

USE OF STRIGOLACTONE FOR STRESS RELIEF AND INCREASED PRODUCTIVITY IN
HIGH-YIELDING ENVIRONMENTS

BY

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THESIS

Submitted in partial fulfillment of the requirements
for the degree of Masters of Science in Crop Sciences
in the Graduate College of the
University of Illinois at Urbana-Champaign, 2017

Urbana, Illinois

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ABSTRACT

Due to the projected global population increase, food production will need to increase by 60 percent. Of this food production increase, 90 percent is projected to originate from intensified management and increases in yield. Producers will need to utilize new technologies in order for food production to reach its fullest potential. Strigolactones have recently been classified as plant growth regulators, as they have been implicated in the regulation of shoot inhibition and root growth and development. The objective of this study was to determine the ability of a strigolactone to increase the grain yield of corn (*Zea mays* L) in combination with varying levels of crop management. This study was conducted in Champaign, IL in 2015 and in Harrisburg, Champaign, and Yorkville, IL in 2016. Treatment applications were designed to evaluate the strigolactone analog AB-01, developed by Asilomar Bio, Inc, as either a seed treatment or foliar application. Hybrids in this study were evaluated at planting densities of 79,000, 88,000, and 108,600 plants ha⁻¹. In no instance, when averaged over locations, management level, or hybrid, did strigolactone treatments significantly increase grain yield. However, foliar applications of AB-01 resulted in a significant reduction in yield when grown at Champaign in 2016. Although the AB-01 seed treatment had no impact on root biomass accumulation at the planting densities of 79,000 or 88,800 plant ha⁻¹, there was significant increase in R6 root biomass accumulation in response to the AB-01 seed treatment when grown under the intensive management system that utilized a planting density of 108,600 plants ha⁻¹, suggesting strigolactone may be an effective strategy for increasing root growth under high planting populations.

ACKNOWLEDGEMENTS

I would like to express my gratitude for having the opportunity to continue my education in the Crop Physiology Laboratory at the University of Illinois. Under the guidance of Dr. Fred Below, I was able to perform innovative field research utilizing plant growth regulators. My research would not have been possible without contributions from the Crop Physiology Laboratory team members including Juliann Seebauer, Tryston Beyrer, Adriano Mastrodomenico, Shelby Mann, Katie Parker, Brad Bernhard, Alison Vogel, and Cole Hendrix. I would further like to thank the visiting scholars and numerous undergraduate students for their help carrying out experiments. This research would not have been possible without the generous funding and support from Asilomar Bio, Inc., BASF, Monsanto Company, The Mosaic Company, and Syngenta. Support and guidance from my committee members Dr. Stephen Moose and Dr. Steve Huber has been received with sincere gratitude.

A special thanks is dedicated to my parents, sister, significant other, and friends who have supported my aspirations and continued education.

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LITERATURE REVIEW

The world today is facing a crisis. As of mid-2015, the world population was 7.3 billion people and is estimated to reach 9.7 billion people by the year 2050 (United Nations, 2015). To feed the growing population, global agricultural production will need to increase by more than 60 percent (Alexandratos and Bruinsma, 2012). With the trend for rural areas to become more urbanized, only about 10 percent of this increased production could come from arable land expansion. The remaining 90 percent of the agricultural production increase will have to originate from an increase in cropping intensity and increases in yield; 77 percent of which is estimated to come from yield increases (Bruinsma, 2009). One of the world's major field crops is corn (*Zea mays*, L.), which currently is produced at a global yield output level of 5.73 metric tons ha⁻¹ and is projected to involve more than 180 million hectares of land for production in 2017 (USDA, 2017). The United States is the world leader in corn production, accounting for 37 percent of the global production while using only 19 percent of the world production area, due to its yield output of 10.96 metric tons ha⁻¹ being nearly two and half times greater than the foreign production level of other countries (USDA, 2017). The top three states of Iowa, Illinois, and Nebraska produced 157.7 million metric tons in 2015, accounting for 45 percent of the United States corn grain production (USDA, 2015).

Corn yields have increased dramatically in the United States from 4.6 Mg ha⁻¹ in 1965 to 11.75 Mg ha⁻¹ in 2016 (USDA-NASS, 1965; USDA-NASS, 2016a). Approximately 60 percent of this recent yield increase can be attributed to genetic improvement, with the remainder credited to cultural practices (Duvick, 2005). The most notable genetic improvements have come from traits that provide the corn plant increased stress tolerance and grain production efficiency. Corn

breeders have selected for traits that increase tolerance to abiotic stress like increased tolerance to drought, and conversely, increased tolerance to cool and wet growing conditions. The corn plant's tolerance to biotic stresses has also been improved by breeders incorporating or increasing resistant genes to pests such as the European corn borer (*Ostrinia nubilalis*). While breeders have selected for a reduction in tiller production and more upright leaf architecture, the overall yield potential per plant has not increased. Consequently, breeders have selected for corn varieties with increased tolerance for high planting densities (Duvick, 2005). While breeders have selected superior inbreds to produce superior hybrids, corn hybrids vary in their yield response to environmental and agronomic management. The agriculture community characterizes hybrids as either "workhorse" (defensive) or "racehorse" (offensive) (Laue and Hicks, 2005). Workhorse-type hybrids are tolerant of low nitrogen conditions and produce stable yields; while racehorse-type hybrids exhibit large yield increases in response to applied fertilizer as well as to higher plant populations.

The use of fertilizers and pesticides has played a significant role in increasing corn yield. Nitrogen and phosphorous fertilizer consumption increased 7- and 3.5- fold, respectively, from 1960 to 1995; however in the future, increasing fertilizer applications isn't likely to be as effective in powering yields as it was in the past few decades, due to the law of diminishing rate of returns (Tilman et al., 2002). Of the other changes to cultural practices, the increase in plant density has played a crucial, if not the most influential role in the rise in grain yield. Over the last 30 years, planting populations have increased 40 percent in the state of Illinois from an average of 54,855 plants ha⁻¹ to 76,847 plants ha⁻¹ (USDA NASS 1982; USDA NASS 2016b). Planting density is one the most important production decisions, as yield is limited by an inadequate number of plants at lower planting densities and conversely limited at high planting densities due to an increase of aborted kernels and barren plants (Hashemi et al., 2005). Planting density also establishes the level

of intra-row competition, as increases in plant density concurrently increases the inter-plant competition by decreasing the distance between plants when row spacing is kept constant (Rossini et al., 2011). Plants compete with one another above-ground for light interception and below-ground for water, nutrients, and root space. As a result of this competition, there is a reduction in per plant root biomass and yield when grown in close proximity to each other (Casper and Jackson, 1997; Jiang et al., 2013). Additionally, when corn is grown under high seeding rates, there is a decrease in root activity in the deeper layers of soil, and when root systems of neighboring plants overlap, there is a reduction in root absorption efficiency (Jiang et al., 2013). Consequently, this reduction in root absorption efficiency, coupled with a reduction in root distribution, could decrease the uptake of nutrients that are acquired through diffusion, such as phosphorus (Haegele et al., 2014).

