RICE CULTURE

Effects of Gibberellic Acid on Rice Germination and Seedling Emergence in Stress Conditions

W.G. Yan, R.H. Dilday, R.S. Helms and F.M. Bourland

ABSTRACT

Poor emergence resulting in inadequate stand establishment is a major problem associated with direct-seeded rice production, especially for semidwarf cultivars. In order to gain information on the problem, plant type related to gibberellic acid (GA3) and seeding depth was studied. A total of 21 cultivars including 9 semidwarfs and 12 talls had seed treated with GA3 at 25 parts per million (ppm) and evaluated for germination at 50, 55, 60, 65, 72, and 77°F in 1991; and for seedling emergence at planting depths of 0.75 and 2.0 in. over two years. GA3 effectively improved germination and stand establishment and resulted in faster seed germination and seedling emergence. The improvement was greater in stress situations, i.e., semidwarf vs. tall plant type, cold vs. optimal temperature, and deep vs. reasonably shallow planting. The conventional tall cultivars germinated faster and also emerged faster than the semidwarf cultivars, but the semidwarfs gained greater benefits from GA3, especially for germination at cold temperatures and emergence at deep seeding. The emergence speed and stand establishment were greater at the shallow planting than at the deep depth, but the cultivars responded more to GA3 at the deep planting. As a result, GA3 can work as a buffer to maintain good germination along with a healthy stand establishment for direct-seeded rice. The buffer effect would be more important for semidwarf than tall rice, especially when planting early and/or deeply. In other words, treating seed with GA3 would provide a security for the production of direct-seeded semidwarf rice.

1 This is a completed study.
INTRODUCTION

Poor emergence and inadequate stand establishment frequently associated with drill-seeded semidwarf rice are largely attributed to short mesocotyl and coleoptile length (Dilday et al., 1990). The semidwarf 1 (sd1) gene responsible for the semidwarf growth habit in rice has been isolated and shown to interfere with the signal transduction pathway, which impairs the biosynthesis of the gibberellin (GA) growth hormone (Hedden, 2003). Treating seed with gibberellic acid (GA₃) effectively increases the length of mesocotyl and coleoptile in rice, with semidwarf rice cultivars having more increase of length than traditional tall cultivars (Yan et al., 1993). If this hormone promotes growth activities such as germination and the growth rate of the mesocotyl and coleoptile in the seedling stage, then emergence and stand establishment will be enhanced.

Seed or seedling vigor is defined as the properties of the seed that determine the capability and performance during germination and seedling emergence (Perry, 1980). The effects of seed vigor on germination, emergence, and stand establishment are well documented (Dunand, 1992). Effects have been reported on total, rate, and uniformity of germination and emergence. All of these factors can influence dry-matter accumulation by the plant and thus potentially affect yield. Total emergence determines plant density, and there is a strong relationship between plant density and yield. Planting depth influences mesocotyl and coleoptile length and their relative contributions to emergence.

In the present study, 21 prominent rice cultivars from the southern US were seed-treated at 25 ppm with GA₃ in order to accomplish the objectives of: 1) evaluating the effect of GA₃ on seed vigor expressed as seed germination, seedling emergence, and stand establishment; 2) investigating the influence of plant type on seed vigor; 3) determining the variation created by planting depth of seeds on seedling vigor; and 4) describing the interactions of GA₃, plant type, and planting depth.

PROCEDURES

Influence of GA₃ on Germination at Various Temperatures

Twenty-one cultivars, all of which had germination between 90 and 95%, were determined immediately prior to seeding (Table 1). Based on previous studies, two rates of GA₃, 0 and 25 ppm were used in this study (Dunand, 1992; Yan et al., 1993). The seeds were treated with an aqueous solution of GA₃ and then air dried by Abbott Laboratories, Chemical and Agricultural Products Division in North Chicago, Ill., for both germination and seedling emergence tests.

