Parental Selection in Rice Cultivar Improvement

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Abstract: The evaluation of rice (Oryza sativa L.) cultivars assists breeders in identifying useful trait relationships and in selecting parents as donors of specific traits. This study was conducted to compare long-grain rice cultivars using genotype × trait (GT) biplot analysis and determine potential donors of traits related to grain yield and quality. Seventeen cultivars in the 2005 and 2006 Uniform Regional Rice Nursery in Beaumont, Texas, USA were analyzed for 20 traits using GT biplot analysis. The GT biplots showed the diversity among cultivars with regards to yield-related traits. Cultivars recommended as donor parents were: Trenasse, Spring, Presidio, and Cocodrie for high grain yield and head rice rate; Trenasse and Presidio for semi-dwarfness; Banks for tall plant height; Wells for high flag leaf area, panicle weight, and number and mass of filled grains per panicle; Hidalgo for high tiller density; Francis for high number of spikelets per panicle; Spring and Trenasse for short flowering duration; Cheniere for more days to heading and maturity and Spring for less days; and Spring and Hidalgo for high grain weight. Breeders can use these cultivars with specific traits to increase grain yield and quality.

Key words: diversity; genotype × trait biplot analysis; grain yield; grain quality; parental selection; rice

In rice (Oryza sativa L.) breeding programs, parents used in crosses are selected from cultivars and advanced breeding lines. While new cultivars should possess superior combinations of traits, parents should serve as excellent donors of one or more traits being targeted by the breeding program (Yan and Frégeau-Reid, 2008). The traits of parents should include high levels of grain yield, tiller density, panicle weight, number of grains per panicle, head rice rate, and insect pest and disease resistance. Identifying and using cultivars that have most of these targeted traits as parents in crosses is important to the rice breeders in creating the population to develop new cultivars. Traditionally, breeders would create genotype × trait (GT) tables, sort and rank the genotypes based on selection criteria traits, then intercross the genotypes that top the various trait rankings. This procedure is logical and easy when a few traits are considered, but it becomes difficult and less efficient as more traits are considered, that is, more genotypes are selected as parents for intercrossing. A more efficient method of multi-trait data analysis and selection of cultivars as parents is the genotype × trait biplot analysis, which has been applied on soybeans (Glycine max) (Yan and Rajcan, 2002), oats (Avena sativa) (Yan and Frégeau-Reid, 2008) and corn (Zea mays) (Dolatabad et al, 2010), but not to parental selection in rice. In these cases, trait relationships were not obtained simply through correlation between two traits, but through considering the interrelationships of all measured traits and the overall pattern of the data in different locations and years.

High performing long-grain rice cultivars are included as checks in the Uniform Regional Rice Nursery (URRN) in Beaumont, Texas, USA to serve as a standard for comparison in the release of new cultivars. These include popular cultivars such as Cocodrie, Wells, and Francis, and newly released cultivars in rice growing states in the United States (US). They vary in plant type and various traits such as maturity, plant height, and tillering ability, but all have the typical long grain and amylose content common in US long-grain cultivars. As high yielding cultivars, these check cultivars are usually grown in the hybridization blocks of breeding programs, and serve as parents in developing new crosses. Information that shows the diversity of cultivars that are used as both checks in yield trials and parents in rice cultivar improvement programs is lacking. The determination of which cultivar is the best source for specific traits that improve grain yield is important. GT biplot analysis would enable the identification of cultivars that perform well in several desirable traits and hence be recommended as parents.
of crosses in rice improvement programs. It would also assist breeders in identifying useful relationships among traits. The objective of this research was to compare US long-grain rice cultivars using GT biplot analysis and determine potential donors of traits related to grain yield and quality.

