		
Feltus et al., <i>Theor. Appl. Genet.</i> , 112(7): 1295-1305, 2006; summary of QTL from BTx623/IS3620C; BTx623/ <i>S. propinquum</i>		
Locus	Map location	Marker
QMa50.txs-A	SBI01, ~182-186 cM	Xgap36
QMa50.txs-C	SBI03, ~140 cM	Xumc16-Xtxs422
QMa50.txs-F1	SBI09, ~143 cM	Xedo393
QMa50.txs-F2	SBI09, ~143 cM	Xedo393
QMa50.txs-H	SBI08, ~130-136 cM	Xtxp105-Xtxs1294
QMa50.txs-I	SBI06, ~10-36 cM	Xumc119-Xedo718
Lin et al. ( <i>Genetics</i> , 141(1): 391-411, 1995), Paterson et al. ( <i>Proc. Natl. Acad. Sci. USA</i> , 92(13): 6127-6131, 1995)		
Locus	Map location	Marker
QMa1.uga-G	SBI09, ~129-150 cM	Xumc132-pSB445
QMa1.uga-D	SBI06, ~31-59 cM	
QMa5.uga-D	SBI06, ~8-20 cM	tiller flowering (overlaps Ma1)

Feltus et al. (*Appl. Genet.*, 112(7):1295-1305, 2006) reported a flowering time QTL (QMa5.uga-D) that controls tiller flowering time that overlaps the region spanned by Ma1 and Ma6. It is formally possible that QMa5.ugaD corresponds to a different allele of Ma1 or Ma6 or a different flowering time gene.

Lin et al. (*Genetics*, 141(1):391-411, 1995) mapped a flowering time QTL (FlrAvgD1=QMa1.ugaD) on SBI06 (31-59cM) and suggested that this QTL could correspond to Ma1. Klein et al. (*Plant Genome*, 48: S 12-22, 2008) using genotypes known to segregate for Ma1 showed that Ma1 mapped to an adjacent region on SBI06 (~11-21cM). The data in Lin et al. (*Genetics*, 141(1):391-411, 1995) are inconsistent with the assigned map location of QMa1.ugaD in Feltus et al. (*Theor. Appl. Genet.*, 112(7):1295-1305, 2006). Data in Lin et al. (*Genetics*, 141(1):391-411, 1995) show that QMa1.ugaD maps to the same location as QMa5.ugaD (Feltus et al., *Theor. Appl. Genet.*, 112(7):1295-1305, 2006).

Embodiments discussed in the context of methods and/or compositions of the invention may be employed with respect to any other method or composition described herein. Thus, an embodiment pertaining to one method or composition may be applied to other methods and compositions of the invention as well.

As used herein the terms “encode” or “encoding” with reference to a nucleic acid are used to make the invention

readily understandable by the skilled artisan however these terms may be used interchangeably with “comprise” or “comprising” respectively.

As used herein the specification, “a” or “an” may mean one or more. As used herein in the claim(s), when used in conjunction with the word “comprising”, the words “a” or “an” may mean one or more than one.

The use of the term “or” in the claims is used to mean “and/or” unless explicitly indicated to refer to alternatives only or the alternatives are mutually exclusive, although the disclosure supports a definition that refers to only alternatives and “and/or.” As used herein “another” may mean at least a second or more.

Throughout this application, the term “about” is used to indicate that a value includes the inherent variation of error for the device, the method being employed to determine the value, or the variation that exists among the study subjects.

An “assemblage” of seeds refers to a grouping, such as a packet or bag, of seeds.

Other objects, features and advantages of the present invention will become apparent from the following detailed description. It should be understood, however, that the detailed description and the specific examples, while indicating preferred embodiments of the invention, are given by way of illustration only, since various changes and modifications within the spirit and scope of the invention will become apparent to those skilled in the art from this detailed description.

### III. Examples

The following examples are included to demonstrate preferred embodiments of the invention. It should be appreciated by those of skill in the art that the techniques disclosed in the examples which follow represent techniques discovered by the inventors to function well in the practice of the invention, and thus can be considered to constitute preferred modes for its practice. However, those of skill in the art should, in light of the present disclosure, appreciate that many changes can be made in the specific embodiments which are disclosed and still obtain a like or similar result without departing from the spirit and scope of the invention.

#### Example 1

Sorghum Genes and Alleles Comprising a Regulatory System that Represses Flowering Time in Long Day Photoperiods (Long Day Floral Repression Pathway: LD-R)

A photoperiod responsive flowering time regulatory pathway was elucidated that operates in sorghum, as shown in FIG. 1. Induction of flowering in most plants including sorghum requires activation of the gene FT (a florigen). There is a family of genes that encode FT proteins, therefore activation of one or more of the FT gene family members could induce flowering. In Murphy et al. (2011) three genes in the FT gene family, Hd3a, ZCN8, and ZCN12, were differentially activated in short days compared to long days, therefore these genes may all be involved in the regulation of flowering time in sorghum. All three of these sorghum FT-like genes are regulated by the activity of PHYB, PHYC, PRR37 and Ghd7. The protein encoded by FT is transmitted to the apex where it induces transition of the shoot apex from a vegetative meristem to a floral meristem. Sorghum is a short day plant meaning that flowering time can be delayed in many genotypes in long days compared to short days. Ma1 (PRR37) and Ma6 (GHD7) are repressors of flowering in long days but not short days. These genes act synergistically to inhibit flowering by repressing Ehd1 (activator of



FT), by activating expression of CO, a repressor of flowering, and by repressing FT directly or indirectly.

The genes PRR37 (Ma1) and GHD7 (Ma6) have been identified together with null alleles of these genes that inactivate flowering repression that occurs in long days mediated by this regulatory system. Expression of PRR37 and GHD7 is regulated by the circadian clock, and by light signaling through the photoreceptors PHYB and PHYC. Mutant alleles encoding the photoreceptors PHYB (ma3, ma3R) and PHYC (ma5) have been identified that reduce or eliminate the repressing action of PRR37 and GHD7 on flowering. Ma2 represses flowering in long days and recessive alleles of this locus reduce photoperiod sensitivity. Additional loci/genes are known to modulate this pathway. Recessive alleles of Ma4 have been found to reduce photoperiod sensitivity. Recessive alleles that decrease the activity of Ehd1 will cause later flowering and recessive alleles of CO will cause earlier flowering. Therefore, alleles of these additional genes/loci (Ma2, Ma3, Ma4, CO, Ehd1, etc.) that affect the photoperiod responsive flowering pathway can be used in accordance with the invention to further modify and refine the exact flowering time of inbreds and hybrids.

Several alleles of PRR37 (Ma1) were identified in the course of map-based cloning this gene (Murphy et al., *PNAS* 108:16469-74, 2011). In addition to the dominant version of Ma1 (PRR37), prr37-1 null mutants (coding region disruption), and weak alleles were identified in sorghum germplasm (FIG. 2).

Dominant and recessive alleles of GHD7 were identified during the course of map-based cloning the gene corresponding to Ma6. One GHD7 allele from BTx623 (and ATx623) was identified that has a disrupted coding region and is a null allele (FIG. 3). A second null or weak GHD7 allele was identified in Rio and Hegari.

Dominant and recessive alleles of Ma5 (PhyC) were identified during the course of map-based cloning the gene corresponding to Ma5. One recessive PhyC allele was identified in R.07007 that contains mutations in functionally important protein loops consistent with a recessive allele.

Other recessive alleles of PRR37, GHD7 and PhyC are present in sorghum germplasm and may be used in the inbred/hybrid designs described below.