Of the 21 cultivars involved in the experiment, eight were developed in Arkansas, ten in Texas, two in Louisiana, and one in California (Table 1). Nine of the 21 cultivars were semidwarfs, which possess the sd1 gene (Rutger, 1992), and were defined as plants ranging from 30 to 35 in. in height (Dilday et al., 1990). The semidwarf cultivars
had a 1000-seed weight of 1.5 g greater than the tall cultivars. Semidwarf L-202 had the largest seed.

Germination tests were conducted in temperature- and humidity-controlled growth chambers in 1991. Three sets of 30 seeds from each of the 21 cultivars were placed on two pieces of Whatman No. 1 filter paper inside individual petri dishes (100 X 15 mm). The seeds were germinated in the dark at constant temperatures of 50, 550, 60, 65, 72, and 77°F. Germination counts were made daily from the day when germination started. Germination percentages for each dish during the interval of germination were used to develop a germination index. This index, adapted from McKenzie et al. (1980), combines germination percentage and days needed for germination together by the formula:

$$\text{Germination Index} = \frac{t-1}{\sum_{n=0}^{t} X_n(t-n)/t}$$

where $X_n = \text{germination percentage on the nth count}$

$n = \text{the nth day of counting germinations minus 1}$

$t = \text{total days of counting germinations}$

For example, at 55°F germination, percentages were recorded on day 7, 8, 9, 10, 11, 12, and 14 after seeding. Therefore, $n$ was 0, 1, 2, 3, 4, 5, and 7, and $t$ was 8. As a result, the percentages were multiplied by 8, 7, 6, 5, 4, 3, and 1 (8-0, 8-1, ......), respectively. The sum of the resulting products was divided by 8 for each dish to give the germination index (GI). Obviously, this index provides a weighted scale that favors both early germination and more germination.

**Influence of GA$_3$ on Seedling Emergence at Different Depths of Planting**

Field evaluations were conducted at Stuttgart, Ark., over 2 years, 1990 (Year 1) and 1991 (Year 2). Three replications in Year 1 and six in Year 2 were a split-block design in which planting depth was the main plot treatment, and cultivars and GA$_3$ were sub-plot treatments.

Sixteen cultivars were planted on 24 May of Year 1. Six were semidwarf: Gulfmont, L-202, Mercury, Texmont, Rexmont, and Lemont. Ten were tall: Katy, Alan, Millie, Labelle, Bond, Newbonnet, Lebonnet, Tebonnet, Mars, and Skybonnet. Initial emergence appeared on the 7th day after seeding, and the number of seedlings was then recorded daily until the 15th day, excluding the 10th day because of rain. In Year 2, the experiment included all the 21 cultivars. The test was seeded on 23 April, emergence began on the 6th day, and seedling emergence was recorded daily through the 17th day, excluding the 10th and 16th days due to rain. A final stand count was recorded on the 24th day after seeding.

The land was prepared for uniform planting depth and rolled, so that the soil was uniformly compact and essentially level. Three grams of seeds (ca. 150 grains) were planted in each row of three-row plots using a Hege 500 cone planter. Rows were 4.5 ft
long with an 8-in. spacing. Emergence counts were taken on the center 1-ft long area in the middle row of each plot.

Emergence data were used to develop an emergence index for each plot as described for the germination index.

RESULTS

Seed Germination Associated with GA3 and Plant Type at Various Temperatures

At 50°F, germination did not occur until the 13th day after experiment initiation, and germination reached its maximum of 76% on the 23rd day. The number of days required for initial germination decreased as temperatures increased until stabilizing at 3 days at 72°F. Total germination percentage increased until stabilizing at over 90% at 60°F.

Cultivars

Averaged over all temperatures, the tall cultivars Millie, Mars, Alan, and Katy had the fastest germination and Labelle, Bond, Lebonnet, and Rico had the slowest germination. Semidwarf cultivars with the fastest germination were Rosemont, Delmont, and Mercury while those with the slowest germination were Gulfmont, Lemont, and Texmont. There was no relationship between germination speed and seed size.

