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Bioassay of Winter Wheat for Gibberellic Acid Sensitivity

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ABSTRACT

Increasing winter wheat seedling growth would make it a better winter cover crop. Gibberellic acid (GA3) seed treatment may accomplish this by stimulating stem growth. A bioassay, mimicking field conditions, could determine the relative sensitivity of conventional and semi-dwarf cultivars. In growth chambers set for cool (10°C/4°C) and warm (21°C/4°C) conditions, wheat seeds were treated with 0 and 125 to 16,000 ppm GA3. The cultivars Goodstreak (tall or conventional) and Wesley (semi-dwarf) were compared as standards. Emergence and plant height were measured. “Goodstreak” showed a significant growth promotion at 500 ppm GA3 when seeds were dipped and 2000 ppm when GA3 was applied in-furrow under both temperature regimes. “Wesley” in general required the same or a higher dose of GA3. Separately, the seeds of nine other cultivars were treated with GA3 as the standards. Based on maximum height promotion, the most sensitive cultivars under cool conditions were Goodstreak, Harry, Millenium, and Wahoo; under warm conditions, the most sensitive cultivars were Alliance, Goodstreak, Jagalene, and Millenium. In general, the least GA3 sensitive cultivars were Arrowsmith, Scout66, and Wesley. “Buckskin” and “InfinityCL” were intermediate. The rye cultivar Rymin also was tested and showed less sensitivity to GA3 than “Goodstreak”. When 6 benzyladenine (6BA) with GA3 was applied to “Goodstreak” and “Wesley” seed, emergence, plant height and weight, and tiller formation were reduced. Wheat cultivars will respond to GA3 and differ in the amount of GA3 needed. The results of this growth chamber study will guide subsequent field trials.

Keywords: Plant Growth Regulator; Gibberellin; Planting Aid; Cover Crop

1. Introduction

Introducing winter wheat into irrigated cropping systems is limited by an overlap between optimal planting date of winter crops such as wheat and rye with optimal harvest date for summer crops such as dry bean and potato in the High Plains [1]. Stimulating seedling growth of wheat under cooler conditions could allow later planting in the fall and possibly reduce wind erosion. Another aspect is that when soils are dry before planting winter wheat, it is recommended to plant seeds deeper, about 7.5 cm, in the anticipation that the seedling roots will reach water. However, in this case, emergence takes longer and is less due to the greater distance for the coleoptile to reach the surface. In both cases, a stimulation of stem growth would improve wheat health.

A possible method of promoting stem growth of late-planted and deep-planted winter wheat is to apply a growth promoter to seeds. This could enhance emergence and stem elongation. Recently [2], the promotion of seedling growth was accomplished with treating seeds with growth-promoting bacteria in a greenhouse. However, this may be accomplished directly by applying the natural product gibberellic acid (GA3) to wheat seeds. The promotion of stem growth by gibberelins has been known since the 1930s when a rice disease was identified to be due to a pathogenic fungus Gibberella fujikuroi [3]. More than 130 gibberellins have been identified. GA3 is the key gibberellin, is highly active and is well known to stimulate stem elongation [4,5]. Greenhouse bioassays for stem elongation resulting from foliar-applied GA3 on legumes (Phaseolus vulgaris) have been reported [6,7]. Winter wheat stimulation by GA3 presents the problem that popular cultivars for irrigated wheat production are semi-dwarf, that is, they contain genes that may lower production of gibberelins or desensitize plants to endogenous GA3 and other gibberellins [8,9].