### Example 2

Design of R-lines and A/B-lines Yielding Hybrids with Incrementally later Flowering Times

a. List of alleles used in the design of specific R-lines and A/B-lines:

- i. SbPRR37 (Ma1), present in R.07007 (and 100M)
    1. Sbpr37-1, null allele from SM100 (and BTx406)
    2. Sbpr37-2, partially active allele from Blackhull kafir (and Tx7000)
    3. Sbpr37-3, null allele from BTx623 (and ATx623)
  - ii. GHD7 (Ma6)
    1. SbGHD7 (Ma6), dominant allele in R.07007
    2. Sbghd7-1, null allele present in BTx623 (and ATx623)
    3. Sbghd7-2, null or weak allele present in Rio, Hegari
  - iii. PhyC (Ma5), present in BTx623
    1. SbphyC-1 (ma5), recessive allele present in R.07007
- b. List of exemplary genotypes to construct:

i.	A/B-1:	ma1Ma5ma6	Early, 60-80 days to flowering
ii.	R1:	Ma1ma5Ma6	Early, 60-80 days to flowering

-continued

iii.	R2:	Ma1ma5ma6	Early, 60-80 days to flowering
iv.	R3:	ma1ma5Ma6	Early, 60-80 days to flowering
v.	R4:	ma1Ma5ma6	Early, 60-80 days to flowering

c. Method for constructing the A/B and R-lines with the genotypes listed above in b.

i.	R.07007	Ma1ma2Ma3Ma4ma5Ma6
ii.	BTx623	ma1Ma2Ma3Ma4Ma5ma6
iii.	PS genotypes	Ma1Ma2M3Ma4Ma5Ma6

iv. PI genotypes Current PI grain sorghum genotypes are often recessive for ma1ma6 or sometimes only for ma1 or ma6.

v. Genotypes with recessive ma5 can be derived by crossing R.07007, a source of phyC-1 (ma5) to a target genotype followed by marker-assisted selection or direct selection for the allele of ma5 from R.07007. Any line derived from R.07007 that contains recessive ma5 can subsequently become a source of this recessive gene in subsequent rounds of breeding.

vi. Genotypes with recessive ma1 and ma6 can be derived from various accessions that contain these alleles. For example, lines containing Ma1and/or Ma6 when crossed to BTx623 (ma1-3, ma6-1) will generate F2/F3 progeny that segregate for these alleles. Marker-assisted selection based on mutations present in recessive prr37 or ghd7 alleles can be used to construct the specified A/B and R-genotypes listed above.

d. List of hybrids: (Examples, exact flowering dates depend on planting time in relation to day length at specific latitudes. All of the hybrids listed are also Ma2\_Ma3\_Ma4\_)

i.	A/B-1 X R1:	Ma1ma1, Ma5ma5, Ma6ma6	Late (170-210 DAE)
ii.	A/B-1 X R2:	Ma1ma1, Ma5ma5, ma6ma6	Mid (80-120 DAE)
iii.	A/B-1 X R3:	ma1ma1, Ma5ma5, Ma6ma6	Mid (80-120 DAE)
iv.	A/B-1 X R4:	ma1ma1, Ma5ma5, ma6ma6	Early (60-80 DAE)

e. If the R-line and A/B-line genotypes used for production of hybrid seed both contain weak recessive genes for Ma2, Ma3, or Ma4, then hybrids will flower earlier than the hybrids listed above. If the R-lines contain alleles of Ma1-Ma6 that have greater activity than those used in the above illustration, then hybrids will flower later.

### Example 3

Design of R- and AB-lines with Complementary Alleles at Maturity and Dwarfing (Dw) Loci that Facilitate the Production of Tall Hybrids from Shorter Inbreds

Alleles for genes for traits such as plant height can be combined with alleles for genes that control flowering time in order to produce short R-line and B-line genotypes that when crossed produce tall hybrids of the specified flowering time.

a. Four dwarfing genes that affect primarily the length of stem internodes have been identified in sorghum: Dw1, Dw2, Dw3, Dw4. Recessive Dw alleles reduce internode length and overall plant height.

b. Design goal: For sweet sorghum and high biomass sorghum, tall plants have higher yield although very tall plants may have increased lodging. Therefore hybrids that are 1-dwarfs are ideal (0 dwarfs have not been reported

probably because no further internode length increase occurs in 0-dwarfs vs. a 1-dwarf). The source of Dw alleles makes a difference in final internode length and height. For example, 1-dwarf plants that include Dw4 (dw1Dw2Dw3Dw4) will have longer internodes than 1-dwarf plants that do not (Dw1Dw2Dw3dw4).

c. Dominant and recessive alleles exist for each Dw locus. For example;

- i. Dw1, LG-09, ~57.3 Mbp, dw1 from Dwarf Yellow Milo (A/BTx623)
- ii. Dw2, LG-06, ~42.6 Mbp, dw2 from Double Dwarf Yellow Milo
- iii. Dw3, LG-07, ~58.1 Mbp, dw3 from Blackhull kafir
- iv. Dw4, mapping in progress, Dw4 from standard broom-corn

d. Genotypes of exemplary A/B-lines and R-lines designed:

i.	A/B-1	dw1Dw2dw3dw4;	ma1Ma5ma6
ii.	A/B-2	dw1Dw2Dw3dw4;	ma1Ma5ma6
iii.	A/B-3	Dw1Dw2dw3dw4;	ma1Ma5ma6
iv.	R1	Dw1dw2Dw3dw4;	Ma1ma5Ma6
v.	R2	Dw1dw2dw3Dw4;	Ma1ma5Ma6
vi.	R3	dw1Dw2Dw3dw4;	Ma1ma5Ma6

e. Method for designing A/B- and R-lines with the Dw genotypes listed above.

- i. Accessions and breeding lines containing dominant or recessive alleles of the four dwarfing loci are known. Crosses with accessions/breeding lines with known dwarfing loci alleles can be crossed to genotypes with complementary alleles and using marker-assisted selection, lines with the specified genotypes constructed.
- ii. The genotypes listed below provide one source of dominant and recessive alleles at the four Dw loci. Other sources of alleles are available and could be used for R-line and A/B-line design.

1.	BTx623	dw1Dw2dw3dw4
2.	R.07007	dw1Dw2Dw3dw4
3.	M35-1	Dw1dw2Dw3dw4
4.	Std broomcorn	Dw1Dw2dw3Dw4

iii. Example: When R.07007 is crossed to M35-1, progeny segregating for Dw1 and Dw2, will result allowing selection for two different 2-dwarf R-line genotypes

- 1. Dw 1 dw2Dw3dw4
- 2. dw1Dw2Dw3dw4

iv. If R.07007 is crossed to Standard broomcorn, progeny segregating for Dw1, Dw3 and Dw4 will be present allowing the selection of several 2-dwarf genotypes;

- 1. Dw1Dw2dw3dw4
- 2. dw 1Dw2 dw3Dw4
- 3. dw1Dw2Dw4dw4

f. Examples of Genotypes of 1-dwarf Hybrids:

i.	A/B-1 × R1	Dw1dw1, Dw2dw2, Dw3dw3, dw4dw4
ii.	A/B-1 × R2	Dw1dw1, Dw1dw2, dw3dw3, Dw4dw4
iii.	A/B-2 × R2	Dw1dw1, Dw2dw2, Dw3dw3, dw4dw4

[All of the above genotypes will be photoperiod sensitive and flower late allowing full expression and optimal utilization of the 1-dwarf genotypes.] Other traits of value such as disease resistance, drought tolerance, sugar content, biomass composition can likewise be added to R-lines or A/B-lines having the maturity genotypes specified above so that they flower when optimal during a growing season.

Example 4

Alleles of PRR37 (Ma1), PHYC (Ma5) and GHD7 (Ma6)

- a. Alleles of Ma1:
  - (i) PRR37-1 (Ma1) is present in R.07007, 100M, and all very late flowering plants.
  - (ii) prr37-1 (ma1-1) is a null allele in BTx406 and SM100 (milo allele).
  - (iii) prr37-4 (ma1-4) is found in Bonita.
  - (iv) prr37-2 (ma1-2, weak allele) is found in Blackhull kafir and genotypes derived from BHK.

(v) prr37-3 (ma1-3, null allele) is found in ATx623. ATx623 has two mutations corresponding to prr37-2 and prr37-3.

b. Alleles of Ma6:

- (i) GHD7 is a dominant allele found in R.07007.
- (ii) ghd7-1 is a null allele present in ATx623 corresponding to the GTCGA insertion (282-286) which results in a stop codon.

c. Alleles of Ma5:

Most germplasm is dominant for Ma5 (PHYC). The only recessive ma5 source identified to date is from R.07007 (phyC-1). This genotype has mutations in PHYC that are consistent with disruption of function. However, the ma5 allele is not a null, and should be considered a weak allele until further functional analysis is carried out.