Crop Growth and Development

Corn growth and development is classified into stages, and the most common staging system for corn is the collar method. The collar method divides plant development into V (vegetative) and R (reproductive) stages (Abendroth et al., 2011; Nielsen, 2002). The vegetative stages are determined by the number of full leaves up to and including the uppermost leaf with a fully defined collar. The collar is defined as the area where the leaf blade and the leaf sheath, that is, leaf portion that wraps around the stem, meet. The plant will continue to grow and produce leaves until the plant reaches the tasseling stage (VT). At the VT growth stage, the plant has completed its vegetative growth and the reproductive development commences. During the vegetative growth stages, there are critical growth stages that greatly influence the grain yield potential of the plant. At V5-V6, all leaves and have been initiated and the kernel row number on the ears have been determined. Once a plant reaches the V15-V16 growth stage, the potential

kernel number per row has been determined (Abendroth et al., 2011). Since yield is comprised of components (ears m^{-2} x kernels ear^{-1} x individual kernel weight), receiving stress such as drought stress or nutrient deficiencies during the middle vegetative growth stages can severely impact yield potential (Abendroth et al., 2011; Fageria et al., 2006). Drought stress during vegetative growth has shown to cause a reduction in plant height and leaf area index (Çakir, 2004).

Reproductive stages are focused on the development of the kernels and are determined by examining the middle section of the primary ear and begin with the silking stage (R1) and conclude at physiological maturity (R6) (Abendroth et al., 2011). The R1 growth stage begins with the emergence of silks from the husk of the ear and allows for pollination and subsequent ovule fertilization. Since each silk is attached to a potential kernel, the pollination period is the most sensitive reproductive period to stress for the corn plant. Failure to successfully fertilize the potential ovules will result in a reduction in kernel number and thereby may reduce yield potential. Moisture stress during flowering has shown to produce serious yield loss due to multiple factors with poor pollination being a primary driver in that reduction (Çakir, 2004). Kernel weight is primarily accrued during the R3-R5 grain filling stages known as milk, dough, and dent stages, respectively; and is determined by source-sink relationships that establish kernel growth rates and effective filling periods (Abendroth et al., 2011; Gambín et al., 2006). During the dough and dent growth stages, more than half of the final kernel dry weight is accumulated. Plants experiencing a stress during these grain filling growth stages may produce reduced kernel weights and consequently, reduced yield (Abendroth et al., 2011). Typical stresses that can occur during the grain filling period are water and heat stress. When the daily temperatures were increased by seven °C, kernel weight was reduced by 7% while when plants received moisture during the grain filling period, plants produced heavier kernels; however, the increased kernel weights could be explained

by having few kernels per ear. (Çakir, 2004; Wilhelm et al., 1999). When one yield component increases in response to the decrease of the complementary yield component, this is known as yield component compensation.

Leaf Greenness

Chlorophyll concentration in the leaves of a plant is directly associated with the photosynthetic potential of the plant and is frequently utilized as an indicator of general plant health (Hatfield et al., 2008; Ling et al., 2011). Historically, chlorophyll concentration is determined in a laboratory by extracting the compounds from the leaf material. While the extraction method is accurate and well established, the leaf material must be removed from the plant, thus it is a destructive process (Ling et al., 2011). There are however, methods that can be utilized to estimate the chlorophyll in the leaf nondestructively. One of those methods is through the use of the SPAD-502 plus chlorophyll meter (Konica Minolta Sensing Americas, Inc., Ramsey, NJ). The SPAD-502 meter measures leaf transmittance and produces a relative value that is proportional to the amount of chlorophyll in the sample that has been shown to be accurate to the extraction method within 6% in *Arabidopsis* (Markwell et al., 1995; Ling et al., 2011).

Another non-destructive method to evaluate plant health is via the normalized difference vegetative index (NDVI). The measurement of NDVI is calculated by using near-infrared and visible light and is reported on a range from -1 to 1 (Pettorelli et al., 2005). The NDVI method has been used for estimating chlorophyll status, nitrogen levels, leaf area index, and grain yield (Shanahan et al., 2003; Carlson and Ripley, 1997; Shanahan et al., 2001). Numerous crop sensors are commercially available, and the sensors utilize modulated emitting diodes to direct light on to the canopy instead of ambient light (Shaver et al., 2010).

Classic Plant Growth Regulators

Plant growth, development, and yield can be influenced by growth regulators. Plant growth regulators (PGRs) are defined as organic compounds other than nutrients, that are utilized at low concentrations and promote, inhibit, or modify any physiological process in the plant's growth and development (Basra, 2000). Some naturally occurring substances as well as synthetic compounds are considered PGRs, whereas plant hormones, also known as "phytohormones," are substances that only occur naturally (Basra, 2000; Salisbury and Ross, 1992a). There are currently five main groups of PGRs, and they are organized by their chemical structure and their main physiological effect. The five groups include auxins, gibberellins, cytokinins, abscisic acid, and ethylene. Although these are the five main groups, other signaling compounds are continuing to be discovered (Taiz and Zeiger, 1998a).

The first PGR group to be discovered was auxin. Charles Darwin first observed the physiological auxin response of plants bending towards a light source. What Darwin was observing is known as "phototropism." By blocking light to various plant parts, Darwin's experiments showed that the tip of the coleoptile perceived the light. When the tip of the coleoptile was covered the plant would no longer bend towards the light. Frits Went also observed that plants would curve towards a light source; however, Went's experiment showed that the bending of the plant in the presence of light was due to an unknown internal chemical compound (Taiz and Zeiger, 1998a). Went was the first person to coin the phrase auxin, and the unknown compound is now known to be indoleacetic acid (IAA). Auxins are a group of similar compounds synthesized in active meristems, primarily the apical meristem, and are derived from the amino acid tryptophan, and have unidirectional transport within the phloem (Basra, 2000; Taiz and Zeiger, 1998a). Auxins stimulate cell enlargement and elongation, repress the growth of auxiliary buds, stimulate lateral

root formation, and regulate leaf and fruit abscission. Synthetic auxins are often used as herbicides for control of broadleaf weeds (Salisbury and Ross, 1992a).

The gibberellin group was discovered when plant pathologists isolated a chemical, gibberellic acid, from the *Gibberella fujikuroi* fungus that caused the "foolish seedling disease" in rice farms in Japan. The foolish seedling diseases elicited rice plants to grow tall, but not produce seed (Salisbury and Ross, 1992a; Taiz, and Zeiger, 1998b). More than 100 gibberellin compounds discovered are known to exist in angiosperms, fungi, and some species of bacteria. Gibberellins can be found throughout the plant, but are primarily produced in young tissues like leaves, buds, and immature seeds (Basra, 2000; Salisbury and Ross, 1992a). One of the best-known physiological responses of plants to gibberellins is that exogenous applications of gibberellic acid will induce stem elongation in dwarf plants and internode elongation in grass species. Gibberellins have other effects on plant growth and development as well; gibberellins can initiate flowering and stimulate the catabolism of storage compounds in germinating seeds (Salisbury and Ross, 1992a; Taiz and Zeiger, 1998b). Gibberellins have been used commercially in agriculture for a variety of end uses. The beverage industry utilizes the catabolic-promotion property to stimulate amylase enzymes to convert starch to sugar in the malting of barley (Basra, 2000; Taiz and Zeiger, 1998b). Other commercial uses for gibberellic acid include increased grape production, increasing the sugar production of sugar cane, and breaking dormancy in conifer breeding programs (Taiz and Zeiger, 1998b).