The genetics of plant height in wheat is known to be complex and is determined by more than 20 Rht (“re-
duced height”) genes with different types of genetic mechanism, which are located across 17 of 21 chromosomes in wheat [10-13]. Depending on their reaction to exogenous GA₃, the Rht genes are classified into two groups: GA₃-sensitive (synthesis mutants) and GA₃-insensitive [11]. Dwarfism in wheat lines carrying GA₃-sensitive genes is due to either the absence of or a modified spectrum of endogenous gibberellins. These genes are involved in GA₃ biosynthesis and normal growth can be restored by exogenous GA₃. The most important dwarfing gene of this category used agronomically in wheat is Rht8c (formerly known as Rht8), which was first introduced into European wheat in the 1930s and now is widely used in many wheat cultivars adapted to warm climates [14,15]. The GA₃-insensitive dwarfism in wheat lines is either due to reduced or lack of response to exogenous GA₃. Major GA₃-insensitive Rht genes are at two loci on the chromosome 4BS and 4DS; each locus has multiple alleles that induce varying degrees of dwarfism. Four major GA₃-insensitive genes are Rht-B1b (formerly Rht1), Rht-D1b (formerly Rht2), Rht-B1c (formerly Rht3), and Rht-D1c (formerly Rht10) of which RhtB1b and RhtD1b are the two most widely GA₃-insensitive dwarfing genes in modern wheat cultivars [16, 17]. Wheat cultivars carrying these semi-dwarf genes do not respond (increase in plant height) to endogenous GA₃.

The objective of this study was to determine whether winter wheat cultivars, both regular and semi-dwarf types, would respond to seed-applied GA₃ with increased stem elongation. This information would then be used in field trials to stimulate growth of late-season planted winter wheat.

2. Materials and Methods

2.1. Growth Chamber Conditions

Experiments were conducted in two growth chambers (Conviron model CMP 3023). One chamber was set for cool conditions, 10°C day and 4.4°C night, and the other for warm conditions, 21.1°C day and 4.4°C night (Figure 1). Plants were exposed to six hours (11 am to 5 pm) each day to either 10°C or 21.1°C, and six hours (11 pm to 5 am) at 4.4°C. The remaining hours were gradual transitions periods between day and night temperatures. Daylight was supplied by a bank of florescent light bulbs set at level 4 for a 12-hour photoperiod corresponding to day and night temperatures. Lamps were approximately 1.5 m above plants.

2.2. Plant Material and Trial Conditions

The winter wheat cultivars Goodstreak and Wesley were standards in all tests and in 2006, the cultivars Alliance, Arrowsmith, Buckskin, Harry, InfinityCL, Jagalene, Mil-
Table 1. Description of winter wheat cultivars.

| Cultivar       | Complimentary Grouping | Height Description | Coleoptile Length | Rht genes | References |
|---------------|------------------------|-------------------|-------------------|-----------|------------|
| Alliance      | Chisholm               | Moderately short  | Short             | Rht1Bb (Rht1) | [18] |
| Arrowsmith    |                        | Moderately tall   | Moderately long   | Rht1Bb (Rht1) | [19] |
| Buckskin      | Scout                  | Tall              | Long              |           | [20] |
| Goodstreak    | Colt                   | Tall              | Long              |           | [21] |
| Harry         | Brule                  | Moderately short  | Short             | Rht1Bb (Rht1) | [22] |
| InfinityCL    |                        | Moderately tall   | -                 | Rht1Bb (Rht1) | [23] |
| Jagalene      | Abilene                | Moderately short  | Moderately short  | Rht1Bb (Rht1) | Syngenta |
| Millenium     |                        | Moderately tall   | Moderately short  | Rht1Bb (Rht1) | [24] |
| Scout66       | Scout                  | Tall              | Long              |           | [25] |
| Wahoo         | Arapahoe               | Medium            | Medium            | Rht1Bb (Rht1) | [26] |
| Wesley        | Sumner                 | Short             | Short             | Rht1Bb (Rht1) & Rht8c (Rht8) | [27] |

1 Cultivars within each complimentary group share at least 50% of the same parent lines. 2 Source was [28] Guedira et al., 2010.