\* \* \*

All of the methods disclosed and claimed herein can be made and executed without undue experimentation in light of the present disclosure. While the compositions and methods of this invention have been described in terms of preferred embodiments, it will be apparent to those of skill in the art that variations may be applied to the methods and in the steps or in the sequence of steps of the method described herein without departing from the concept, spirit and scope of the invention. More specifically, it will be apparent that certain agents which are both chemically and physiologically related may be substituted for the agents described herein while the same or similar results would be achieved. All such similar substitutes and modifications apparent to those skilled in the art are deemed to be within the spirit, scope and concept of the invention as defined by the appended claims.

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tcgaatgatg ctaggaatac agtctttaa tgtttgtcga aaggtgctgt tgacttttta 480
gtcaatccta tacgtaagaa tgaacttaag aatctttggc agcatgatg gagacggtgt 540
cacagctcaa gtggtagtg aagtgaagt ggcattcaga cgcagaagtg tggcaaatca 600
aaagtgga aagaatctgg taataatagt ggtagcaatg acagtcacga caacgaagca 660
gacatgggac ttaatgcaag ggatgacagt gataatggca gtggcactca agcgcagagc 720
tcattggacta agtgtgctgt ggagatggac agcccacagg caatgtctct ggatcagtta 780
gccgattcac ctgatagcac ttgtgcgtaa gtaatccacc caaagtcaga gatatgtagc 840
aacagacggc taccagacga cttcaaggaa aaggacttgg agatagtggt ccctggaaat 900
ttatatatag atcaccaatc tcccccaat gagaggccta tcaaagcaac agatggacgt 960
tgtgagtaac caccaaaaaa caattcgaag gagtcaatga tgcaaaatct agaggacca 1020
actgttcgag ctgctgatct aattggttca atggccaaaa acatggatc ccaggaggca 1080
gagagagctg cagatacccc taatctccct tccaaagtgc cagaaggga agataagaac 1140
aagcatgaca aaattttgcc atcacttgag ttgagtttga agagtcgag atcatgtgga 1200
tatggtgcca atacagtaa agctgatgaa caacagaatg tattaagaca gtcaaatctc 1260
tcagctttta caaggtaoca tacatctacg gttccaatc aaggtgggac tggattagta 1320
gggagctgtt cgccacatga caacagctca gaggctatga aaacagattc tacttaaac 1380
atgaagtaaa attcagatgc tgcctcaata aaacaaggct ccaacggaag tagcaataac 1440
aatgacatgg gttccactac aaagaatgtt gtgacaaaag ccaactacaaa taataaggac 1500
agggtaatgt tgccctcatc agctattaat aaggctaag gacacacatc agcattccac 1560
cctgtgcagc attggacgat ggttccagct aatgcagcag gagggacagc gaaggctgat 1620
gaagtggcca acattgcagg ttacccttca ggtgacatgc agtgtaacct gatgcaatgg 1680
taccctcgtc caacccttca ttacgtccag tttgatggtg cacgggagaa tggatgatcg 1740
ggagccctgg aatgtggttc ctccaacgta tttgatcctc cagttgaagg tcaagctact 1800
aactatggtg tgaacaggag caactcaggc agtaacaatg caaccaaggg gcagaatgga 1860
agtaatacag ttggtgcaag catggctggt ccaaatgcaa atgcaaatgg taatgctgga 1920
cgaacaaaaca tggagattgc taatgaggtc atcgacaaaa gtggacatgc aggaggtggc 1980
aatgggagtg gcagtgccag tggcaatgac acatatgtca aacggcttgc agcgggcttg 2040
acaccacgac aagcacaact aaagaaatag agagagaaaa agaaagatcg aaactttggg 2100
aaaaaggtgc ggtaccagag cagaaagagg ctggccgacc agcggccgcg gtttcgtggg 2160
cagttcgtga agcaagcctt gcaagatcag ggcgaacagg acggaactgg agagagatga 2220

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&lt;210&gt; SEQ ID NO 4

&lt;211&gt; LENGTH: 738

&lt;212&gt; TYPE: PRT

&lt;213&gt; ORGANISM: Sorghum bicolor

&lt;400&gt; SEQUENCE: 4

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Met Met Leu Arg Asn Asn Asn Asn Asn Leu Arg Ser Asn Gly Pro Ser  
 1 5 10 15  
 Asp Gly Leu Leu Ser Arg Pro Thr Pro Ala Val Leu Gln Asp Asp Asp  
 20 25 30  
 Asp Gly Gly Asp Asp Asp Thr Glu Asn Gln Gln Gln Glu Ala Val Tyr  
 35 40 45  
 Trp Glu Arg Phe Leu Gln Lys Lys Thr Ile Asn Val Leu Leu Val Glu  
 50 55 60  
 Ser Asp Asp Cys Thr Arg Arg Val Val Ser Ala Leu Leu Arg His Cys  
 65 70 75 80  
 Met Tyr Gln Val Ile Ser Ala Glu Asn Gly Gln Gln Ala Trp Asn Tyr  
 85 90 95  
 Leu Glu Asp Lys Gln Asn Asn Ile Asp Ile Val Leu Ile Glu Val Phe  
 100 105 110  
 Met Pro Gly Val Ser Gly Ile Ser Leu Leu Ser Arg Ile Met Ser His  
 115 120 125  
 Asn Ile Cys Lys Asn Ile Pro Val Ile Met Met Ser Ser Asn Asp Ala  
 130 135 140  
 Arg Asn Thr Val Phe Lys Cys Leu Ser Lys Gly Ala Val Asp Phe Leu  
 145 150 155 160  
 Val Asn Pro Ile Arg Lys Asn Glu Leu Lys Asn Leu Trp Gln His Val  
 165 170 175  
 Trp Arg Arg Cys His Ser Ser Ser Gly Ser Gly Ser Glu Ser Gly Ile  
 180 185 190  
 Gln Thr Gln Lys Cys Gly Lys Ser Lys Gly Gly Lys Glu Ser Gly Asn  
 195 200 205  
 Asn Ser Gly Ser Asn Asp Ser His Asp Asn Glu Ala Asp Met Gly Leu  
 210 215 220  
 Asn Ala Arg Asp Asp Ser Asp Asn Gly Ser Gly Thr Gln Ala Gln Ser  
 225 230 235 240  
 Ser Trp Thr Lys Cys Ala Val Glu Met Asp Ser Pro Gln Ala Met Ser  
 245 250 255  
 Leu Asp Gln Leu Ala Asp Ser Pro Asp Ser Thr Cys Ala Val Ile His  
 260 265 270  
 Pro Lys Ser Glu Ile Cys Ser Asn Arg Arg Leu Pro Asp Asp Phe Lys  
 275 280 285  
 Glu Lys Asp Leu Glu Ile Gly Gly Pro Gly Asn Leu Tyr Ile Asp His  
 290 295 300  
 Gln Ser Ser Pro Asn Glu Arg Pro Ile Lys Ala Thr Asp Gly Arg Cys  
 305 310 315 320  
 Glu Tyr Pro Pro Lys Asn Asn Ser Lys Glu Ser Met Met Gln Asn Leu  
 325 330 335  
 Glu Asp Pro Thr Val Arg Ala Ala Asp Leu Ile Gly Ser Met Ala Lys  
 340 345 350  
 Asn Met Asp Thr Gln Glu Ala Ala Arg Ala Ala Asp Thr Pro Asn Leu  
 355 360 365  
 Pro Ser Lys Val Pro Glu Gly Lys Asp Lys Asn Lys His Asp Lys Ile  
 370 375 380  
 Leu Pro Ser Leu Glu Leu Ser Leu Lys Arg Ser Arg Ser Cys Gly Tyr  
 385 390 395 400  
 Gly Ala Asn Thr Val Lys Ala Asp Glu Gln Gln Asn Val Leu Arg Gln  
 405 410 415

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Ser Asn Leu Ser Ala Phe Thr Arg Tyr His Thr Ser Thr Ala Ser Asn  
 420 425 430

Gln Gly Gly Thr Gly Leu Val Gly Ser Cys Ser Pro His Asp Asn Ser  
 435 440 445

Ser Glu Ala Met Lys Thr Asp Ser Thr Tyr Asn Met Lys Ser Asn Ser  
 450 455 460

Asp Ala Ala Pro Ile Lys Gln Gly Ser Asn Gly Ser Ser Asn Asn Asn  
 465 470 475 480