**MATERIALS AND METHODS**

This study analyzed 17 long-grain rice cultivars that were common checks in 2005 and 2006 at the URRN in the Texas A&M System, AgriLife Research and Extension Center in Beaumont, Texas, where the soil is an Entic Pelludert (fine, montmorillonitic, and thermic). The cultivars were Banks (Moldenhauer et al, 2007b), Cheniere (Linscombe et al, 2006a), Cocodrie (Linscombe et al, 2000), Cybonnet (Gibbons et al, 2006), Cypress (Linscombe et al, 1993), Dellrose (Jodari et al, 1996), Dixiebelle (McClung et al, 1998), Francis (Moldenhauer et al, 2007c), Hidalgo (McClung et al, 2007), L205 (Tseng et al, 2001), Presidio (McClung, 2005a), Priscilla (Mississippi State University, 2009), Saber (McClung et al, 2005b), Spring (Moldenhauer et al, 2007a), Trenasse (Linscombe et al, 2006b), and Wells (Moldenhauer et al, 2007d). Each cultivar was drill-seeded in plots that were 5.8 m × 1.2 m in size and consisted of six rows. Seedling emergence dates of the yield trials were 14 April, 2005 and 15 April, 2006. Recommend cultural and agronomic practices were applied to the trials in both years.

The 20 traits gathered for each cultivar from two plots or replications were: 1) plant height at 34 d after emergence (DAE); 2) tiller density at 40 DAE; 3) flag-leaf length; 4) flag-leaf width; 5) flag-leaf area, estimated as flag-leaf length × flag-leaf width × 0.75; 6) number of days to heading; 7) number of days to maturity; 8) flowering duration (number of days from start of flowering to 100% flowering); 9) plant height at harvest; 10) panicle weight; 11) number of filled grains per panicle; 12) number of unfilled grains per panicle; 13) number of spikelets per panicle; 14) filled grain mass per panicle; 15) seed-setting rate; 16) 1000-grain weight; 17) panicle type (rated as 1, compact; 3, intermediate; and 5, open); 18) grain yield; 19) milled rice rate; and 20) head rice rate. Plant height was measured from the ground surface to the tip of the panicle of three plants in a plot. Tiller density (m⁻²) was estimated from the number of main stems plus tillers counted from a 30-cm row portion within each plot. Leaf parameters were estimated from five leaves per plot, and panicle traits were estimated from five main culm panicles per plot. In general, a main culm panicle is heavier than a tiller panicle due to its higher number of grains per panicle, and panicle weight decreases with younger or later tillers. Hence, for specificity and consistency in comparing panicle traits among genotypes, main culm panicles were sampled.

Data were standardized to a mean of 0 and a standard deviation of 1 for each trait. For each year, the standardized data were analyzed using the ‘Which Won Where’, ‘Rank on any Tester’, and ‘Combine two Testers’ functions of the GGEbiplot software (Yan, 2001; Yan and Kang, 2003). The Which Won Where function was used to identify the cultivars that had the highest values regarding one or more traits. The Rank on any Tester function was used to rank the cultivars based on each trait. The Combine two Testers function was used to rank the cultivars based on two traits at a time, that is, grain yield and head rice rate. GT biplots were produced using these functions of the GGEbiplot software.

**RESULTS**

**GT biplots in 2005 and 2006**

There were significant differences ($P < 0.05$) among cultivars, years and year × cultivar in 9, 12 and 11 of the 20 traits, respectively (Table 1). Due to the significant effects of years and year × cultivar, GT biplot analysis was conducted for each year.

The GT biplots showed the diversity of the 17 cultivars in terms of 20 traits. The GT biplot for 2005 (Fig. 1) identified six cultivars as best donors for single or multiple traits, and grouped the 17 cultivars based on traits that make them potential donors. Banks was the highest performing cultivar for eight traits (numbers of days to heading and maturity, flowering duration, plant height at harvest, panicle weight, numbers of spikelets and filled grains per panicle, and filled grain weight per panicle), Hidalgo was the highest for six traits (plant height at 34 DAE, tiller density at 40 DAE, flag leaf width and area, seed-setting rate, and 1000-grain weight), Trenasse was the highest for six traits (plant height at 34 DAE, tiller density at 40 DAE, flag leaf width and area, seed-setting rate, and 1000-grain weight), Trenasse was the highest for two traits (panicle type and grain yield), Dellrose was the highest for two traits (milled rice rate and head rice rate), Wells was the highest for flag leaf length, and Francis for number of unfilled grains per panicle.