2.4. Data and Statistical Analysis

In 2005, emergence and plant heights were measured at 18 and 31 days after planting (DAP), and fresh weight was measured at 66 DAP. In 2006, only plant height was measured at 30 DAP under warm conditions and 40 DAP under cool conditions. In 2007, plant height was measured at 5 DAP under warm conditions. In 2009, measurements of emergence at 14 DAP, plant height at 17 and 28 DAP, and tiller number at 28 DAP were conducted under warm conditions. Data from each experiment were analyzed using SAS Proc ANOVA (version 9.1, SAS Institute, Cary, NC) and means were separated using least significant difference (SAS Institute) for each cultivar.

3. Results

3.1. Bioassay Development

In developing a bioassay for winter wheat sensitivity to GA3, cvs. Goodstreak with a regular growth habit and Wesley, a semi-dwarf, were treated and planted. These were placed in one of two growth chambers set to “warm” and “cool” conditions. Treatment was applied as a seed dip or as a furrow drip. Under warm conditions in 2005, the emergence of both Goodstreak and Wesley was unaffected by GA3 applied up to 2000 ppm applied as a seed dip, but above that, there was a significant decrease of emergence (Table 2). Under cool conditions, the emergence was not inhibited until the seed was treated with 8000 ppm. Furrow application of GA3 had no effect on emergence even at 16,000 ppm. Plant height at 18 DAP showed a significant increase when Goodstreak seed was treated with 500 ppm regardless of the chamber temperature regime (Table 2). With furrow treatment, height of Goodstreak was promoted as well but 2000 ppm was required to achieve a significant increase over the check. Wesley was less sensitive to GA3 than Goodstreak. For Wesley, plant height was increased by treating seed with 2000 ppm and placed in the warm chamber and 500 ppm when placed in the cool chamber (Table 2). Furrow application of GA3 required 4000 ppm in the warm chamber and 2000 ppm in the cool chamber to elicit a significant height increase.

3.2. Cultivar Evaluation

The seed of nine additional wheat cultivars were treated with GA3, planted and placed into the two growth chambers each with a different temperature regime. Under warm conditions, three cultivars, Infinity CL, Scout 66 and Wahoo, did not show a significant height increase with GA3 applied at 250 ppm while the other eight of the 11 cultivars did (Table 3). Under cool conditions, three cultivars, Alliance, Buckskin and Jagalene, showed a decreased sensitivity to GA3 and three cultivars, Infinity CL, Scout 66 and Wahoo, showed an increased sensitivity compared to their performance under warm conditions (Table 3). The other five cultivars responded to the same exposure to GA3 under both temperature regimes. Note Goodstreak, a tall cultivar, reached a maximum response with 250 ppm GA3 while Wesley, a semi-dwarf cultivar, reached a maximum response at 1000 ppm (Table 3). Application of 4000 ppm GA3 increased plant height for all cultivars under both temperature regimes. When seeds were exposed to 16,000 ppm GA3, there was no emergence under cool conditions and 0% to 16% emergence under warm conditions (data not shown).

3.3. Rye Comparison

A short-term bioassay using seed dips and seeding under warm conditions was verified in 2007 and the rye cv.
Table 2. Growth of winter wheat cvs. Goodstreak and Wesley grown in growth chambers set for 21.1°C/4.4°C (warm chamber) or 10°C/4.4°C (cool chamber) day/night temperature cycle after seed or furrow application of gibberellic acid (GA₃), 2005.

| GA₃ ppm | “Goodstreak” | | | | “Wesley” | |
|---------|--------------|---|---|---|---|---|
|         | Warm Chamber | Cool Chamber | Warm Chamber | Cool Chamber | Warm Chamber | Cool Chamber |
|         | Seed¹        | Furrow¹      | Seed          | Furrow       | Seed          | Furrow       |
| 0       | 100 A¹       | 100          | 94 A          | 100          | 100 A         | 94           |
| 125     | 94 A         | 94           | 100 A         | 100          | 89 A          | 72           |
| 250     | 94 A         | 100          | 100 A         | 94           | 94 A          | 94           |
| 500     | 100 A        | 100          | 100 A         | 100          | 89 A          | 100          |
| 1000    | 89 A         | 100          | 100 A         | 89           | 94 A          | 89           |
| 2000    | 89 A         | 100          | 100 A         | 100          | 100 A         | 94           |
| 4000    | 67 B         | 94           | 100 A         | 94           | 67 B          | 100          |
| 8000    | 7 C          | 94           | 34 B          | 100          | 12 C          | 94           |
| 16000   | 2 C          | 94           | 2 C           | 100          | 2 C           | 83           |