Asp Met Gly Ser Thr Thr Lys Asn Val Val Thr Lys Pro Thr Thr Asn  
 485 490 495

Asn Lys Asp Arg Val Met Leu Pro Ser Ser Ala Ile Asn Lys Ala Asn  
 500 505 510

Gly His Thr Ser Ala Phe His Pro Val Gln His Trp Thr Met Val Pro  
 515 520 525

Ala Asn Ala Ala Gly Gly Thr Ala Lys Ala Asp Glu Val Ala Asn Ile  
 530 535 540

Ala Gly Tyr Pro Ser Gly Asp Met Gln Cys Asn Leu Met Gln Trp Tyr  
 545 550 555 560

Pro Arg Pro Thr Leu His Tyr Val Gln Phe Asp Gly Ala Arg Glu Asn  
 565 570 575

Gly Gly Ser Gly Ala Leu Glu Cys Gly Ser Ser Asn Val Phe Asp Pro  
 580 585 590

Pro Val Glu Gly Gln Ala Thr Asn Tyr Gly Val Asn Arg Ser Asn Ser  
 595 600 605

Gly Ser Asn Asn Ala Thr Lys Gly Gln Asn Gly Ser Asn Thr Val Gly  
 610 615 620

Ala Ser Met Ala Gly Pro Asn Ala Asn Ala Asn Gly Asn Ala Gly Arg  
 625 630 635 640

Thr Asn Met Glu Ile Ala Asn Glu Val Ile Asp Lys Ser Gly His Ala  
 645 650 655

Gly Gly Gly Asn Gly Ser Gly Ser Gly Ser Gly Asn Asp Thr Tyr Val  
 660 665 670

Lys Arg Leu Ala Ala Gly Leu Thr Pro Arg Gln Ala Gln Leu Lys Lys  
 675 680 685

Tyr Arg Glu Lys Lys Lys Asp Arg Asn Phe Gly Lys Lys Val Arg Tyr  
 690 695 700

Gln Ser Arg Lys Arg Leu Ala Asp Gln Arg Pro Arg Phe Arg Gly Gln  
 705 710 715 720

Phe Val Lys Gln Ala Leu Gln Asp Gln Gly Glu Gln Asp Gly Thr Gly  
 725 730 735

Glu Arg

<210> SEQ ID NO 5  
 <211> LENGTH: 741  
 <212> TYPE: DNA  
 <213> ORGANISM: Sorghum bicolor

<400> SEQUENCE: 5

atgtcagggc cagcatgogg tgtgtgoggt gcagccgcct gctgcccgca cctcttcac 60  
 accggcgacg agaacgacga cttcaacagc eggggggect tgttctctgt ctteccctgcg 120  
 gcggttcacc atcatgagcc cagccccagc agcatgcagc agcagcctcc ggcgggggtgc 180  
 ctgcacgagt tccagttctt tggccatcag gacaacgatg accaccaaga aagcatcgcc 240  
 tggctctctg accaccggcc gccacctgcg catgatgtcg acgacgacga ccggtcccca 300



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getgagaacc agcagcctca tcaccgggcg ttgaccctg ttgggacgga gggaaaacggg 360
ctcacctttg aggttgatgc ccggctgggc ctgcgcagcg ggggcgcgcg ccggcaaaaca 420
gcagagacag cagcagcaag cgccaccatc atgtcattct gtgggagcac attcacagac 480
gccgcaagct cgaggctcaa ggagccaacc ctgactgacg acagtacgct gcaaatgccg 540
gtaggtcagt caacggagag ggaggctaag ttgatgaggt acaaggagaa gaggatgatg 600
aggtgttatg agaagcagat aagatatgca tccaggaaag cctatgcgca ggtgagaccc 660
cgggtgaaag gtcgctttgc caaggttaacc gaagcctgct ccgccacagc agacaatggt 720
ggcaacgacc acctgctctg a 741

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<210> SEQ ID NO 6
<211> LENGTH: 246
<212> TYPE: PRT
<213> ORGANISM: Sorghum bicolor

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<400> SEQUENCE: 6

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Met Ser Gly Pro Ala Cys Gly Val Cys Gly Ala Ala Ala Cys Cys Arg
 1           5           10           15
His Leu Phe His Thr Gly Asp Glu Asn Asp Asp Phe Asn Ser Arg Arg
          20           25           30
Ala Leu Phe Ser Val Phe Pro Ala Ala Val His His His Glu Pro Ser
          35           40           45
Pro Ser Ser Met Gln Gln Gln Pro Pro Ala Gly Cys Leu His Glu Phe
 50           55           60
Gln Phe Phe Gly His Gln Asp Asn Asp Asp His Gln Glu Ser Ile Ala
 65           70           75           80
Trp Leu Phe Asp His Pro Pro Pro Pro Ala His Asp Val Asp Asp Asp
          85           90           95
Asp Arg Ser Pro Ala Glu Asn Gln Gln Pro His His Arg Ala Phe Asp
          100          105          110
Pro Phe Gly Thr Glu Gly Asn Gly Leu Thr Phe Glu Val Asp Ala Arg
          115          120          125
Leu Gly Leu Gly Ser Gly Gly Ala Ala Arg Gln Thr Ala Glu Thr Ala
          130          135          140
Ala Ala Ser Ala Thr Ile Met Ser Phe Cys Gly Ser Thr Phe Thr Asp
          145          150          155          160
Ala Ala Ser Ser Arg Leu Lys Glu Pro Thr Leu Thr Asp Asp Ser Gln
          165          170          175
Leu Gln Met Pro Val Gly Gln Ser Thr Glu Arg Glu Ala Lys Leu Met
          180          185          190
Arg Tyr Lys Glu Lys Arg Met Met Arg Cys Tyr Glu Lys Gln Ile Arg
          195          200          205
Tyr Ala Ser Arg Lys Ala Tyr Ala Gln Val Arg Pro Arg Val Lys Gly
          210          215          220
Arg Phe Ala Lys Val Thr Glu Ala Cys Ser Ala Thr Ala Asp Asn Val
          225          230          235          240
Gly Asn Asp His Leu Leu
          245

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<210> SEQ ID NO 7
<211> LENGTH: 746
<212> TYPE: DNA
<213> ORGANISM: Sorghum bicolor

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&lt;400&gt; SEQUENCE: 7

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atgtcagggc cagcatgogg tgtgtgoggt gcagccgct gctgccggca cctcttcac    60
accggcgaag agaacgaaga cttcaacagc cggcgggct tgttctctgt cttccctgag    120
gcggttcacc atcatgagcc cagccccagc agcatgcagc agcagcctcc ggcgggggtgc    180
ctgcacgagt tccagttctt tggccatcag gacaacgatg accaccaaga aagcatcgcc    240
tggtctctcg accaccggcc gccacctgag catgatgtcg agtcgacgac gacgaccggt    300
ccccagctga gaaccagcag cctcatcacc gggcgtttga cccgtttggg acggagggaa    360
acgggctcac ctttgaggtt gatgccggc tgggcctcgg cagcgggggc gccgccggc    420
aacagcaga gacagcagca gcaagcgcca ccatcatgtc attctgtggg agcacattca    480
cagacgccgc aagctcgagg ctcaaggagc caaccctgac tgacgacagt cagctgcaaa    540
tgccggtagg tcagtcaacg gagaggagg ctaagttgat gaggtacaag gagaagagga    600
tgaggaggtg ttatgagaag cagataagat atgcatccag gaaagcctat gcgcaggtga    660
gaccccggtg gaaaggtcgc tttgccaagg taaccgaagc ctgctccgcc acagcagaca    720
atggttgcaa cgaccactg ctctga                                         746