GA3

Treating the seed with GA3 increased germination speed as indicated by the GI (Fig. 1). The increase was greater at lower temperatures. The treated seed germinated 77% faster than the check at 50°F and 60% faster at 55°F. However, as the temperature increased the effect of GA3 on germination speed decreased and completely disappeared at 77°F. As to final germination percentage, 17% more germination due to GA3 was achieved at 50°F, and then after, the treated seeds were about the same with the checks.

Plant Type

The final germination percentages between tall and semidwarf cultivars over all the temperatures were not significantly different. But the germination index or speed of germination was significantly and consistently different over all the temperatures (Fig. 1). Averaged over all temperatures, tall cultivars germinated 8% faster than semidwarfs, ranging from 5% at 60°F to 12% at 55°F.

GA3 and Plant Type

GA3 seed treatment speeded germination of semidwarf cultivars more than tall cultivars as seen in the GI (Fig. 1). Before the seed were treated with GA3, tall cultivars germinated 13% faster than semidwarf cultivars, averaged over all temperatures, ranging from 6% at 77°F to 26% at 55°F. However, after treating the seed with GA3, tall cultivars germinated only 4% faster than semidwarf cultivars, averaged over all temperatures ranging from 0% at 60°F to 8% at 77°F. More responsiveness to GA3 in
Semidwarf cultivars compared to tall cultivars was also verified in another way. For semidwarf cultivars, germination speed was increased 90% at 50°F by treating with GA3, and 80% when temperature was raised to 55°F. The increased germination speed was reduced to 30% at 60°F, and further to 20% at 72°F and 77°F, and finally became 0 at 77°F. However, for tall cultivars, germination speed was increased 70% at 50°F by GA3, and 50% when temperature was raised to 55°F. The increased germination speed was reduced to 20% at 60°F and further to 10% at 65°F and 72°F and eventually became 0 at 77°F.

**Seedling Emergence and Stand Establishment Associated with GA3, Plant Type, and Depth of Planting**

In the test of Year 1, both stand establishment (final number of seedlings) and emergence speed (emergence index) were significantly affected by plant type (semidwarfs vs. talls); cultivars within each type; GA3 (treated vs. untreated); and the interaction of GA3 with plant type (Table 2). Further, planting depth (0.75 versus 2 in.) significantly influenced emergence speed. In Year 2, three more interactions, planting depth with plant type, planting depth with cultivars in each plant type, and GA3 with planting depth, affected emergence speed significantly relative to Year 1. Also, stand establishment was affected by planting depth.

**Cultivars**

In Year 1, three tall cultivars: Katy, Alan, and Millie emerged the fastest. The semidwarf cultivars, in general, emerged slower and had poorer stand establishment. However, the semidwarf cultivars had emergence speed statistically equivalent to three conventional cultivars: Tebonnet, Mars, and Skybonnet. In Year 2, Katy again had the fastest speed of emergence among all cultivars tested; however, its emergence speed was not significantly different from another tall cultivar, Newbonnet. The semidwarf cultivars, except for Mercury, had the slowest emergence; however, they were not significantly different from four tall cultivars, Bond, Rico, Orion, and Lebonnet.

**GA3**

Seed treatment with GA3 significantly increased seedling number of emergence from the initial to final stand counts and emergence speed when compared to the control in both years (Fig. 2). The treated seed emerged 90% faster in Year 1 and 33% faster in Year 2 than the untreated check. Stand establishment of the treated seed was 38% higher than the untreated check in Year 1, and there was no difference in Year 2.