Emergence at 18 DAP², %

| GA₃ ppm | Warm Chamber | Cool Chamber |
|---------|--------------|--------------|
|         | 129 B        | 123 D        |
| 0       | 54 B         | 56 C         |
| 125     | 71 B         | 53 C         |
| 250     | 78 B         | 52 C         |
| 500     | 86 A         | 52 C         |
| 1000    | 90 A         | 60 BC        |
| 2000    | 140 C        | 89 A         |
| 4000    | 169 B        | 77 A         |
| 8000    | 63 C         | 52 B         |
| 16000   | -            | 197 A        |

Plant height³ at 18 DAP, mm³

| GA₃ ppm | Alliance | Arrowsmith | Buckskin | Goodstreak | Harry | InfinityCL | Jagalene | Millenium | Scout66 | Wahoo | Wesley |
|---------|----------|------------|----------|------------|-------|------------|----------|-----------|---------|-------|--------|
| 0       | 258 B    | 258 C      | 268 C    | 297 B      | 241 C | 236 C      | 214 B    | 221 B     | 308 B   | 251 B | 227 C  |
| 250     | 321 A    | 302 B      | 321 B    | 375 A      | 277 B | 253 BC     | 256 A    | 259 A     | 324 B   | 272 AB| 274 B  |
| 1000    | 319 A    | 318 AB     | 417 A    | 410 A      | 300 AB| 272 AB     | 250 A    | 255 A     | 350 B   | 272 AB| 303 A  |
| 4000    | 317 A    | 330 A      | 461 A    | 428 A      | 328 A | 305 A      | 267 A    | 277 A     | 440 A   | 282 A | 306 A  |
|          |          |            |          |            |       |            |          |           |         |       |        |

| GA₃ ppm | Warm Chamber at 30 DAP² | Cool Chamber at 40 DAP³ |
|---------|-------------------------|-------------------------|
| 0       | 258 B²                  | 258 C                  |
| 250     | 321 A                  | 302 B                  |
| 1000    | 319 A                  | 318 AB                 |
| 4000    | 317 A                  | 330 A                  |

Plant height³, mm³

| Cultivar       | Plant height³, mm³ |
|----------------|--------------------|
| Alliance       | 258 B              |
| Arrowsmith     | 321 A              |
| Buckskin       | 319 A              |
| Goodstreak     | 317 A              |
| Harry          | 410 A              |
| InfinityCL     | 428 A              |
| Jagalene       | 173 B              |
| Millenium      | 235 A              |
| Scout66        | 175 A              |
| Wahoo          | 192 A              |
| Wesley         | 201 A              |

1Seeds were dipped in GA₃ and then planted, or seeds were first planted and GA₃ was applied with a pipette at 0.125 ml per seed. 2DAP = days after planting. 3Mean separation of GA₃ rates for each column (cultivar, thermal period, and application method) using least significant difference at P < 0.05. 4Plant height was measured from potting soil to the highest leaf tip. 51 inch = 254 mm.