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&lt;210&gt; SEQ ID NO 8

&lt;211&gt; LENGTH: 239

&lt;212&gt; TYPE: PRT

&lt;213&gt; ORGANISM: Sorghum bicolor

&lt;400&gt; SEQUENCE: 8

```

Met Ser Gly Pro Ala Cys Gly Val Cys Gly Ala Ala Ala Cys Cys Arg
1          5          10          15
His Leu Phe His Thr Gly Asp Glu Asn Asp Asp Phe Asn Ser Arg Arg
20          25          30
Ala Leu Phe Ser Val Phe Pro Ala Ala Val His His His Glu Pro Ser
35          40          45
Pro Ser Ser Met Gln Gln Gln Pro Pro Ala Gly Cys Leu His Glu Phe
50          55          60
Gln Phe Phe Gly His Gln Asp Asn Asp Asp His Gln Glu Ser Ile Ala
65          70          75          80
Trp Leu Phe Asp His Pro Pro Pro Pro Ala His Asp Val Glu Ser Thr
85          90          95
Thr Thr Thr Gly Pro Gln Leu Arg Thr Ser Ser Leu Ile Thr Gly Arg
100         105         110
Leu Thr Arg Leu Gly Arg Arg Glu Thr Gly Ser Pro Leu Arg Leu Met
115         120         125
Pro Gly Trp Ala Ser Ala Ala Gly Ala Pro Pro Gly Lys Gln Gln Arg
130         135         140
Gln Gln Gln Gln Ala Pro Pro Ser Cys His Ser Val Gly Ala His Ser
145         150         155         160
Gln Thr Pro Gln Ala Arg Gly Ser Arg Ser Gln Pro Leu Thr Thr Val
165         170         175
Ser Cys Lys Cys Arg Val Ser Gln Arg Arg Gly Arg Leu Ser Gly Thr
180         185         190
Arg Arg Arg Gly Gly Gly Val Met Arg Ser Arg Asp Met His Pro Gly
195         200         205
Lys Pro Met Arg Arg Asp Pro Gly Lys Val Ala Leu Pro Arg Pro Lys
210         215         220
Pro Ala Pro Pro Gln Gln Thr Met Leu Ala Thr Thr Thr Cys Ser

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225	230	235	
<210> SEQ ID NO 9			
<211> LENGTH: 3408			
<212> TYPE: DNA			
<213> ORGANISM: Sorghum bicolor			
<400> SEQUENCE: 9			
atgtcgtcgc	cgttgaacaa	ccgggggacg	tgctcccga gcagctctgc gcggtccag 60
cacagcgcgc	gggtggtggc	gcagacgcc	gtggacgcgc agctgcacgc cgagttcgag 120
agctcccagc	gcaacttoga	ctactctctg	tcggtgagcg ccgccatccg accgtcggtc 180
agcaccagca	ccgtctccac	ctaccaccag	accatgcagc ggggcctcta catccagccc 240
ttcggctgoc	tgctcgcogt	ccaccggac	accttcacgt tgctcgccta cagcgagaac 300
gcgcccgaga	tgctcgcact	caegccacac	gcggtcccca ccatcgacca gcgggacgcg 360
ctcgcctctg	gcgcccagct	gcgcacgctc	ttccgctcgc agagctccgt cgcgctgcac 420
aaggccgcca	ccttcgggga	ggtcaacctg	ctcaacccca tcctcgtgca tgccaggacg 480
tcggggaagc	ccttctacgc	catattgcac	cggatcgacg tcggccttgt catcgacctt 540
gagccggtea	accagttga	cgtgccagtc	actgctcggg gtgcgcttaa gtcgtacaag 600
ctcgcgcgca	aggccatctc	caggctgcag	tcgctgccca gcgggaacct gtcgctgctg 660
tgcgatgtgc	ttgtccgtga	ggtgagcag	ctcacgggct atgaccgggt catggcgtag 720
aagttccatg	aggatgagca	tggtgaggtc	atctccaggt gcaggaggtc tgatctggag 780
ccgtatcttg	gcctgcaact	cccagccacc	gacatcccgc aggcgtccag gttcttgttt 840
atgaagaaca	aagtgaggat	gatatgtgat	tgctctgcca ctctggtgaa gatcattcag 900
gatgatagcc	tagcacagcc	tctcagctc	tggtgttcca ccctcagggc ttcccatggt 960
tgccatgcac	agtacatggc	aaacatgggt	tctgttgcac cgcttgatgat gtcagtgact 1020
ataagcaatg	atgaggagga	agatgttgat	accgggagtg accaacaacc gaaaggcagg 1080
aaactgtggg	ggctggtcgt	ctgccatcat	acaagcccga ggctcgtccc tttcccacta 1140
aggtacgctt	gcgagtttct	cttgcaagta	tttgccatc agctaacaac ggagggtgaa 1200
ttggctgctc	aggcaaaagga	gaggcacatc	ctcagaacgc aaacccttct ttgtgatag 1260
ctcctgcggg	atgctcctgt	tgggatattt	accagctcac ctaatgtgat ggatctagta 1320
aagtgcgatg	gagctgcatt	gtattaccag	aaccagcttt tggctcctgg atcaacaccc 1380
tccgagtcag	agataaagag	cattgccaca	tggtgcagc agaaccatga tggttcaact 1440
gggctgagta	ctgacagctt	agtggaagca	ggttacctct gtgctgctgc acttcgtgaa 1500
gttgtgtgtg	gcatggcggc	tataaagatc	tcttccaaag attttatctt ctggttccga 1560
tcgcacacaa	caaaggagat	caagtggggt	ggggctaagc atgaaccggg tgacgcagat 1620
gacaatggca	ggaagatgca	tccacgatct	tcattcaagg ccttcttggg ggtggttaaa 1680
tggagaagtg	ttccctggga	ggatgtgaa	atggatgcta ttcattcttt gcagttaata 1740
ttacgtggct	ccctgcaaga	tgaagatgcc	aacagaaaca atgtaaggct cattgtaaaa 1800
gctccacctg	atgatacgaa	gaagatagag	gggctacttg aactaagaac agttacaaac 1860
gagatggtcc	gcttaattga	gacagcaacc	gcccctgtct tggtctgca cattgcccgt 1920
aacataaatg	gatggaacaa	taaagctgca	gaactaacag ggttacctgt aatggaagcc 1980
atagggaggc	ctctgataga	tcttgttgtt	gttgattcta ttgaagtggg taagcggatt 2040
ttggactcag	ctttacaagg	aattgaagag	caaaatctgg aatcaagct taaagcattc 2100

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catgaacagg aatgcaatgg tccaataatc ttgatgggta actcctgctg tagtcgggac 2160
ctttcagaga aagtcattgg agtttgcttt gtaggacaag atttgaccac gcagaagatg 2220
attatggata agtatactag gatacaagga gactatggtg ccatagtaaa gaaccccagt 2280
gagctcatcc ctcccatatt tatgatcaat gatcttggtt cctgcttaga gtggaataaa 2340
gctatgcaga agattaccgg tatacagagg gaagatgta tagataagtt gttaattggg 2400
gaggtottca cccttcatga ttatggctgt agggtgaaag atcatgctac tctaacgaaa 2460
cttagcatac tgatgaatgc agtgatttct ggtcaggatc ctgagaagct cctttttggt 2520
ttcttcgaca cagatgggaa gtatattgaa tccttgctga cagtgaacaa gagaataaat 2580
gctgagggta agatcactgg cgctatttgc tttctgcatg tggccagtcc agagcttcag 2640
catgctctcc aggtgcagaa aatgtctgaa caagctgcca caaacagttt taaggaatta 2700
acttacattc atcaagaatt aaggaacca ctcaatggca tgcaatttac ttgcaactta 2760
tgggagcctt ccgaattgac agaggagcag aggaaacttc tttcatctaa tattctctgt 2820
caggaccagc tgaaaaagat tttacatgac actgatcttg aaagcattga acagtgctat 2880
atggagatga acacagtaga gttcaacctt gaggaagctc ttaatacggc cctaatagcaa 2940
ggcatttcctt tgggcaagga aaagcgaatt tctattgaac gtgattggcc ggtggaaata 3000
tcacgcatgt acctttacgg ggacaattta aggettccagc aggtcctagc agactatctg 3060
gcatgcgccc ttcaattcac acaaccagct gaaggaccta tcgtgctcca ggtcattccc 3120
aagaagggaaa acattgggtc tggcatgcag attgctcatt tggagttcag gattgtccat 3180
ccagctccag gcgtccccga ggccctgata caggagatgt tccggcacia cccagaggtg 3240
tccagggagg gcctcggcct gtacatatgc cagaagctgg tgaaaacgat gagtggcacg 3300
gtacagtacc tacgagaagc cgatacctca tcgttcatca tcctgataga gttcccagtc 3360
gcccagctca gcagcaagcg gtccaagcct tcgacgagta aattctga 3408

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&lt;210&gt; SEQ ID NO 10

&lt;211&gt; LENGTH: 1135

&lt;212&gt; TYPE: PRT

&lt;213&gt; ORGANISM: Sorghum bicolor

&lt;400&gt; SEQUENCE: 10