A third group of PGRs is cytokinins. Cytokinins are compounds that stimulate cellular division, namely cytokinesis. Cytokinins were observed in the 1940s when coconut milk was shown to contain compounds that stimulated mature cells to enter cellular division. A few years later, Skoog discovered the first synthetic analog of cytokinin and named it kinetin (Salisbury and

Ross, 1992b; Taiz and Zeiger, 1998c). Cytokinins are synthesized in both root and shoot meristems; however, the root tip is the primary site of synthesis. When cytokinin is produced in the root, it is transported through the xylem, while the cytokinin from young developing tissues is distributed locally through the tissue (Basra, 2000; Taiz and Zeiger, 1998c). Cytokinins can elicit a wide variety of biological responses, including: stimulation of cell division, lateral bud development, delaying of senescence, and increases in chlorophyll development and retention (Salisbury and Ross, 1992b).

More recently, abscisic acid was discovered simultaneously in cotton bolls and in sycamore leaves (Taiz and Zeiger, 1998d). Abscisic acid is a 15-carbon sesquiterpenoid that is synthesized in chloroplasts and other plastids, and transported via both xylem and phloem in the plant (Salisbury and Ross, 1992b). Abscisic acid mainly functions in the plant as protection from stress. Applications of abscisic acid to a plant will cause stomatal closing in the leaves, and during periods of water stress abscisic acid concentrations in leaves may increase 20-40 fold. When the plant roots experience water stress, plastids supply abscisic acid to leaves indicating that water supply is becoming depleted (Salisbury and Ross, 1992b). Interestingly, during water stress, abscisic acid increases concurrently with increases in the production of reactive oxygen species in corn, and consequently the plant is stimulated to increase production of antioxidant enzymes (Jiang and Zhang, 2002).

Ethylene is a gaseous compound produced by plants during leaf abscission, flower senescence, and fruit ripening (Taiz and Zeiger, 1998e). While the effects of ethylene have been witnessed by many cultures throughout the years, it was first established to directly affect plants when Neljubow revealed that it caused stem elongation inhibition, stem thickening, and horizontal growth (Salisbury and Ross, 1992b). All parts of plants produce ethylene and are stimulated by

numerous conditions including environmental conditions, plant injury, and other hormones (Salisbury and Ross, 1992b; Taiz and Zeiger, 1998e). Ethylene production increases in response to hypoxia (flooding), heat stress, and cold temperatures in chilling sensitive plants (Morgan and Drew, 1997). Due to ethylene's effect on many physiological processes, it is used commercially in agriculture as a compound known as "ethephon." Ethephon is a liquid, slow release ethylene that is used to increase fruit ripening in apples, degreening in citrus fruits, and the synchronization of flowering in pineapple (Taiz and Zieger, 1998e). Ethephon has been shown to increase yields in corn and wheat in environments that are conducive to lodging (Norberg et al., 1988; Simmons et al., 1988).

Strobilurin – Foliar Fungicides

Strobilurins are a recently developed group of man-made compounds that are primarily used as fungicides, but also act as plant growth regulators. These fungicides are popular due to their broad-spectrum control of a wide range of pathogens on a wide range of grain, fruit, and vegetable crops (Grossman and Retzlaff, 1997). Increasing plant density reduces airflow between the crop plants, providing a moister environment favorable to fungus growth. Fungicides that contain strobilurin chemistry are effective in controlling mycelium and spores by inhibiting mitochondrial respiration (Bartlett et al., 2002; Vincelli, 2012). Aside from strobilurin's control of plant pathogens, strobilurin fungicides have been associated with numerous physiological traits. Of those physiological traits, strobilurin fungicides have been associated with the "stay green" effect. The "stay green" effect can be classified as altering the timing of senescence initiation, and subsequent reduction in the rate that chlorophyll is degraded (Thomas and Howarth, 2000). The over production of reactive oxygen species in response to both abiotic and biotic stresses results in the degradation of cell membranes and ultimately cell death (Bhattacharjee, 2005). Reactive

oxygen species are usually found in plant cells, but are typically scavenged by antioxidants within the cell (Prochazkova et al., 2001). While reactive oxygen species production is increased in response to abiotic stress, ethylene production is as well, which is a PGR associated with senescence (Taiz and Zieger, 1998e). Strobilurin applications have shown to reduce the activity of ACC synthase and subsequent decrease in ethylene production on wheat (Grossman et al., 1999). By reducing ethylene production, strobilurin fungicides are implicated in delayed senescence, and sustained plant health.

Strigolactone – A New Phytohormone

Strigolactones (SLs) are carotenoid-derived plant compounds that were initially discovered as a germination stimulant for *Striga* (*Striga lutea*) (Eshel and Beeckman, 2013; Waldie et al, 2014). *Striga*, also known as witchweed, is an obligate parasitic weed of corn, sorghum, and many other subsistence crops in Africa and Asia (Nickrent and Musselman, 2004). *Striga* utilizes the SLs that are exuded from the roots of its host plant as a cue to guarantee there will be a suitable host in proximity after germination (Waldie et al, 2014). It was later determined that synthetic SLs also stimulate the hyphal branching of arbuscular mycorrhizal fungi (AMF), and have been implicated to play a role in root growth, lateral root formation, root hair elongation, salinity responses, and shoot branching. Recently, SLs have been shown to act as long-distance branching factor and have been classified as a new plant hormone (Eshel and Beeckman, 2013; Waldie et al, 2014).

Root development and communication are affected by SLs. Studies using *Arabidopsis* showed that under carbohydrate deficiency conditions, applications of a synthetic SL (GR24) resulted in an increase in primary root development; however, inhibition of primary root length was also reported under conditions with adequate carbohydrate levels (Eshel and Beeckman,

2013). These results indicate that SLs are positive regulators of primary root development, but dependent on the growing conditions. In tomatoes the increase in the primary root length from SLs was due to increases in cell elongation, rather than cell division (Rasmussen et al., 2013). In addition to primary root development, SLs also affect lateral root formation, depending on the growing conditions. Under sufficient phosphate levels, SLs decrease lateral root formation, but SLs increase lateral root formation in the presence of phosphate deficiencies (Eshel and Beeckman, 2013; Rasmussen et al., 2013; Ruyter-Spira et al., 2011). Synthetic SLs were also reported to increase root hair elongation on *Arabidopsis*, potentially increasing the plant's ability to increase nutrient uptake (Kapulnik et al., 2011). These findings indicate that SLs are regulators of plant responses to low-nutrient environments via the MAX2-signaling pathway (Eshel and Beeckman, 2013).

In the soil, SLs have been acknowledged as stimulants of hyphal branching in arbuscular mycorrhizal fungi (AMF) and are used by the fungi for host recognition (Eshel and Beeckman, 2013). Arbuscular mycorrhizal fungi are soil fungi that form a symbiotic relationship with the roots of plants. It is estimated that this symbiotic relationship is formed with over 80 percent of the terrestrial plants on earth (Akiyama and Hayashi, 2006; Eshel and Beeckman, 2013). The AMF infect the root of the host plant and create a bi-directional exchange between the two organisms. In exchange for carbon provided by the host plant, AMF enhance the root's ability to uptake nutrients by effectively increasing the root's distribution within the soil (Eshel and Beeckman, 2013). Strigolactones have been shown to induce AMF hyphal branching, implying that SLs are important signaling compounds for this beneficial association (Akiyama, and Hayashi, 2006; Eshel and Beeckman, 2013).