Table 3. Growth of eleven winter wheat cultivars grown in growth chambers set for either at 21.1°C/4.4°C (warm chamber) or at 10°C/4.4°C (cool chamber) day/night temperature cycle after seed application¹ of gibberellic acid (GA₃), 2006.

| GA₃ ppm | Warm Chamber at 30 DAP² | Cool Chamber at 40 DAP³ |
|---------|-------------------------|-------------------------|
| 0       | 258 B²                  | 258 C                  |
| 250     | 321 A                  | 302 B                  |
| 1000    | 319 A                  | 318 AB                 |
| 4000    | 317 A                  | 330 A                  |

1Seeds were dipped in GA₃ and then planted in flats. ²DAP = days after planting. ³Plant height was measured from potting soil to the highest leaf tip. ¹1 inch = 254 mm. ²Mean separation of GA₃ rates for each cultivar (row) using least significant differences at P < 0.05.
Rymin was tested. Goodstreak showed a significant height increase at 5 and 13 DAP when treated with 500 ppm GA$_3$ while Wesley did not show a response this early even with 1000 ppm (Table 4). This agreed with the test in 2005 when height was measured at 18 DAP, but in 2007, a response was observed for both wheat cultivars at 250 ppm when measurements were taken 30 DAP (Table 3). The rye cv. Rymin did not show a height increase until seeds were exposed to 1000 ppm (Table 4).

### 3.4. Addition of 6BA

In 2009, this bioassay was used to determine whether 6BA could supplement GA$_3$ growth promotion and increase tillering of wheat seedlings. Goodstreak seed was treated with 500 ppm GA$_3$ with and without three concentrations of 6BA, 125, 500 and 2000 ppm. Wesley was likewise treated but 1000 ppm GA$_3$ was used. Goodstreak when treated with 500 ppm GA$_3$ alone showed a significant height promotion at 17 and 28 DAP (Table 5) as expected from the bioassay. But when adding 6BA at 500 ppm or 2000 ppm, height was decreased as well as tiller number and plant fresh weight (Table 5). Wesley height was not affected by 1000 ppm GA$_3$ as in previous tests but the addition of 6BA at 2000 ppm decreased plant height, plant weight and tiller number (Table 5). 6BA at 2000 ppm also suppressed emergence of both cultivars.

#### Table 4. Plant height of rye cv. Rymin in comparison to winter wheat cvs. Goodstreak and Wesley grown in a growth chamber set for 21.1˚C/4.4˚C (warm chamber) day/night temperature cycle after seed application$^1$ of gibberellic acid (GA$_3$), 2007.

| GA$_3$ ppm | 5 DAP$^2$ | 13 DAP | 5 DAP | 13 DAP | 5 DAP | 13 DAP |
|------------|-----------|---------|--------|--------|-------|--------|
| 0          | 136 B$^3$ | 173 B   | 112 B  | 203 B  | 98    | 166    |
| 125        | 153 AB    | 190 AB  | 115 B  | 210 B  | 105   | 174    |
| 250        | 154 AB    | 199 AB  | 115 B  | 204 B  | 103   | 159    |
| 500        | 158 AB    | 198 AB  | 134 A  | 232 A  | 107   | 176    |
| 1000       | 161 A     | 213 A   | 148 A  | 235 A  | 108   | 175    |

$^1$Seeds were dipped in GA$_3$ and then planted. $^2$DAP = days after planting. $^3$Plant height was measured from potting soil to the highest leaf tip. $^4$1 inch = 254 mm.

#### Table 5. Growth of winter wheat cvs. Goodstreak and Wesley grown in a growth chamber set for 21.1˚C/4.4˚C (warm chamber) day/night temperature cycle after seed application$^1$ of gibberellic acid (GA$_3$) with 6-benzyladenine (6BA), 2009.

| GA$_3$ ppm | 6BA ppm | 14 DAP$^3$ | 17 DAP | 28 DAP | 28 DAP | 28 DAP |
|------------|---------|------------|--------|--------|--------|--------|
| 0          | 0       | 97 A$^5$   | 103 B  | 139 B  | 3.0 A  | 0.13 A |
| 500        | 0       | 97 A       | 132 A  | 176 A  | 3.0 A  | 0.15 A |
| 500        | 125     | 97 A       | 125 A  | 172 A  | 3.0 A  | 0.12 AB|
| 500        | 500     | 100 A      | 120 AB | 149 B  | 2.6 B  | 0.10 B |
| 500        | 2000    | 43 B       | 66 C   | 77 C   | 2.1 C  | 0.04 C |