```

Met Ser Ser Pro Leu Asn Asn Arg Gly Thr Cys Ser Arg Ser Ser Ser
1          5              10              15
Ala Arg Ser Arg His Ser Ala Arg Val Val Ala Gln Thr Pro Val Asp
20          25              30
Ala Gln Leu His Ala Glu Phe Glu Ser Ser Gln Arg Asn Phe Asp Tyr
35          40              45
Ser Ser Ser Val Ser Ala Ala Ile Arg Pro Ser Val Ser Thr Ser Thr
50          55              60
Val Ser Thr Tyr His Gln Thr Met Gln Arg Gly Leu Tyr Ile Gln Pro
65          70              75              80
Phe Gly Cys Leu Leu Ala Val His Pro Asp Thr Phe Thr Leu Leu Ala
85          90              95
Tyr Ser Glu Asn Ala Pro Glu Met Leu Asp Leu Thr Pro His Ala Val
100         105              110
Pro Thr Ile Asp Gln Arg Asp Ala Leu Ala Val Gly Ala Asp Val Arg
115         120              125
Thr Leu Phe Arg Ser Gln Ser Ser Val Ala Leu His Lys Ala Ala Thr
130         135              140

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Phe Gly Glu Val Asn Leu Leu Asn Pro Ile Leu Val His Ala Arg Thr  
 145 150 155 160  
 Ser Gly Lys Pro Phe Tyr Ala Ile Leu His Arg Ile Asp Val Gly Leu  
 165 170 175  
 Val Ile Asp Leu Glu Pro Val Asn Pro Val Asp Val Pro Val Thr Ala  
 180 185 190  
 Ala Gly Ala Leu Lys Ser Tyr Lys Leu Ala Ala Lys Ala Ile Ser Arg  
 195 200 205  
 Leu Gln Ser Leu Pro Ser Gly Asn Leu Ser Leu Leu Cys Asp Val Leu  
 210 215 220  
 Val Arg Glu Val Ser Glu Leu Thr Gly Tyr Asp Arg Val Met Ala Tyr  
 225 230 235 240  
 Lys Phe His Glu Asp Glu His Gly Glu Val Ile Ser Glu Cys Arg Arg  
 245 250 255  
 Ser Asp Leu Glu Pro Tyr Leu Gly Leu His Tyr Pro Ala Thr Asp Ile  
 260 265 270  
 Pro Gln Ala Ser Arg Phe Leu Phe Met Lys Asn Lys Val Arg Met Ile  
 275 280 285  
 Cys Asp Cys Ser Ala Thr Leu Val Lys Ile Ile Gln Asp Asp Ser Leu  
 290 295 300  
 Ala Gln Pro Leu Ser Leu Cys Gly Ser Thr Leu Arg Ala Ser His Gly  
 305 310 315 320  
 Cys His Ala Gln Tyr Met Ala Asn Met Gly Ser Val Ala Ser Leu Val  
 325 330 335  
 Met Ser Val Thr Ile Ser Asn Asp Glu Glu Glu Asp Val Asp Thr Gly  
 340 345 350  
 Ser Asp Gln Gln Pro Lys Gly Arg Lys Leu Trp Gly Leu Val Val Cys  
 355 360 365  
 His His Thr Ser Pro Arg Phe Val Pro Phe Pro Leu Arg Tyr Ala Cys  
 370 375 380  
 Glu Phe Leu Leu Gln Val Phe Gly Ile Gln Leu Asn Lys Glu Val Glu  
 385 390 395 400  
 Leu Ala Ala Gln Ala Lys Glu Arg His Ile Leu Arg Thr Gln Thr Leu  
 405 410 415  
 Leu Cys Asp Met Leu Leu Arg Asp Ala Pro Val Gly Ile Phe Thr Gln  
 420 425 430  
 Ser Pro Asn Val Met Asp Leu Val Lys Cys Asp Gly Ala Ala Leu Tyr  
 435 440 445  
 Tyr Gln Asn Gln Leu Leu Leu Leu Gly Ser Thr Pro Ser Glu Ser Glu  
 450 455 460  
 Ile Lys Ser Ile Ala Thr Trp Leu Gln Glu Asn His Asp Gly Ser Thr  
 465 470 475 480  
 Gly Leu Ser Thr Asp Ser Leu Val Glu Ala Gly Tyr Pro Gly Ala Ala  
 485 490 495  
 Ala Leu Arg Glu Val Val Cys Gly Met Ala Ala Ile Lys Ile Ser Ser  
 500 505 510  
 Lys Asp Phe Ile Phe Trp Phe Arg Ser His Thr Thr Lys Glu Ile Lys  
 515 520 525  
 Trp Gly Gly Ala Lys His Glu Pro Val Asp Ala Asp Asp Asn Gly Arg  
 530 535 540  
 Lys Met His Pro Arg Ser Ser Phe Lys Ala Phe Leu Glu Val Val Lys  
 545 550 555 560

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Trp Arg Ser Val Pro Trp Glu Asp Val Glu Met Asp Ala Ile His Ser  
                           565                                          570                                          575  
  
 Leu Gln Leu Ile Leu Arg Gly Ser Leu Gln Asp Glu Asp Ala Asn Arg  
                           580                                          585                                          590  
  
 Asn Asn Val Arg Ser Ile Val Lys Ala Pro Pro Asp Asp Thr Lys Lys  
                           595                                          600                                          605  
  
 Ile Gln Gly Leu Leu Glu Leu Arg Thr Val Thr Asn Glu Met Val Arg  
                           610                                          615                                          620  
  
 Leu Ile Glu Thr Ala Thr Ala Pro Val Leu Ala Val Asp Ile Ala Gly  
                           625                                          630                                          635                                          640  
  
 Asn Ile Asn Gly Trp Asn Asn Lys Ala Ala Glu Leu Thr Gly Leu Pro  
                           645                                          650                                          655  
  
 Val Met Glu Ala Ile Gly Arg Pro Leu Ile Asp Leu Val Val Val Asp  
                           660                                          665                                          670  
  
 Ser Ile Glu Val Val Lys Arg Ile Leu Asp Ser Ala Leu Gln Gly Ile  
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 Glu Glu Gln Asn Leu Glu Ile Lys Leu Lys Ala Phe His Glu Gln Glu  
                           690                                          695                                          700  
  
 Cys Asn Gly Pro Ile Ile Leu Met Val Asn Ser Cys Cys Ser Arg Asp  
                           705                                          710                                          715                                          720  
  
 Leu Ser Glu Lys Val Ile Gly Val Cys Phe Val Gly Gln Asp Leu Thr  
                           725                                          730                                          735  
  
 Thr Gln Lys Met Ile Met Asp Lys Tyr Thr Arg Ile Gln Gly Asp Tyr  
                           740                                          745                                          750  
  
 Val Ala Ile Val Lys Asn Pro Ser Glu Leu Ile Pro Pro Ile Phe Met  
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 Ile Asn Asp Leu Gly Ser Cys Leu Glu Trp Asn Lys Ala Met Gln Lys  
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 Glu Val Phe Thr Leu His Asp Tyr Gly Cys Arg Val Lys Asp His Ala  
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 Thr Leu Thr Lys Leu Ser Ile Leu Met Asn Ala Val Ile Ser Gly Gln  
                           820                                          825                                          830  
  
 Asp Pro Glu Lys Leu Leu Phe Gly Phe Phe Asp Thr Asp Gly Lys Tyr  
                           835                                          840                                          845  
  
 Ile Glu Ser Leu Leu Thr Val Asn Lys Arg Ile Asn Ala Glu Gly Lys  
                           850                                          855                                          860  
  
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                           865                                          870                                          875                                          880  
  
 His Ala Leu Gln Val Gln Lys Met Ser Glu Gln Ala Ala Thr Asn Ser  
                           885                                          890                                          895  
  
 Phe Lys Glu Leu Thr Tyr Ile His Gln Glu Leu Arg Asn Pro Leu Asn  
                           900                                          905                                          910  
  
 Gly Met Gln Phe Thr Cys Asn Leu Leu Glu Pro Ser Glu Leu Thr Glu  
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 Glu Gln Arg Lys Leu Leu Ser Ser Asn Ile Leu Cys Gln Asp Gln Leu  
                           930                                          935                                          940  
  