Strigolactones also play a regulatory role in shoot development and branching at axillary buds. Axillary buds are located in the axil of the leaves and do not develop into branches until they are released of their dormancy. It is suggested that SLs work with auxin to repress the outgrowth and inhibit branching of the axillary buds (Eshel and Beeckman, 2013; Xie et al., 2010). Aside from working as a shoot branch-inhibiting plant hormone, SLs also play a role in the shoot's responses to drought. Wild-type and SL-deficient *Arabidopsis* plants were much more tolerant to drought stress when exogenous applications of synthetic SL were applied, suggesting that SLs may positively regulate drought stress within the plant (Ha et al., 2014). The application of the synthetic SL induced faster stomatal closure, effectively reducing the transpiration rate (Ha et al., 2014). While there are no examples of utilizing the synthetic SL GR24 as a foliar application, Asilomar Bio, Inc. reported increased kernel set, kernel weight, and subsequent yield increases of 19% when the synthetic SL AB-01 was applied to corn at the tasseling (VT) growth stage (Davidson et al., 2015). While SL is suggested to have these characteristics, it still difficult to generalize at this time about the effects of strigolactones on shoot growth and development (Brewer et al., 2013).

To produce enough food to feed the expanding population of the future, and while rural areas continue to become urbanized, producers around the world will have to increase their yield intensification drastically. While growing superior genetics and increasing the planting population will be the key to the world's success, increasing planting density increases inter-plant competition and reduces root mass and volume. Increasing the inter-plant competition also has the potential to intensify biotic and abiotic stresses, and in order to maintain food security, producers will need to utilize every technology available to mitigate these stresses. Strigolactones have been shown to play a role in primary and lateral root formation, root hair elongation, and drought stress responses, positioning SLs to be a possible strategy to mitigate stress and increase corn productivity. The

ability of strigolactones to regulate plant root development and formation may in turn increase early plant growth and subsequent ovule potential. Corn is known to be sensitive to water stress during pollination, and as such SLs may help facilitate kernel development under stress and increase final kernel number per ear.

The objective of this research was to evaluate the ability of different formulations of synthetic strigolactone analog AB-01 on relieving population stress and increasing grain yield of corn when grown in intensive production systems. The hypothesis of this research was that strigolactones would result in greater corn productivity due to its ability to regulate root development, which could potentially increase ovule potential by increasing early plant growth, while foliar strigolactone applications could potentially reduce kernel abortion and facilitate kernel development. The results of this research could provide a better understanding of the true value of implementing strigolactones into producer's management practices.

MATERIALS AND METHODS

Location

The experiment in 2015 was conducted at the Crop Science Research and Education Center (CSREC) in Champaign, IL. The field was tile drained with a subsurface drip irrigation (SDI) system; however, due to abundant precipitation in 2015 (Table 1), the SDI system was not used to supply water during the growing season. The location was maintained weed-free with a pre-emergence application of S-metolachlor [2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl) acetamide] + atrazine (1-Chloro-3-ethylamino-5-isopropylamino-2,4,6-triazine) + mesotrione (2-[4-(Methylsulfonyl)-2-nitrobenzoyl] cyclohexane-1,3-dione), known as Lumax (Syngenta, Greensboro, NC) and a post-emergence application of glyphosate (N-phosphonomethyl glycine, in the form of trimethylsulfonium salt) as Touchdown (Syngenta, Basel, Switzerland). The soil was level (0-2% slope), well-drained and classified as a Drummer-Flanagan silty clay loam. A composite soil sample for the experiment was obtained from a depth of 0-15 cm before planting and tested using the Mehlich-3 extraction. Soil test results were: 3.8% organic matter; 22.5 meq per 100g CEC, 6.1 pH, 13 ppm P, and 125 ppm K. The trial had soybean [*Glycine max* (L.) Merr.] as the previous crop in a corn-soybean rotation and conventional tillage was used. A base nitrogen rate of 202 kg ha⁻¹ was applied prior to planting as liquid urea ammonium nitrate (28-0-0). Due to abundant precipitation during vegetative growth, a supplemental nitrogen application of 67 kg ha⁻¹, as urea ammonium nitrate, was applied through the irrigation system on 22 July at the R3 growth stage for a total nitrogen application of 269 kg N ha⁻¹.

In 2016, two experiments, evaluation of AB-01 treatments in combination with crop management intensity and/ or foliar fungicide (Experiment A) and evaluation of AB-01 as a seed treatment (Experiment B) were each conducted at Champaign, Harrisburg, and Yorkville to evaluate three distinct north to south environments in Illinois. All locations were maintained weed-free with a pre-emergence application of Lumax and a post emergence application of glyphosate (N-phosphonomethyl glycine, in the form of potassium salt) as RoundUp (Monsanto, St. Louis, MO). The Champaign location also received a post emergence application of diflufenzopyr (2-(1-[[[3,5-difluorophenylamino] carbonyl)-hydrazono] ethyl]-3-pyridinecarboxylic acid) + dicamba (3,6-dichloro-2-methoxybenzoic acid) as Status (BASF, Research Triangle Park, NC) and Harrisburg received a post emergence application of topramezone [3-(4,5-dihydro-isoxazolyl)-2-methyl-4-(methylsulfonyl)phenyl](5-hydroxy-1-methyl-1H-pyrazol-4-yl)methanone as Armezon (BASF, Research Triangle Park, NC). All locations were level, well-drained, and well-suited to provide evenly distributed soil fertility, pH, soil organic matter, and water availability. A composite soil sample was obtained from a depth of 0-15 cm before planting, for all trials and locations, and tested using the Mehlich-3 extraction. At Harrisburg, the soil-type was a Haro silty clay loam, and the soil test results were: 2.9% organic matter; 20.2 meq per 100g CEC, 6.7 pH, 20 ppm P, and 142 ppm K. In Champaign, the soil-type was a Drummer-Flanagan Association silty clay loam. Soil test results were: 3.6% organic matter; 18.0 meq per 100g CEC, 6.7 pH, 36 ppm P, and 118 ppm K. At the northern location of Yorkville, the soil-type was a Drummer-Saybrook Association silty clay loam soil with a soil test of: 5.0% organic matter; 22.6 meq per 100g CEC, 6.5 pH, 112 ppm P, and 193 ppm K. A base nitrogen rate of 202 kg ha⁻¹ was applied prior to planting as urea ammonium nitrate (28-0-0) in Champaign and Yorkville, and as urea (46-0-0) in Harrisburg for both experiments.

Experimental Design

The experiment in 2015 involved two different treatment factors: planting density and chemical treatments (Table 2). Treatments were arranged in a randomized complete block experimental design with eight replications. Each experimental unit consisted of plots four rows wide and 11.43 m in length with 0.76 m row spacing. The experiment evaluated AB-01 PGR, a strigolactone analog, developed by Asilomar Bio, Inc. and consisted of a seed treatment at planting and/or as a foliar application at the VT/R1 growth stage. The AB-01 treatments were compared to a foliar fungicide application of Headline AMP (BASF, Research Triangle Park, NC) at the VT/R1 growth stage. Seed treatment applications of AB-01 were suspended in acetone at 0.075 mg a.i. seed⁻¹ using seed treatment equipment and mixed until dry. Foliar applications of AB-01 and the foliar fungicide were applied with a backpack sprayer using a 187 L ha⁻¹ spray volume carrier and an application rate of 4.9 grams a.i. ha⁻¹ and 1.05 L ha⁻¹, respectively, with no surfactant or adjuvants included on 14 July 2015. A versatile high-yielding commercial hybrid [Stone 6148RIB (Monsanto germplasm)] was grown at a standard population of 79,000 and an ultra-high population of 108,600 plants ha⁻¹ to assess the impact of AB-01 in the potentially more stressful condition of an extremely high plant density.