Before treating with GA3, tall cultivars had a stand establishment 56% greater and emerged 1.31 times faster than semidwarf cultivars in Year 1 and, similarly, had a 50% greater stand establishment and emerged 93% faster in Year 2. However, after treating with GA3, the difference of stand establishment and emergence speed was greatly reduced between tall and semidwarf cultivars. Tall cultivars had a 20% greater stand establishment and emerged 16% faster than semidwarf cultivars in Year 1, and had a 39% greater stand establishment and emerged 42% faster in Year 2.
When planting depth changed from 0.75 in. to 2 in., some of the reduction of stand establishment and emergence speed was recovered by treating seed with GA3, especially in Year 1. The untreated seed, when planted shallow, established a stand 14% greater and emerged 32% faster than at deep planting. However, for the treated seed, stand establishment and emergence speed of the deep planting were almost the same as the shallow planting. In Year 2, GA3 was more effective on stand establishment than on emergence speed, especially at deep planting.

Plant Type

Semidwarf cultivars had poorer stand establishment and slower emergence than tall cultivars (Fig. 3). In Year 1, semidwarf cultivars had a stand establishment 33% less and emerged 45% slower than tall cultivars. In Year 2, the stand establishment of semidwarf cultivars was 45% less with an emergence of 60% slower when compared to tall cultivars.

However, semidwarf cultivars had greater response to GA3 than tall cultivars, especially in Year 1. The treated semidwarf cultivars had a stand establishment 62% more and emerged 2.04 times faster than the untreated semidwarfs. In Year 2, the GA3 treated semidwarfs established 5% greater stand and emerged 67% faster than the untreated semidwarfs. On the other hand, 24% greater stand establishment and 53% faster emergence resulted from the seed treatment with GA3 for tall cultivars in Year 1. In Year 2, GA3 had no effect on stand establishment, but caused the treated talls to emerge 23% faster.

In Year 1, both semidwarf and tall cultivars did not suffer as much as they did in Year 2 from deep planting (Fig. 3). When semidwarfs were planted at a 2-in. depth in Year 1, the stand was 14% less and the emergence was 15% slower when compared to the shallow planting of 0.75 in. The deep planting (2 in.) did not cause significant differences in stand establishment for tall cultivars in Year 1, but did bring about 17% faster emergence. In Year 2, semidwarfs had 95% less stand establishment and emerged 2.56 times slower when planting was changed from 0.75 in. to 2 in. For tall cultivars, stand establishment was 55% less and emergence was 1.52 times slower when planting was changed from shallow to deep.

Planting Depth

The effect of planting depth on seedling emergence and emergence speed varied from year to year, and a dramatic effect was observed in Year 2 (Fig. 4). Shallow planting at 0.75 in. resulted in a 7% greater stand and emerged 16% faster than deep planting at 2 in. in Year 1. In Year 2, shallow planting had 68% greater stand establishment and emerged 1.82 times faster than deep planting.

GA3 had a great impact on seedling emergence, and the impact was much more pronounced in deep planting (Fig. 4). In Year 1, the GA3-treated seed that was planted shallow had a stand 31% greater and emerged 67% faster than the untreated seed. At the deep planting, GA3 resulted in a 40% greater stand and 1.05 times faster emergence as compared to the untreated seed. In Year 2, at shallow planting, GA3 did not cause a significant difference from the check on stand establishment but did cause 34% faster emergence. Similarly at deep planting, there was no significant difference in stand
establishment between the treated and untreated seed, but the treatment resulted in 32% faster emergence.

Deep planting impacted the seedling emergence of semidwarf cultivars more than that of tall cultivars. In Year 1, semidwarf cultivars had a 25% reduction in stand establishment and emerged 46% slower than tall cultivars at the shallow planting. At the deep planting, the stand establishment of the semidwarfs was further reduced to 41% less, and the emergence speed was 43% slower than the talls. This reduction was even greater in Year 2. At the shallow planting, semidwarf cultivars had a stand establishment 33% less and emerged 48% slower than tall cultivars. The stand establishment of the semidwarfs was further reduced to 67% less, and the emergence speed became 1.14 times slower than the talls when planting deeply.