The GT biplot for 2006 (Fig. 2) indicated that Wells was the highest performing cultivar for 12 traits (flag leaf length, width and area, numbers of days to heading.
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and maturity, flowering duration, plant height at harvest, panicle weight, numbers of filled and unfilled grains per panicle, number of spikelets per panicle, and filled grain weight per panicle). Trenasse was the highest for three traits (panicle type, milled rice rate and head rice rate), Francis was the highest for three traits (plant height at 34 DAE, 1000-grain weight, and grain yield), and Dixiebelle was the highest for two traits (tiller density at 40 DAE and seed-setting rate).

Wells and Trenasse were the only two cultivars that showed the best performance for a specific trait in both years. In both years, Wells was the highest in flag leaf length, while Trenasse was the highest in panicle type rating (i.e., it had an intermediate panicle type).

**Consistently high and low performers for yield and yield-related traits**

Wells was consistently ranked among the top three cultivars in 2005 and 2006 for the following traits: plant height at 34 DAE and at harvest; flag leaf length, width and area; panicle weight; number of filled grains per panicle; and filled grain weight per panicle. Other cultivars that were consistently ranked in the top three in 2005 and 2006 were: Hidalgo for higher tiller density at 40 DAE; Cheniere for increased number of days to heading and maturity; Banks for longer flowering duration, higher plant height at harvest, and more number of unfilled grains per panicle; Francis for longer flowering duration, and larger number of spikelets per panicle; Trenasse for intermediate panicle type, and higher grain yield and head rice rate; and Spring for higher milled rice rate.

The cultivars that ranked the top three for seed-setting rate in 2005 were Hidalgo, Spring and Dellrose, whereas in 2006, they were Dixiebelle, Trenasse and Presidio. As for 1000-grain weight, Hidalgo, Spring and L205 were in the top three in 2005, whereas Francis, Wells and Banks were among the top three in 2006.

Trenasse was consistently ranked in the lowest three in 2005 and 2006 for tiller density at 40 DAE, flag leaf length, width and area, number of days to heading, flowering duration, panicle weight, numbers of spikelets and grains per panicle, and filled grain weight per panicle. Other cultivars that were consistently ranked among the lowest three in 2005 and 2006 were: Francis for lower tiller density at 40 DAE and milled rice rate; Spring for shorter flowering duration and fewer numbers of days to heading and maturity;

### Table 1. Significance of the effects of cultivar, year, and year × cultivar on 20 traits based on the evaluation of 17 US cultivars grown in Beaumont, Texas, USA in 2005 and 2006.

<table>
<thead>
<tr>
<th>Trait</th>
<th>Mean 2005</th>
<th>Mean 2006</th>
<th>P-value for significance of effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>23.3</td>
<td>32.4</td>
<td>0.0084 0.0015 0.1786</td>
</tr>
<tr>
<td>T2</td>
<td>458.5</td>
<td>770.7</td>
<td>0.1775 0.0017 0.0089</td>
</tr>
<tr>
<td>T3</td>
<td>25.4</td>
<td>29.4</td>
<td>0.0579 0.0058 0.0005</td>
</tr>
<tr>
<td>T4</td>
<td>1.57</td>
<td>1.67</td>
<td>0.0014 0.1031 0.2156</td>
</tr>
<tr>
<td>T5</td>
<td>30.0</td>
<td>37.0</td>
<td>0.0900 0.0033 0.0051</td>
</tr>
<tr>
<td>T6</td>
<td>86.9</td>
<td>79.9</td>
<td>&lt; 0.0001 &lt; 0.0001 0.0735</td>
</tr>
<tr>
<td>T7</td>
<td>5.9</td>
<td>4.7</td>
<td>0.2572 0.2740 0.3620</td>
</tr>
<tr>
<td>T8</td>
<td>124.6</td>
<td>118.6</td>
<td>0.0355 &lt; 0.0001 &lt; 0.0001</td>
</tr>
<tr>
<td>T9</td>
<td>95.4</td>
<td>98.4</td>
<td>0.0004 0.2728 0.2995</td>
</tr>
<tr>
<td>T10</td>
<td>2.96</td>
<td>2.36</td>
<td>0.0544 0.0011 0.0008</td>
</tr>
<tr>
<td>T11</td>
<td>127.4</td>
<td>99.9</td>
<td>0.2046 0.0006 0.0270</td>
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<td>T12</td>
<td>30.3</td>
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<td>T13</td>
<td>157.7</td>
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<td>75.0</td>
<td>&lt; 0.0001 0.1015 0.6008</td>
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<td>T16</td>
<td>22.3</td>
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<td>0.0001 0.3459 0.1907</td>
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<td>T17</td>
<td>2.2</td>
<td>1.5</td>
<td>0.0798 0.0858 &lt; 0.0001</td>
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<tr>
<td>T18</td>
<td>9 537.3</td>
<td>9 196.4</td>
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<tr>
<td>T19</td>
<td>68.4</td>
<td>71.3</td>
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<tr>
<td>T20</td>
<td>53.3</td>
<td>59.7</td>
<td>0.2444 0.0031 &lt; 0.0001</td>
</tr>
</tbody>
</table>