 Lys Lys Ile Leu His Asp Thr Asp Leu Glu Ser Ile Glu Gln Cys Tyr  
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 Met Glu Met Asn Thr Val Glu Phe Asn Leu Glu Glu Ala Leu Asn Thr  
                           965                                          970                                          975  
  
 Val Leu Met Gln Gly Ile Pro Leu Gly Lys Glu Lys Arg Ile Ser Ile

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980			985			990									
Glu	Arg	Asp	Trp	Pro	Val	Glu	Ile	Ser	Arg	Met	Tyr	Leu	Tyr	Gly	Asp
	995						1000						1005		
Asn	Leu	Arg	Leu	Gln	Gln	Val	Leu	Ala	Asp	Tyr	Leu	Ala	Cys	Ala	
	1010						1015						1020		
Leu	Gln	Phe	Thr	Gln	Pro	Ala	Glu	Gly	Pro	Ile	Val	Leu	Gln	Val	
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Ile	Pro	Lys	Lys	Glu	Asn	Ile	Gly	Ser	Gly	Met	Gln	Ile	Ala	His	
	1040						1045						1050		
Leu	Glu	Phe	Arg	Ile	Val	His	Pro	Ala	Pro	Gly	Val	Pro	Glu	Ala	
	1055						1060						1065		
Leu	Ile	Gln	Glu	Met	Phe	Arg	His	Asn	Pro	Glu	Val	Ser	Arg	Glu	
	1070						1075						1080		
Gly	Leu	Gly	Leu	Tyr	Ile	Cys	Gln	Lys	Leu	Val	Lys	Thr	Met	Ser	
	1085						1090						1095		
Gly	Thr	Val	Gln	Tyr	Leu	Arg	Glu	Ala	Asp	Thr	Ser	Ser	Phe	Ile	
	1100						1105						1110		
Ile	Leu	Ile	Glu	Phe	Pro	Val	Ala	Gln	Leu	Ser	Ser	Lys	Arg	Ser	
	1115						1120						1125		
Lys	Pro	Ser	Thr	Ser	Lys	Phe									
	1130						1135								

<210> SEQ ID NO 11  
 <211> LENGTH: 3408  
 <212> TYPE: DNA  
 <213> ORGANISM: Sorghum bicolor

<400> SEQUENCE: 11

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agctcccagc gcaacttcga ctactctctg tcggtgagcg ccgccatccg accgtcggtc	180
agcaccagca ccgtctccac ctaccaccag accatgcagc ggggcctcta catccagccc	240
ttcggctgcc tgctcgccgt ccacccggac accttcacgt tgctgccta cagcgagaac	300
gcgcccgaga tgctcgacct cagccacac gcggtcccca ccatcgacca gcgggacgcg	360
ctcgccgtcg tcgcccagct gcgcacgctc ttccgctcgc agagctccgt cgcgctgcac	420
aaggccgcca ccttcgggga ggtcaacctg ctcaaccca tcctcgtgca tgccaggacg	480
tcgaggaagc ccttctacgc catattgcac cggatcgacg tcggccttgt catcgacctt	540
gagccggtca acccagttga cgtgccagcc actgctgcgg gtgcgcttaa gtcgtacaag	600
ctcgccgcca aggccatctc caggctgcag tcgctgccc gcgggaacct gtcgctgctg	660
tgcgatgtgc ttgtccgtga ggtgagcag ctcacgggct atgaccgggt catggcgtag	720
aagttccatg aggatgagca tggtagggtc atttccagat gcaggaggtc tgatctggag	780
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atgaagaaca aagtgaggat gatatgtgat tgctctgcca ctctggtgaa gatcattcag	900
gatgatagcc tagcacagcc tctcagcctc tgtggttcca ccctcagggc ttccatggt	960
tgccatgcac agtacatggc aaacatgggt tctgttgcac cgcttgtgat gtcagtgact	1020
ataagcaatg atgaggagga agatgttgat accgggagtg accaacaacc gaaaggcagg	1080
aaactgtggg ggctggtcgt ctgccatcat acaagcccga ggctcgtccc tttcccacta	1140
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catgaacagg	aatgcaatgg	tccaataatc	ttgatggtta	actcctgctg	tagtcgggac	2160
ctttcagaga	aagtcattgg	agtttgcttt	gtaggacaag	atctgaccac	gcagaagatg	2220
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gagctcatcc	ctcccatatt	tatgatcaat	gatcttgggt	cctgcttaga	gtggaataaa	2340
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gctgagggta	agatcactgg	cgctatttgc	ttctgcatg	tggccagtcc	agagcttcag	2640
catgctctcc	aggtgcagaa	aatgtctgaa	caagctgcca	caaacagttt	taaggaatta	2700
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ttggatcctt	ccgaattgac	agaggagcag	aggaaacttc	tttcatetaa	tattctctgt	2820
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atggagatga	acacagtaga	gttcaacctt	gaggaagctc	ttaatacggg	cctaattgcaa	2940
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aagaagggaaa	acattggggtc	tggcatgcag	attgctcatt	tggagttcag	gattgtccat	3180
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gtacagtacc	tacgagaagc	cgatacctca	tcgttcatca	tcctgataga	gttcccagtc	3360
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&lt;210&gt; SEQ ID NO 12

&lt;211&gt; LENGTH: 1135

&lt;212&gt; TYPE: PRT



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&lt;213&gt; ORGANISM: Sorghum bicolor

&lt;400&gt; SEQUENCE: 12

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 Ala Arg Ser Arg His Ser Ala Arg Val Val Ala Gln Thr Pro Val Asp  
 20 25 30  
 Ala Gln Leu His Ala Glu Phe Glu Ser Ser Gln Arg Asn Phe Asp Tyr  
 35 40 45  
 Ser Ser Ser Val Ser Ala Ala Ile Arg Pro Ser Val Ser Thr Ser Thr  
 50 55 60  
 Val Ser Thr Tyr His Gln Thr Met Gln Arg Gly Leu Tyr Ile Gln Pro  
 65 70 75 80  
 Phe Gly Cys Leu Leu Ala Val His Pro Asp Thr Phe Thr Leu Leu Ala  
 85 90 95  
 Tyr Ser Glu Asn Ala Pro Glu Met Leu Asp Leu Thr Pro His Ala Val  
 100 105 110  
 Pro Thr Ile Asp Gln Arg Asp Ala Leu Ala Val Val Ala Asp Val Arg  
 115 120 125  
 Thr Leu Phe Arg Ser Gln Ser Ser Val Ala Leu His Lys Ala Ala Thr  
 130 135 140  
 Phe Gly Glu Val Asn Leu Leu Asn Pro Ile Leu Val His Ala Arg Thr  
 145 150 155 160  
 Ser Arg Lys Pro Phe Tyr Ala Ile Leu His Arg Ile Asp Val Gly Leu  
 165 170 175  
 Val Ile Asp Leu Glu Pro Val Asn Pro Val Asp Val Pro Ala Thr Ala  
 180 185 190  
 Ala Gly Ala Leu Lys Ser Tyr Lys Leu Ala Ala Lys Ala Ile Ser Arg  
 195 200 205  
 Leu Gln Ser Leu Pro Ser Gly Asn Leu Ser Leu Leu Cys Asp Val Leu  
 210 215 220  
 Val Arg Glu Val Ser Glu Leu Thr Gly Tyr Asp Arg Val Met Ala Tyr  
 225 230 235 240  
 Lys Phe His Glu Asp Glu His Gly Glu Val Ile Ser Glu Cys Arg Arg  
 245 250 255  
 Ser Asp Leu Glu Pro Tyr Leu Gly Leu His Tyr Pro Ala Thr Asp Ile  
 260 265 270  
 Pro Gln Ala Ser Arg Phe Leu Phe Met Lys Asn Lys Val Arg Met Ile  
 275 280 285  
 Cys Asp Cys Ser Ala Thr Leu Val Lys Ile Ile Gln Asp Asp Ser Leu  
 290 295 300  
 Ala Gln Pro Leu Ser Leu Cys Gly Ser Thr Leu Arg Ala Ser His Gly  
 305 310 315 320  
 Cys His Ala Gln Tyr Met Ala Asn Met Gly Ser Val Ala Ser Leu Val  
 325 330 335  
 Met Ser Val Thr Ile Ser Asn Asp Glu Glu Glu Asp Val Asp Thr Gly  
 340 345 350  
 Ser Asp Gln Gln Pro Lys Gly Arg Lys Leu Trp Gly Leu Val Val Cys  
 355 360 365  
 His His Thr Ser Pro Arg Phe Val Pro Phe Pro Leu Arg Tyr Ala Cys  
 370 375 380  
 Glu Phe Leu Leu Gln Val Phe Gly Ile Gln Leu Asn Lys Glu Val Glu  
 385 390 395 400