The two experiments in 2016 were designed and modified based on the 2015 results to evaluate hybrids with different characteristics for optimal management along with AB-01 treatments in combination with different levels of crop management intensity and/ or foliar fungicide. Experiment A consisted of three different treatment factors: AB-01 PGR, management level, and foliar fungicide (Table 3); while Experiment B involved two different treatment factors: hybrid and AB-01 seed treatment (Table 4). In Experiment A, treatments were arranged in a split-split experimental plot design with management level being the whole plot and foliar fungicide

being the subplot. Each split plot was divided into split-split plots with AB-01 PGR being randomly assigned to each split-split plot. Experiment B treatments were arranged in a randomized complete block experimental design. Both experiments were replicated eight times. Each experimental unit consisted of plots four rows wide and 11.43 m in length with 0.76 m row spacing. Experiment A evaluated the same AB-01 PGR treatments as in 2015 (seed treatment at planting and as a foliar application at the VT/R1 growth stage); however, treatment applications were altered to evaluate the potential synergistic effects between the AB-01 PGR and the foliar fungicide. Seed treatment applications of AB-01 were suspended in acetone at 0.075 mg a.i. seed⁻¹, applied to seeds using seed treatment equipment, and mixed until dry. Foliar applications of AB-01 and the foliar fungicide were applied with a backpack sprayer on 11 July 2016 at Harrisburg and 12 July 2016 in Champaign using a 187 L ha⁻¹ spray volume carrier and an application rate of 4.9 grams a.i. ha⁻¹ and 1.05 L ha⁻¹, respectively, with no surfactant or adjuvants included. The Yorkville location did not receive any foliar applied treatments due to severe lodging during vegetative development. A versatile high-yielding hybrid, DKC 62-77RIB (Monsanto), was grown under standard and intensive management systems for the 2016 Experiment A. The standard management system consisted of the base N application (202 kg N ha⁻¹) and grown at a plant population of 79,000 plants ha⁻¹; while the intensive management system included enhanced fertility of 280 kg ha⁻¹ of MicroEssentials-SZ (12-40-0-10S-1Zn) (The Mosaic Company, Plymouth, MN) banded 10 to 15 cm deep directly beneath the row prior to planting to provide an additional 39 kg N, 112 kg P₂O₅, 28 kg S, and 2.8 kg Zn ha⁻¹, plus an additional 67 kg N ha⁻¹ sidedress application at V6, and grown at a planting population of 108,600 plants ha⁻¹. The sidedress applications were applied on 1 June, 6 June, and 16 June 2016 for the Harrisburg, Champaign, and Yorkville locations, respectively.

To evaluate the theory of the AB-01 seed treatment and hybrid characterization interaction, Experiment B evaluated the AB-01 seed treatment on four hybrids that differ in their yield response to soil N availability and plant population. Two hybrids, DKC61-54RIB (Monsanto) and G10T63-3000GT (Syngenta) are characterized as "workhorse-types" that are tolerant of low N conditions with stable yields, while the other two hybrids DKC63-71RIB (Monsanto) and G11K47-GT (Syngenta) are characterized as "racehorse-types" that exhibit a large yield increase in response to applied fertilizers and higher plant populations. A base N application (202 kg N ha^{-1}) was applied prior to planting to all plots and hybrids were seeded to obtain an approximate final density of $88,800 \text{ plants ha}^{-1}$. Seed treatment applications of AB-01 were suspended in acetone at $0.075 \text{ mg a.i. seed}^{-1}$ using seed treatment equipment and mixed until dry.

Leaf Greenness and Growth Measurements

In 2015, leaf greenness was measured at the V5 growth stage (26 May) and at the R3 growth stage (23 July) to determine the effect of the strigolactone treatments on plant health. Leaf greenness measurements were conducted using a Minolta SPAD-502 Plus (Konica Minolta Sensing Americas, Inc., Ramsey, NJ) chlorophyll meter, evaluating the uppermost fully expanded leaf at V5 or the ear leaf at R3. To assess the treatment impacts on plant growth, plant and ear height determinations were made on 29 July 2015. Plant heights were measured from the ground to the tip of the tassel and ear height was measured up to the ear node.

In 2016, plot greenness was measured at the V6 and V12 growth stages using a Crop Circle ACS-210 sensor (Holland Scientific, Lincoln, NE) positioned 50-92 cm above the entire plant canopy of row 3. The V6 measurements were conducted on 6 June, 1 June, and 21 June at Harrisburg, Champaign, and Yorkville, respectively; while the V12 measurements were conducted on 30 June and 24 June at Harrisburg and Champaign, respectively. Leaf greenness was also

measured at R3 growth stage using a Minolta SPAD-502 plus chlorophyll meter, evaluating the ear leaf on 8 August at Harrisburg and 3 August at Champaign.

Plant Sampling and Partitioning

To assess the treatment impacts on plant growth, for both trials in 2016, six plants were sampled during vegetative growth stages, V10-V12 in Harrisburg and V8-V10 in Champaign, and at physiological maturity (R6). The V8-V12 plants were sampled on 10 June and 8 June at Harrisburg and Champaign, respectively, and dried and weighed to estimate early vegetative biomass; while the R6 plants were sampled on 12 September and 16 September at Harrisburg, and Champaign, respectively. At physiological maturity, the plants were partitioned into their components (grain vs stover) and biomass was determined by weighing the fresh plant stover and processing it through a Vermeer BC600XL chipper (Vermeer Corporation, Pella, IA) to obtain representative stover aliquots (i.e., subsamples). The stover subsamples were weighed to determine fresh weight (FW), and then weighed again after drying to 0 % moisture in a forced air oven at 75°C to measure dry weight (DW) to calculate stover dry weight by Equation 1.

$$\text{Stover DW} = \text{Total FW} \times \left(\frac{\text{aliquot DW}}{\text{aliquot FW}} \right) \quad (1)$$

The corn ears were dried and then weighed for grain and cob weight. The grain was removed using a corn sheller (AEC Group, St Charles, IA), weighed, and analyzed for moisture content using a Dickey John moisture reader (GSF, Ankeny, IA). Cob weight was obtained by difference, and dry leaf and stalks weights were summed to calculate the overall plant dry mass as shown in Equation 2.

$$\text{Total DW} = \text{Stover DW} + \text{Cob DW} + \text{Grain DW} \quad (2)$$

To assess the AB-01 seed treatment impacts on root growth in each plot in 2016, six random whole plants, including roots, were sampled from the treated rows using a spade 15 cm

from the base of the stalk at the V8 and R6 growth stage at the Champaign location only. Soil was washed from the roots by soaking and pressurized spray, then were subsequently oven dried and weighed.

Grain Yield

Prior to harvest, plants were counted in one of the harvest rows to verify proper emergence and determine final plant populations. The middle two rows of each plot were harvested with an Specialized Plot Combine SPC-40 combine (ALMACO, Nevada, IA) on 28 September in 2015 and on 22 September, 5 October, 13 October in 2016 for Harrisburg, Champaign, and Yorkville, respectively. The combine is equipped with HarvestMaster's grain gauge system (Juniper Systems, Logan, UT) to provide grain weights and moistures, with the yield standardized to Mg ha⁻¹ at 0% moisture. A subsample of the grain was collected from each plot during harvest and subsequently evaluated for yield components (individual kernel weight (KW) and kernel number (KN)) and for grain quality (protein, oil, and starch concentrations) using near-infrared transmittance spectroscopy (NIT) (Infratec 1241 Grain Analyzer; FOSS). A representative subset of 300 kernels were counted (Old Mill 850-2, San Antonio, TX) and weighed to obtain an average individual kernel weight. Kernel number m⁻² was determined using total plot grain weight and individual kernel weight according to Equation 3.

$$KN = \frac{\text{Total Plot Grain Weight}}{KW} \quad (3)$$

Grain yields and individual kernel weights are presented at 0 % moisture.