Wheat cv. Wesley

| GA$_3$ ppm | 6BA ppm | 17 B | 48 B | 76 C | 1.9 B | 0.09 B |
|------------|---------|------|------|------|-------|--------|
| 0          | 0       | 93 A | 89 A | 113 B| 3.4 A | 0.15 A |
| 1000       | 0       | 87 A | 98 A | 149 A| 3.1 A | 0.15 A |
| 1000       | 125     | 87 A | 98 A | 142 AB| 3.3 A | 0.15 A |
| 1000       | 500     | 90 A | 89 A | 113 B| 2.9 A | 0.09 B |
| 1000       | 2000    | 17 B | 48 B | 76 C | 1.9 B | 0.09 B |

$^1$Seeds were dipped in GA$_3$ with or without 6BA, and then planted. $^2$Plant height was measured from potting soil to the highest leaf tip. $^3$DAP = days after planting. $^4$1 inch = 254 mm; 1 oz = 28.35 g. $^5$Mean separation of GA$_3$ rates for each column for each cultivar using least significant difference at $P<0.05$. 

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4. Discussion

4.1. Wheat cv. Goodstreak and Wesley

“Goodstreak” is a hard red wheat that is well-adapted to western Nebraska [21]. It grows to a conventional height, tall, and has a long coleoptile (Table 1) adapted for low moisture conditions. “Wesley” is a hard red winter wheat, short with a short coleoptile (Table 1) and has a high yield potential in the north central Great Plains [27]. It is a semi-dwarf whose height tends to be about 15% shorter than “Goodstreak” [21]. Semi-dwarf cultivars tend to emerge erratically due to their slow growth and short coleoptiles. For comparing conventional and semi-dwarf sensitivity to GA3, these two cultivars were deemed excellent representatives. Table 2 did not show a difference in emergence between “Goodstreak” and “Wesley” either between their untreated checks or their response to GA3 applied as a seed dip or in furrow up to 2000 ppm under warm conditions and up to 4000 ppm under cool conditions. GA3 applied to the seed at 4000 ppm under warm conditions and at 8000 ppm under cool conditions significantly lowered emergence and higher rates nearly eliminated it. Furrow application of GA3 had no effect on emergence.

4.2. Wheat Bioassay Comparisons

Allan et al. [29] began developing a bioassay for GA3 sensitivity for wheat by consecutively injecting 100 ppm GA3 into vernalized seedlings transferred into a greenhouse. Dwarf and semi-dwarf cultivars were tested. The shortest cultivars were insensitive to GA3 injection. The three tallest cultivars did respond to GA3 but did not attain the height associated with conventional cultivars. Under both warm and cool conditions, GA3 seed- and furrow-treated “Wesley” attained the height of untreated “Goodstreak” (Table 2). Pinthus and Abraham [30] grew wheat plants of two cultivars with lines differing in height-reducing alleles in vermiculite drenched in 25 ppm GA3 and placed in growth chambers set at continuous 11°C or 25°C. They reported that the tall cultivar, containing no height reducing alleles, responded to GA3 but as dwarfing increased in the lines, the response greatly diminished. At the higher temperature, height increased more rapidly than at cooler temperatures. Table 2 showed that for “Goodstreak” temperature did not affect GA3 sensitivity for the stimulation of plant height. For “Wesley” however, cool (10°C) conditions increased the sensitivity to both seed- and furrow-applied GA3 stimulation of growth. Pereira et al. [31] soaked wheat seeds in GA3 for 4 d. At 2°C, maximum stimulation of coleoptile length was with 500 ppm GA3 for all isolines. At 18°C, the response to GA3 was diminished in dwarfing isolines. They concluded that GA3 insensitivity was highly influenced by higher temperatures as was observed with “Wesley” (Table 2).