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Leu Ala Ala Gln Ala Lys Glu Arg His Ile Leu Arg Thr Gln Thr Leu  
405 410 415

Leu Cys Asp Met Leu Leu Arg Asp Ala Pro Val Gly Ile Phe Thr Gln  
420 425 430

Ser Pro Asn Val Met Asp Leu Val Lys Cys Asp Gly Ala Ala Leu Tyr  
435 440 445

Tyr Gln Asn Gln Leu Leu Leu Leu Gly Ser Thr Pro Ser Glu Ser Glu  
450 455 460

Ile Lys Ser Ile Ala Thr Trp Leu Gln Glu Asn His Asp Gly Ser Thr  
465 470 475 480

Gly Leu Ser Thr Asp Ser Leu Val Glu Ala Gly Tyr Pro Gly Ala Ala  
485 490 495

Ala Leu Arg Glu Val Val Cys Gly Met Ala Ala Ile Lys Ile Ser Ser  
500 505 510

Lys Asp Phe Ile Phe Trp Phe Arg Ser His Thr Thr Lys Glu Ile Lys  
515 520 525

Trp Gly Gly Ala Lys His Glu Pro Val Asp Ala Asp Asp Asn Gly Arg  
530 535 540

Lys Met His Pro Arg Ser Ser Phe Lys Ala Phe Leu Glu Val Val Lys  
545 550 555 560

Trp Arg Ser Val Pro Trp Glu Asp Val Glu Met Asp Ala Ile His Ser  
565 570 575

Leu Gln Leu Ile Leu Arg Gly Ser Leu Gln Asp Glu Asp Ala Asn Arg  
580 585 590

Asn Asn Val Arg Ser Ile Val Lys Ala Pro Pro Asp Asp Thr Lys Lys  
595 600 605

Ile Gln Gly Leu Leu Glu Leu Arg Thr Val Thr Asn Glu Met Val Arg  
610 615 620

Leu Ile Glu Thr Ala Thr Ala Pro Val Leu Ala Val Asp Ile Ala Gly  
625 630 635 640

Asn Ile Asn Gly Trp Asn Asn Lys Ala Ala Glu Leu Thr Gly Leu Pro  
645 650 655

Val Met Glu Ala Ile Gly Arg Pro Leu Ile Asp Leu Val Val Val Asp  
660 665 670

Ser Ile Glu Val Val Lys Arg Ile Leu Asp Ser Ala Leu Gln Gly Ile  
675 680 685

Glu Glu Gln Asn Leu Glu Ile Lys Leu Lys Ala Phe His Glu Gln Glu  
690 695 700

Cys Asn Gly Pro Ile Ile Leu Met Val Asn Ser Cys Cys Ser Arg Asp  
705 710 715 720

Leu Ser Glu Lys Val Ile Gly Val Cys Phe Val Gly Gln Asp Leu Thr  
725 730 735

Thr Gln Lys Met Ile Met Asp Lys Tyr Thr Arg Ile Gln Gly Asp Tyr  
740 745 750

Val Ala Ile Val Lys Asn Pro Ser Glu Leu Ile Pro Pro Ile Phe Met  
755 760 765

Ile Asn Asp Leu Gly Ser Cys Leu Glu Trp Asn Lys Ala Met Gln Lys  
770 775 780

Ile Thr Gly Ile Gln Arg Glu Asp Val Ile Asp Lys Leu Leu Ile Gly  
785 790 795 800

Glu Val Phe Thr Leu His Asp Tyr Gly Cys Arg Val Lys Asp His Ala  
805 810 815

Thr Leu Thr Lys Leu Ser Ile Leu Met Asn Ala Val Ile Ser Gly Gln

-continued

820				825				830							
Asp	Pro	Glu	Lys	Leu	Leu	Phe	Gly	Phe	Phe	Asp	Thr	Asp	Gly	Lys	Tyr
	835						840						845		
Ile	Glu	Ser	Leu	Leu	Thr	Val	Asn	Lys	Arg	Ile	Asn	Ala	Glu	Gly	Lys
	850						855						860		
Ile	Thr	Gly	Ala	Ile	Cys	Phe	Leu	His	Val	Ala	Ser	Pro	Glu	Leu	Gln
	865						870						875		880
His	Ala	Leu	Gln	Val	Gln	Lys	Met	Ser	Glu	Gln	Ala	Ala	Thr	Asn	Ser
			885								890				895
Phe	Lys	Glu	Leu	Thr	Tyr	Ile	His	Gln	Glu	Leu	Arg	Asn	Pro	Leu	Asn
			900								905				910
Gly	Met	Gln	Phe	Thr	Cys	Asn	Leu	Leu	Asp	Pro	Ser	Glu	Leu	Thr	Glu
			915				920								925
Glu	Gln	Arg	Lys	Leu	Leu	Ser	Ser	Asn	Ile	Leu	Cys	Gln	Asp	Gln	Leu
	930						935						940		
Lys	Lys	Ile	Leu	His	Asp	Thr	Asp	Leu	Glu	Ser	Ile	Glu	Gln	Cys	Tyr
	945						950						955		960
Met	Glu	Met	Asn	Thr	Val	Glu	Phe	Asn	Leu	Glu	Glu	Ala	Leu	Asn	Thr
			965								970				975
Val	Leu	Met	Gln	Gly	Ile	Pro	Leu	Gly	Lys	Glu	Lys	Arg	Ile	Ser	Ile
			980								985				990
Glu	Arg	Asp	Trp	Pro	Val	Glu	Ile	Ser	Arg	Met	Tyr	Leu	Tyr	Gly	Asp
			995				1000								1005
Asn	Leu	Arg	Leu	Gln	Gln	Val	Leu	Ala	Asp	Tyr	Leu	Ala	Cys	Ala	
	1010						1015								1020
Leu	Gln	Phe	Thr	Gln	Pro	Ala	Glu	Gly	Pro	Ile	Val	Leu	Gln	Val	
	1025						1030								1035
Ile	Pro	Lys	Lys	Glu	Asn	Ile	Gly	Ser	Gly	Met	Gln	Ile	Ala	His	
	1040						1045								1050
Leu	Glu	Phe	Arg	Ile	Val	His	Pro	Ala	Pro	Gly	Val	Pro	Glu	Ala	
	1055						1060								1065
Leu	Ile	Gln	Glu	Met	Phe	Arg	His	Asn	Pro	Glu	Val	Ser	Arg	Glu	
	1070						1075								1080
Gly	Leu	Gly	Leu	Tyr	Ile	Cys	Gln	Lys	Leu	Val	Lys	Thr	Met	Ser	
	1085						1090								1095
Gly	Thr	Val	Gln	Tyr	Leu	Arg	Glu	Ala	Asp	Thr	Ser	Ser	Phe	Ile	
	1100						1105								1110
Ile	Leu	Ile	Glu	Phe	Pro	Val	Ala	Gln	Leu	Ser	Ser	Lys	Arg	Ser	
	1115						1120								1125
Lys	Pro	Ser	Thr	Ser	Lys	Phe									
	1130						1135								

What is claimed is:

1. A method of identifying the genotype of a sorghum plant for a Ma6 locus comprising:
  - a) obtaining a sorghum plant; and
  - b) assaying the sorghum plant for the absence or presence of an allele at the Ma6 locus, wherein the locus comprises SEQ ID NO:5, or SEQ ID NO:7.
2. The method of claim 1, further comprising selecting said sorghum plant comprising said allele and crossing the sorghum plant with a second sorghum plant to obtain an F1 progeny, wherein the F1 progeny comprises the allele.

3. The method of claim 2, further comprising crossing the F1 progeny with itself or a different sorghum plant and selecting a progeny resulting therefrom that comprises the allele.

4. The method of claim 1, wherein the Ma6 locus comprises a nucleic acid encoding a polypeptide with the sequence of SEQ ID NO:8 or the coding sequence of SEQ ID NO:7.

\* \* \* \* \*