Statistical Analysis

Statistical analysis for leaf greenness, plant biomass, grain yield, and yield components was performed using PROC MIXED of SAS (SAS 9.4; SAS Institute Inc., Cary, NC) with the assumption of equal variances. Experimental designs for 2015 and Experiment A of 2016 were not

consistent, and therefore, data for all three experiments were analyzed separately with significance declared at $P \leq 0.10$. Due to the fastidious nature of plant growth regulators and the limited field-based research of strigolactones, significance was declared at 0.10 to be more certain that we would not miss detecting a difference that may exist.

In 2015, the experiment was set up as a randomized complete block design. Chemical treatments and planting density were included in the model as fixed effects, while replication was a random effect. Normality of residuals and potential outliers were assessed using PROC UNIVARIATE.

In 2016, Experiment A was set up as a split-split plot design. Management level, foliar fungicide, and AB-01 treatments were included in the model as fixed effects, while replication and its interactions with fixed effects were included as random effects. Experiment B was set up as a randomized complete block design. Hybrid and AB-01 seed treatment were included in the model as fixed effects, and replication as a random effect.

RESULTS AND DISCUSSION

Weather

During the 2015 growing season, Champaign experienced precipitation 20.1 cm above the 20-year average, with a large excess of precipitation in June during vegetative growth (Table 1). Given the large amount of precipitation during vegetative growth, the trial appeared to be nitrogen deficient, likely due to leaching and denitrification, which justified the supplemental nitrogen application at R3. The trial experienced near-normal temperatures and precipitation during the grain filling period of July and August (Table 1). Illinois experienced abundant rainfall in 2016 as well, as there was 14.5, 8.9, and 28.6 cm above the 20-year average precipitation in Harrisburg, Champaign, and Yorkville, respectively. More specifically, there was above average precipitation in the months July at Harrisburg and July and August in Yorkville. The increased cloud cover, due to the excess rain fall during vegetative growth in 2015 and pollination and grain filling periods in 2016, likely resulted in a decrease of yield potential from a possible reduction in kernel set and kernel weight (Reed et al., 1988). Overall, weather conditions in Illinois during 2015 and 2016 consisted of near average temperatures, coupled by timely precipitation, which provided Illinois with high-yielding environments.

2015

Leaf Greenness and Plant Measurements

Leaf greenness and plant height measurements can be physiological indicators of plant health, and in no instance did the chemical treatments significantly affect leaf greenness, plant height, or ear height (Table 5). Although leaf greenness and plant height measurements were not significantly altered from the chemical treatments, applications of AB-01 tended to increase both parameters. The AB-01 seed treatment tended to increase leaf greenness at V5 for both planting

densities, while at R3 the increase in greenness was only apparent at the standard planting density of 79,000 plants ha⁻¹ (Table 5). While there is very limited literature on how strigolactone impacts chlorophyll concentration in corn, exogenous applications of synthetic strigolactone on rice showed that strigolactone decreased chlorophyll content in strigolactone-deficient mutants; however, there were no significant differences in chlorophyll content between strigolactone-treated and untreated controls in the wild-type plants (Yamada et al., 2014). While AB-01 applications had no effect on ear height, the AB-01 seed treatment tended to produce taller plants at both standard and high planting populations and an almost significant increase when averaged over both populations (Table 5). While it is difficult to generalize how strigolactones affect shoot growth due to limited knowledge in the literature, it appears AB-01 seed treatments tend to increase plant height, which can be indicative of less-stressed plants (Çakir, 2004).

Grain Yield, Yield Components, and Grain Quality

The trial in 2015 averaged 11.5 Mg ha⁻¹ across all chemical treatments and both populations with a significant statistical effect of the chemical treatments on grain yield when averaged over the two populations (Table 6). However, there was no significant interaction between the planting populations and chemical treatment on grain yield (Table 6). Changes in planting population did significantly impact grain yield; for untreated or Headline AMP treated plants, increasing the planting population above the standard level of 79,000 plants ha⁻¹ to 108,600 plants ha⁻¹ tended to increase yield by 0.5-0.8 Mg ha⁻¹, while treatments with AB-01 had no effect or tended to decrease yield at the higher planting density (Table 6). These results are in agreement with Stanger and Lauer (2006) as they too found that yield increased when using planting densities that exceed 100,000 plants ha⁻¹. At the standard planting population, all three AB-01 applications: seed treatment, VT foliar spray, and seed treatment plus VT foliar spray tended to increase grain yield,

with the seed treatment exhibiting the greatest tendency (Table 6). When averaged over both planting populations, the Headline AMP application significantly increased grain yield by 0.8 Mg ha⁻¹ while the AB-01 seed treatment produced a nearly significant yield increase of 0.6 Mg ha⁻¹. These results contradict what Davidson et al. (2015) found, as they reported a significant increase in harvest yield of 19%; however, Davidson's experiment was located in Texas and it is quite possible that the soil in central Illinois is too productive to elicit a significant yield response from strigolactone applications.

Increasing the planting population significantly affected grain yield components; however, there was no significant interaction between the population and chemical treatments (Table 6). Increasing the planting population from 79,000 to 108,600 plants ha⁻¹ resulted in a significant increase in kernel number with a concomitant significant reduction in kernel weight (Table 6). Similar to grain yield, increasing the planting population above 79,000 plants ha⁻¹ resulted in an increase in kernel number for the untreated or Headline AMP treated plants, although it was not a significant increase. While trials conducted by Davidson et al. (2015) exhibited significant increases in kernel set and kernel mass, the data in Table 6 shows that all chemical treatments had a tendency to increase kernel number at the standard population; while all three AB-01 applications had a tendency to have no effect or caused a reduction in kernel number at the high population. Although there was no significant interaction between population and chemical treatments on kernel weight, at the high planting density of 108,600 plants ha⁻¹, all three AB-01 applications, seed treatment, VT foliar spray, and seed treatment plus VT foliar spray tended to increase kernel weight. All chemical treatments had no effect on final plant populations (data not shown), nor kernel weight when averaged over both planting populations; likely due to the near-average temperatures and rainfall during the grain filling periods of July and August (Tables 1 and 6).

When averaged over both planting populations and compared to the average of AB-01 treatments, Headline AMP applications resulted in a significant increase in kernel number, which is directly associated with Headline AMP's significant increase in grain yield (Figure 1). Kernel abortion in corn can be attributed to a shortage of assimilate supply so it is possible that applications of Headline AMP increased plant health during the critical early stages of kernel growth, thus minimizing kernel abortion (Andrade et al. 1999).