Comparing the two cultivars, “Goodstreak” was more sensitive to GA3 than “Wesley” under warm (21°C) conditions. Table 2 suggested that to best highlight differences between these cultivars is to bioassay for GA3 response with seed treatment instead of furrow and possibly to grow plants under the warmer conditions. The higher exposure to GA3 for height stimulation from Wesley compared to Goodstreak is expected because Wesley carries Rht-B1b and Rht8c, two GA3-insensitive genes whereas Goodstreak is not known to carry any such genes. The response of leaf length to applied GA3 in the Rht-B1b and Rht-D1b genotypes increased significantly with lowering of temperature [32]. We also found similar effect of lower temperature in Wesley.

4.3. Cultivar Comparisons

Table 3 showed no distinct pattern between cultivars, conventional or semi-dwarf, in sensitivity to GA3 applied to seed at either temperature. Some cultivars were less sensitive to GA3 under cooler conditions while some showed no difference. Except for three cultivars, Buckskin, Goodstreak, and Scout 66, eight of 11 cultivars in this study carry the same GA3-insensitive semi-dwarf gene Rht-B1b. Wesley carries this gene plus the GA3-sensitive gene Rht8c. The lack of uniform pattern in GA3 response among these eight cultivars may be associated with additional factors. Both Rht-B1b and Rht8c act in semi-dominant fashion, where the genetic background plays an important role in the extent of GA3 response of these genes [11]. Except for the cultivars, Buckskin and Scout 66, other cultivars with known complementary group belong to different complementary groups indicating significant difference in their genetic background. Although dwarf phenotype is associated with GA3 function, another plant hormone, indole-acetic acid (IAA) also plays a role in cell elongation [33,34]. Differences in GA3 response at warm and cool temperatures among different cultivars may be related to a temperature effect on leaf elongation as mediated by the level of endogenous GA3. The leaf elongation response to endogenous and exogenous GA3 may be restricted by the upper limits set by the different Rht alleles [32]. Further study will be necessary to understand basis of such different response of these cultivars to GA3.

4.4. Winter Rye

Winter rye as wheat may be used as a cover crop [35] as well as used for livestock feed and pasture [36]. Like winter wheat, winter rye cultivars may have dwarfing characteristics related to either GA3 insensitivity and synthesis mutants [11]. “Rymin” registered in 1973 [37] is a popular rye grown throughout Nebraska. It grows to a tall or medium height [36,37]. Therefore, GA3 was ap-
plied to seeds of “Rymin” rye and compared to “Good- 
break” and “Wesley” wheat under warm (21˚C) day-
time conditions (Table 4). The sensitivity of “Rymin” to GA3 exposure was less than that of “Goodbreak” but greater than that of “Wesley”. This may indicate that “Rymin” rye responded immediately between “Goodbreak” and “Wesley” wheat.

4.5. Cytokinin Addition

It is well documented that cytokinins promote the growth of lateral buds [4,38]. For cereals, this would suggest that cytokinins could promote tiller formation. One commonly used cytokinin is 6BA. Since GA3 promoted stem growth of wheat, this might be enhanced by adding 6BA to promote tillering as well. Table 4 showed that adding 6BA to GA3 had no effect on enhancing emergence, seedling height, tiller number, or seedling weight compared to GA3 alone. 6BA at 2000 ppm had an inhibitory effect on these growth parameters when added to GA3; at 500 ppm, 6BA inhibited some of these parameters.

5. Conclusion

Treating seed of winter wheat cultivars with GA3 and planting in shallow flats placed under warm daytime temperature (21˚C) with cold nighttime (4˚C) temperatures is a good short turn-around (1 to 3 w) bioassay for both conventional and semi-dwarf cultivars. Winter rye can be tested in the same system. The next study will be to test GA3-treated winter wheat under field conditions and determine whether the growth of late-planted wheat could be stimulated to grow to that size of normally planted wheat.

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