**DISCUSSION**

**GA₃**

Successful rice production depends upon establishing a uniform stand. Early emergence tends to aid plant establishment, which was verified by highly significant, positive correlations between emergence speed and stand establishment in this study (\( r = 0.8 \) in Year 1 and \( 0.9 \) in Year 2). Early-emerged seedlings had larger shoots than late-emerged seedlings. Likewise larger seedlings are more capable of withstanding weeds, diseases, and insects.

This study demonstrated that treating seeds with GA₃ is an effective way to increase the speed of germination and emergence as well as stand establishment for a uniform stand of rice. Fast seed germination resulted in fast seedling emergence, shown by a positive and significant correlation between germination index and emergence index (\( r = 0.6 \)). The enhancement effect from GA₃ is greater when the conditions are stressful physiologically such as semidwarf vs. tall cultivars, and environmentally such as low vs. high temperatures and deep vs. shallow planting. As a result, treating seed with GA₃ can work as a buffer for maintaining seed or seedling vigor. This buffer would enhance seed germination and its seedling’s ability to survive and make the seed more competitive physiologically and environmentally for establishing a uniform stand of rice.

**Semidwarfism**

This study demonstrated that semidwarf rice germinates slower and confirmed that drill-seeded semidwarf rice emerges slower with poorer stand establishment than taller plant types (Dilday et al., 1990). The positive correlations between plant height and stand establishment (\( r = 0.3 \)) as well as emergence speed (\( r = 0.3 \)) were highly significant at the 0.01 level.

Also, this study showed that semidwarf rice is more responsive to GA₃ than taller cultivars in promoting seed germination and seedling emergence, especially when semidwarf rice is stressed, i.e. low vs. high temperatures and deep vs. shallow planting.
Consequently, GA$_3$ is considered to be more important in semidwarf cultivars for improving seed vigor than it is in taller cultivars.

**Planting Depth**

This study demonstrated that shallow planting at 0.75 in. is superior to deep planting at 2 in. for fast emergence and healthy stand establishment. This result was further verified by the negative and highly significant correlations of planting depth with established stands ($r = -0.5$), and with emergence speed ($r = -0.6$). However, when early planting is necessary, treating the seed with GA$_3$ becomes crucial for a healthy and sufficient stand establishment, which is critical for semidwarf cultivars.

**SIGNIFICANCE OF FINDINGS**

Buffer effect of GA$_3$ revealed in this study provides a security for rice production by maintaining good germination in early planting, and good stand establishment in deep planting. This effect is especially important for semidwarf cultivars.

**ACKNOWLEDGMENTS**

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**LITERATURE CITED**


Table 1. Seed size, plant type, grain type, and origin of rice cultivars used in the tests of seed germination and seedling emergence in 1990 and 1991.

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>1000 Seed (g)</th>
<th>Grain type/</th>
<th>Origin</th>
</tr>
</thead>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tall cultivars</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alan</td>
<td>21.3</td>
<td>Long</td>
<td>Arkansas</td>
</tr>
<tr>
<td>Bond</td>
<td>23.9</td>
<td>Long</td>
<td>Arkansas</td>
</tr>
<tr>
<td>Katy</td>
<td>21.5</td>
<td>Long</td>
<td>Arkansas</td>
</tr>
<tr>
<td>Labelle</td>
<td>20.5</td>
<td>Long</td>
<td>Texas</td>
</tr>
<tr>
<td>Lebonnet</td>
<td>23.5</td>
<td>Long</td>
<td>Texas</td>
</tr>
<tr>
<td>Mars</td>
<td>23.0</td>
<td>Medium</td>
<td>Arkansas</td>
</tr>
<tr>
<td>Millie</td>
<td>26.5</td>
<td>Long</td>
<td>Arkansas</td>
</tr>
<tr>
<td>Newbonnet</td>
<td>21.8</td>
<td>Long</td>
<td>Arkansas</td>
</tr>
<tr>
<td>Orion</td>
<td>23.0</td>
<td>Medium</td>
<td>Arkansas</td>
</tr>
<tr>
<td>Rico</td>
<td>23.2</td>
<td>Medium</td>
<td>Texas</td>
</tr>
<tr>
<td>Skybonnet</td>
<td>23.5</td>
<td>Long</td>
<td>Texas</td>
</tr>
<tr>
<td>Tebonnet</td>
<td>23.5</td>
<td>Long</td>
<td>Arkansas</td>
</tr>
<tr>
<td>Mean</td>
<td>22.9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Semidwarf cultivars