Similar to yield component changes, increasing the planting population resulted in a significant effect on grain quality with no significant interaction between the population and chemical treatments (Table 6). All chemical treatments tended to reduce grain oil concentration at the standard planting population of 79,000 plants ha⁻¹ and had a tendency to not effect oil concentration at the higher planting population of 108,600 plants ha⁻¹, except for the AB-01 VT foliar spray treatment which had a tendency to increase oil concentration at the higher planting density (Table 6). All chemical treatments tended to decrease grain protein concentration at the standard planting density; but increase protein concentration at the higher planting density, with again, the AB-01 VT foliar spray exhibiting the greatest increase. The AB-01 seed treatment and VT foliar spray applications tended to elicit an increase in grain starch concentration at the standard planting density, whereas the AB-01 seed treatment plus VT foliar spray and Headline AMP applications tended to result in a decrease in starch concentration. At the higher planting population, all chemical treatments tended to not affect or result in a reduction in starch concentration (Table 6).

2016

Experiment A

Leaf Greenness and Plant Measurements

Overall, changes in either the location or the management system significantly affected both biomass accumulation and leaf greenness (Tables 7 & 8). The AB-01 treatments also affected V6 leaf greenness, V8 root and R6 total biomass accumulation; however, they did not affect R6 stover biomass accumulation or leaf greenness during grain fill (Tables 7 & 8). There was a significant increase in vegetative leaf greenness when switching environments; the southern location of Harrisburg led to the lowest NDVI rating, with significant increase in NDVI ratings when switching to Champaign or to Yorkville (Table 7). Champaign environmental conditions continued to exhibit increased greenness over Harrisburg throughout the growing season (Table 8). Although intensive management tended to increase vegetative leaf greenness compared to standard management when averaged over all locations and strigolactone treatments at the V6 growth stage, the intensive management significantly increased leaf greenness at the V6 growth stage (Table 7). The intensive management's increase of leaf greenness, however, did not continue through the remainder of the season as management system had no effect on R3 SPAD measurements (Table 8). When averaged over all locations and management systems, AB-01 applications had no effect on leaf greenness during V12 or grain-filling (R3) growth stages (Tables 7 & 8), which generally agrees with what Yamada et al. (2014) observed using rice. Similar to leaf greenness responses, switching from the standard to intensive management system resulted in an increase vegetative biomass accumulation when averaged over all locations and strigolactone treatments, while the AB-01 application had no effect on vegetative biomass accumulation when averaged over both locations and management systems (Table 7). Like the early-season biomass

accumulation responses, AB-01 applications had a tendency to have no effect on R6 stover biomass accumulation; however, the AB-01 foliar spray applications significantly reduced R6 total biomass accumulation (Table 8). Strigolactone has been linked to inducing stomatal closure in *Arabidopsis*, and stomatal closure is linked to reduced photosynthesis rates (Chaves et al., 2009; Ha et al., 2014). Stomatal closure stimulated by the AB-01 foliar spray in the absence of stress may have caused the observed significant reduction in biomass accumulation. Contrary to the management systems effect on leaf greenness, switching from standard to intensive management resulted in a reduction of 21.2 and 41.9 g plant⁻¹ for stover and total biomass accumulation, respectively. When averaged over all locations, management systems, and strigolactone treatments, Headline AMP applications significantly increased stover and total biomass accumulation by 8.1 and 15.7 g plant⁻¹ (Table 8). Strobilurin fungicides have been reported to increase the rate of photosynthesis in grass species, consequently increasing carbon fixation (Kanungo and Joshi, 2014). However, Headline AMP applications had no effect on leaf greenness (Table 8), so the increase in biomass accumulation by Headline AMP treated plants was possibly due to its fungicidal properties reducing the incidence of disease.

At the Harrisburg location, the cultural management system had a significant effect on V6 vegetative leaf greenness and biomass accumulation, while foliar fungicide applications only had an effect on R6 biomass accumulation, and strigolactone treatments only had an effect on R3 ear-leaf greenness (Tables 9 & 10). Although management system significantly impacted vegetative leaf greenness, there was no interaction between management systems and the strigolactone treatments (Table 9). AB-01 seed treatments tended to have no effect on vegetative leaf greenness when grown with either the standard or intensive management system (Table 11). While the AB-01 seed treatment application had no effect on leaf greenness at either vegetative growth stages,

the AB-01 seed treatment plus foliar spray treatment significantly reduced ear-leaf greenness when averaged over both management and foliar fungicide applications (Table 10). It is unclear as to why the AB-01 seed treatment plus foliar spray reduced ear-leaf greenness, as neither the seed treatment nor the foliar spray alone caused a significant reduction in ear-leaf greenness. Even though the AB-01 seed treatment plus foliar spray treatment reduced R3 leaf greenness overall at Harrisburg, there was no interaction between AB-01 applications and management system or foliar fungicide applications (Tables 12 and 13).

Plant biomass measurements reflect the amount of CO₂ fixation, water, and nutrients that were utilized and converted into plant mass; and although switching from standard to intensive management systems significantly increased vegetative biomass overall, there was no interaction between management and the AB-01 seed treatment on vegetative biomass accumulation within either management system (Tables 9 & 11). While the intensive management system increased early season biomass, switching from the standard to the intensive management system resulted in significant decreases in both R6 stover and total biomass accumulations (Table 10). Utilization of the foliar fungicide Headline AMP significantly increased both stover and total biomass accumulation at the R6 growth stage (Table 10); however, since Headline AMP applications did not impact ear-leaf greenness during grain fill at Harrisburg either, the increase in R6 biomass accumulation is more likely attributed to a reduction in the incidence of foliar disease. In contrast to the success of the Headline AMP application, none of the strigolactone treatments impacted R6 biomass accumulation. Like the early season biomass accumulation, there was no interaction between the strigolactone treatments and the management system or the foliar fungicide application on final stover or total biomass accumulation (Tables 12-14).

Overall at the Champaign location, switching from the standard to the intensive management system significantly increased vegetative leaf greenness at both vegetative growth stages measured (Table 15). When averaged over the management systems, strigolactone treatments had no impact on vegetative leaf greenness; however, there was a significant interaction between the management systems and strigolactone treatments by the V6 growth stage for NDVI measurements (Table 15). The AB-01 seed treatment, consistently slightly reduced leaf greenness at the V6 growth stage when grown under the standard management system (Table 16). This contradicts the results of Yamanda et al. (2014), which reported no significant difference in chlorophyll concentration in rice in response to synthetic strigolactone applications. Neither management, foliar fungicide applications, nor strigolactone treatments significantly impacted ear-leaf greenness (Table 17). While there was no interaction between the management systems and strigolactone treatments, there was a tendency for the AB-01 foliar spray to reduce ear-leaf greenness under the standard management system (Table 18). When averaged over both management systems, both the AB-01 foliar spray and the AB-01 seed treatment plus foliar spray applications significantly decreased ear-leaf greenness when combined with a Headline AMP application (Table 19). Also, using the AB-01 foliar spray combined with Headline AMP and grown under the intensive management system significantly reduced ear-leaf greenness; however, utilizing the AB-01 seed treatment without the Headline AMP and grown under the standard management system resulted in an increase in ear-leaf greenness (Table 20). Similar to the Harrisburg location, at the Champaign location, the foliar applications of AB-01 could be stimulating unnecessary stomatal closure, and possibly reducing photosynthesis and chlorophyll concentration.