T1, Plant height at 34 d after emergence (cm); T2, Tiller density at 40 d after emergence (m\(^{-2}\)); T3, Flag leaf length (cm); T4, Flag leaf width (cm); T5, Flag leaf area (cm\(^2\)); T6, Number of days to heading (d); T7, Flowering duration (d); T8, Number of days to maturity (d); T9, Plant height at harvest (cm); T10, Panicle weight (g); T11, Number of filled grains per panicle; T12, Number of unfilled grains per panicle; T13, Number of spikelets per panicle; T14, Filled grain weight per panicle (g); T15, Seed-setting rate (%); T16, 1000-grain weight (g); T17, Panicle type (rating: 1, compact; 3, intermediate; 5, open); T18, Grain yield (kg/hm\(^2\)); T19, Milled rice rate (%); T20, Head rice rate (%).

P < 0.05 was considered statistically significant.
Cheniere for lighter 1000-grain weight; Wells for compact panicle type; and Banks for lower milled rice rate.

Trenasse, Cocodrie and Dellrose were among the lowest three in plant height at harvest in 2005, whereas Dixiebelle, Saber and Presidio were the lowest three in 2006. As for grain yield, the lowest three were Banks, Cybonnet and Wells in 2005, and Dixiebelle, Cheniere and Hidalgo in 2006.

**Combined selection for high grain yield and high head rice rate**

Based on the Combine Tester function of GT biplot analysis, Trenasse, Dellrose and Cocodrie were the top three cultivars for the combined traits of high grain yield and high head rice rate in 2005, while Trenasse, Spring and Presidio were the top three in 2006. When cultivar rank is averaged across years, Trenasse is the best donor for these two traits, followed by Spring, Presidio and Cocodrie.

Traits that were associated with the combined traits of high grain yield and high head rice rate in both 2005 and 2006 based on the GT biplots were higher milled rice rate and seed-setting rate, fewer days to heading and maturity, fewer spikelets and filled grains per panicle, lower panicle weight and filled grain weight per panicles, and shorter flowering duration.

**DISCUSSION**

Selection of parents in a crossing program is critical in population improvement and cultivar release and it is one of the most important decisions for breeders (Fehr, 1987). The source of germplasm is a part of this decision process. Commercially grown cultivars are very popular choices as parents to breeders. These cultivars offer the majority of traits of great importance to breeders and the likelihood of getting superior progenies is
high. However, this may lead to lower genetic diversity. Identifying and crossing parents that are on opposite extremes for specific traits is necessary when generation of new variation is of prime importance. From these crosses, a larger variation in the F$_2$ generation can be generated from which the target genotype with the desired trait combinations can be selected. However, if narrower variation is needed for traits or if the objective is to retain the values of traits, then parents with similar phenotypic traits such as commercial cultivars are desirable (McCouch, 2004).

Cultivars that are recommended as parents in developing populations having some important traits related to grain yield and quality are presented below.