Delmont 23.3 Long Texas
Gulfmont 21.3 Long Texas
L-202 28.7 Long California
Lacassine 24.6 Long Texas
Lemont 24.6 Long Texas
Mercury 23.4 Medium Louisiana
Rexmont 22.0 Long Texas
Rosemont 24.9 Long Texas
Texmont 26.9 Long Texas
Mean 24.4

Table 2. Variance analysis of seedling emergence index for cultivars (Cult) of two plant types (Type: tall vs. semidwarf) treated with gibberellic acid (GA₃: treated vs. untreated) and planted at the depths of 0.75 and 2 in. over two years.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Year 1 df</th>
<th>F</th>
<th>Year 2 df</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>1</td>
<td>86.9***</td>
<td>1</td>
<td>123.2***</td>
</tr>
<tr>
<td>Cult (type)</td>
<td>14</td>
<td>9.1***</td>
<td>19</td>
<td>12.4***</td>
</tr>
<tr>
<td>GA₃</td>
<td>1</td>
<td>265.0***</td>
<td>1</td>
<td>48.4***</td>
</tr>
<tr>
<td>GA₃ type</td>
<td>1</td>
<td>16.9***</td>
<td>1</td>
<td>2.2</td>
</tr>
<tr>
<td>Depth</td>
<td>1</td>
<td>15.9***</td>
<td>1</td>
<td>543.9***</td>
</tr>
<tr>
<td>Depth * type</td>
<td>1</td>
<td>0.6</td>
<td>1</td>
<td>4.8*</td>
</tr>
<tr>
<td>Depth * cult (type)</td>
<td>14</td>
<td>0.4</td>
<td>19</td>
<td>2.1**</td>
</tr>
<tr>
<td>GA₃ * depth</td>
<td>1</td>
<td>1.9</td>
<td>1</td>
<td>11.6***</td>
</tr>
<tr>
<td>GA₃ * depth * type</td>
<td>1</td>
<td>0.1</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>GA₃ * depth * cult (type)</td>
<td>28</td>
<td>0.7</td>
<td>38</td>
<td>1.1</td>
</tr>
</tbody>
</table>

* ** *** Significant at P<0.05, 0.01, and 0.001, respectively.
Fig. 1. Effect of plant types of rice cultivars and GA$_3$ on germination index at various temperatures.
Fig. 2. Effect of GA$_3$ on seedling emergence index related to plant type (Tall and Semidwarf, Semi) and planting depth (Shallow, 0.75 in.; and Deep, 2 in.) over two years.
Fig. 3. Effect of plant type (Tall and Semidwarf) on seedling-emergence index related to GA3 (Treated, GA; and Untreated, No GA) and planting depth (Shallow, 0.75 in.; and Deep, 2 in.) over two years.
Fig. 4. Effect of planting depth (Shallow, 0.75 in.; and Deep, 2 in.) on seedling emergence index related to GA3 (Treated, GA; and Untreated, No GA) and plant type (Tall and Semidwarf, Semi) over two years.

LSD$_{0.05}^1$=7: Tall vs. Semi.;
LSD$_{0.05}^2$=7: GA vs. No GA;
LSD$_{0.05}^3$=5: Shallow vs. Deep;

LSD$_{0.05}^1$=6: Tall vs. Semi.;
LSD$_{0.05}^2$=6: GA vs. No GA;
LSD$_{0.05}^3$=4: Shallow vs. Deep;