Trenasse, Spring, Presidio and Cocodrie are recommended parents for their combined high grain yield and head rice rate, the traits that contribute significantly and positively towards gross income. Their path coefficients, the magnitude of their direct effects, on gross income are 0.87 and 0.35, respectively (Samonte, 2008). Moreover, milled rice rate is correlated with head rice rate ($r = 0.60$) and has a direct effect of 0.14 on gross income (Samonte et al, 2008).

Trenasse and Presidio are recommended donors for short plant height or semi-dwarfness, whereas Banks would be a donor for high plant height. Plant height is an important trait since tall plants would have a competitive advantage over weeds during the vegetative stage. However, tall plants tend to lodge, whereas semi-dwarf cultivars can be planted in higher densities. In Texas, rice breeders have selectively bred for semi-dwarfness as the plant height of state cultivars released have decreased from around 140 cm in the 1940s to around 95 cm in 1992 (Tabien et al, 2008). Most current US released cultivars are semi-dwarf in height, mainly due to the incorporation of $sd$-1 semi-dwarfing.

Fig. 2. Genotype × trait biplot showing cultivars that produced the highest values for each of 20 traits when grown in Beaumont, Texas, USA in 2006.

T1, Plant height at 34 d after emergence (DAE); T2, Tiller density at 40 DAE; T3, Flag leaf length; T4, Flag leaf width; T5, Flag leaf area; T6, Number of days to heading; T7, Flowering duration; T8, Number of days to maturity; T9, Plant height at harvest; T10, Panicle weight; T11, Number of filled grains per panicle; T12, Number of unfilled grains per panicle; T13, Number of spikelets per panicle; T14, Filled grain weight per panicle; T15, Seed-setting rate; T16, 1000-grain weight; T17, Panicle type; T18, Grain yield; T19, Milled rice rate; T20, Head rice rate.
gene (Rutgers, 2009). Trenasse and Presidio possess the sd-1 gene, whereas Banks does not.

Wells is recommended as a donor for high flag leaf length, width and area, panicle weight, number of filled grains per panicle, and filled grain weight per panicle. However, Wells is tall at 34 DAE and at harvest because it does not possess the sd-1 gene. Thus, it needs to be crossed with a parent that possesses the sd-1 gene when used in the breeding program. Rice leaf area, which is affected by leaf length and width, contributes to grain yield, as it is the main organ of carbohydrate production through photosynthesis. High levels of panicle weight, number of filled grains per panicle, and filled grain weight per panicle have positive direct effects on grain yield (Samonte et al, 1998, 2006).

Hidalgo is recommended as a good donor for high tiller density. Tiller density has a positive direct effect on panicle density (Samonte et al, 1998), which in turn is a yield component of rice grain yield. Furthermore, high tiller density is indicative of a high maximum node production rate (Samonte et al, 2006), which is one of the primary phenotypic traits recommended (based on model-assisted selection) and bred into the high-yielding limited-water rice plant type of Texas (Wilson et al, 1998, 2000, 2001, 2002; Samonte et al, 2011).

Francis is recommended as a good donor for high number of spikelets per panicle, which has positive direct effects on number of filled grains per panicle, panicle weight and grain yield (Samonte et al, 1998, 2006). However, since Francis has a long flowering duration, which is related to low head rice rate (Tabien et al, 2009), it must be used in crosses with parents possessing short flowering duration or high head rice rate.

Spring and Trenasse are good donors for short flowering duration. Spring is also a recommended donor for early heading and maturity, the traits that are needed to produce both the main and ratoon crop in a growing season. Furthermore, early heading is correlated with shorter flowering duration, which in turn is correlated with higher milled rice rate and head rice rate (Tabien et al, 2009). However, for the high-yielding limited-water rice, Cheniere would be a recommended donor for more days to heading and maturity.

Several cultivars showed high 1000-grain weight, but Spring and Hidalgo were recommended for this trait because they possess other desirable traits discussed above. In contrast, Cheniere is recommended where low grain weight is needed.

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**REFERENCES**