Like the Harrisburg location, switching from standard to intensive management at Champaign significantly increased vegetative biomass accumulation; however, in contrast to Harrisburg, the AB-01 seed treatment application resulted in a significant reduction in vegetative shoot biomass (Table 15). While there was no significant interaction between management level and strigolactone treatments, the AB-01 seed treatment tended to produce a slight decrease in biomass accumulation under both management systems (Table 16). While not measured in Harrisburg, V8 and R6 root biomass measurements were collected in Champaign to assess AB-01 effect on root growth. At the V8 growth stage, switching from standard to intensive management practices increased root biomass accumulation by 0.6 g plant^{-1} , while the AB-01 seed treatment reduced root biomass accumulation by 0.2 g plant^{-1} ; however, that trend did not continue throughout the remainder of the growing season (Table 15). At maturity (R6), the intensive management system significantly reduced root biomass accumulation, on average, by 4.4 g plant^{-1} (Table 15). Although the AB-01 seed treatment had no effect on R6 root biomass accumulation when averaged over both management systems, there was a significant interaction between the management level and the strigolactone treatments; interestingly, the AB-01 seed treatment significantly increased R6 root biomass accumulation when grown under the intensive management system (Table 16). Strigolactones are regulators of plant root responses but are also regulated by the surrounding soil nutrient conditions (Eshel and Beekman, 2013). The contrasting responses of root growth to the interaction of the AB-01 seed treatment and management system, and consequent soil nutritional status presented in Table 16 is similar to that described by Eshel and Beekman (2013) which suggested strigolactone negatively affects root growth under high-phosphorus environments and positively affects root growth under low-phosphorus environments. Since the intensive management system provided banded phosphorus beneath the row, the AB-01

seed treatment led to a reduction in V8 root biomass; however this hypothesis does not explain the increases in R6 root biomass accumulation. Similar to the results in Harrisburg, switching to the intensive management system significantly reduced R6 stover and biomass accumulation while utilizing the foliar fungicide application of Headline AMP significantly increased both stover and total biomass accumulation in Champaign (Table 17). None of the strigolactone applications had any impact on R6 biomass accumulation; however, there was a significant interaction between management and strigolactone treatments (Table 17). When using the standard management system, the AB-01 seed treatment plus foliar spray significantly increased stover biomass accumulation by 8.2 g plant⁻¹, while the AB-01 foliar spray application significantly decreased total biomass accumulation by 11.0 g plant⁻¹ (Table 18).

Grain Yield, Yield Components, and Grain Quality

Overall, the experiment yielded 9.2 and 12.9 Mg ha⁻¹ for the Harrisburg and Champaign locations, respectively, with location, management, and foliar fungicide treatments significantly impacting grain yield (Table 21). When averaged over all other treatments, the intensive management significantly increased yield by 0.9 Mg ha⁻¹, while foliar applications of Headline AMP increased yield by 0.5 Mg ha⁻¹ (Table 21). The yield increases in response to the intensive management system suggests that the standard system may limit maximum yield potential due to insufficient planting density, nitrogen, or fertility (Doberman et al. 2003). The increased population density tolerance of modern hybrids and their response to management inputs is likely associated with increased efficiency of resources and increased interception of radiation (Duvick, 2005; Tokatlidis and Koutroubas, 2004). In no instance, when averaged over all locations, management, and foliar fungicide treatments, did any AB-01 application impact grain yield, although AB-01 applications did significantly impact grain quality, specifically oil and protein

concentration (Table 21). Both the AB-01 seed treatment and the AB-01 seed treatment plus foliar spray application significantly increased oil concentration, while only the AB-01 seed treatment plus foliar spray significantly increased protein concentration (Table 21).

At Harrisburg, both management system and foliar fungicide applications significantly affected grain yield, however there was no significant interactions (Table 22 & 23). Switching from the standard to the intensive management system or utilizing the foliar fungicide Headline AMP application resulted in yield increases of 0.6 Mg ha⁻¹ (Table 22). Due to the AB-01 seed treatment resulting in a nearly significant yield increase at Champaign in 2015 and the success Asilomar Bio, Inc. observed with field trials in Texas utilizing AB-01 applications, we speculated that the harsher environment of Harrisburg could potentially elicit a significant response in yield production. However, in contrast to the findings of Davidson et al. (2015), none of the AB-01 applications had any impact on grain yield at Harrisburg, nor were there any interactions with management or foliar fungicide. However, similar to the overall results, AB-01 significantly affected grain quality at Harrisburg (Table 22). All AB-01 treatments significantly increased grain oil concentration and the AB-01 seed treatment plus foliar spray application significantly increased grain protein concentration; however, the latter was accompanied by a decrease in starch concentration (Table 22).

In Champaign, management system, foliar fungicide, and strigolactone treatments all significantly affected grain yield (Table 24). Just as in Harrisburg, switching from the standard to the intensive management system or applying Headline AMP produced yield increases of 0.9 and 0.5 Mg ha⁻¹, respectively (Table 24). Unfortunately, the AB-01 foliar spray or the AB-01 seed treatment plus foliar spray applications significantly reduced yield by 0.3 and 0.2 Mg ha⁻¹, respectively (Table 24). These results contradict what Davidson et al. (2015) found, and it appears

that strigolactone treatments associated with the AB-01 foliar spray have negative implications on plant growth and yield production. Although there was no interaction between strigolactone treatments and the foliar fungicide applications, there was an interaction of the strigolactone and management system treatments, as well as a three-way interaction between management, foliar fungicide, and strigolactone treatments. While none of the AB-01 applications impacted yield under the intensive management system, both the AB-01 foliar spray and the AB-01 seed treatment plus foliar spray applications significantly reduced yield under the standard management system, particularly when grown without the Headline AMP application (Tables 25 & 26).

The level of management system and the foliar fungicide treatments significantly impacted yield components and grain quality (Table 24). Switching from the standard to the intensive management system resulted in an increase in kernel number per area, with a concurrent reduction in kernel weight due to yield component compensation. Interestingly, in contrast to what was observed in 2015 where Headline AMP applications significantly increased yield due to an increase in kernel number, Headline AMP had no effect on kernel number in 2016. Instead, Headline AMP's yield influence can be attributed to a significant increase of $11.3 \text{ mg seed}^{-1}$. In no instance did any strigolactone treatment significantly impact either kernel number or kernel weight. While not significant, all AB-01 applications tended to decrease kernel number while also having no effect on kernel weight. Again, the results of this study contradict what Davidson et al. (2015) found with field experiments in Texas. Increasing the level of management from standard to intensive resulted in a significant decrease in grain oil concentration with a corresponding increase in starch concentration, while applications of Headline AMP resulted in the exact opposite grain compositional changes (Table 24). In no instance did strigolactone treatments affect grain quality.

Experiment B

Leaf Greenness and Plant Measurements

Overall, location and hybrid significantly affected corn leaf greenness and biomass accumulation, while the AB-01 seed treatment only affected leaf greenness at the R3 growth stage (Table 27). Leaf greenness measurements can be a physiological indicator of plant health; while AB-01 seed treatment applications usually did not change vegetative leaf greenness, they did significantly reduce ear-leaf greenness when averaged over all locations and hybrids (Table 27). In no instance did the AB-01 affect vegetative leaf greenness at any of the three locations when averaged over all of the hybrids (Tables 28-30). While there was no interaction at the Harrisburg or Yorkville location for leaf greenness, there was a significant interaction between hybrids and the AB-01 seed treatment at the Champaign location (Tables 31-33). The AB-01 seed treatment decreased leaf greenness at the V6 growth stage when applied to two hybrids, G10T63-3000GT and G11K47-GT, at the Champaign location (Table 32). This reduction in leaf greenness occurred with both of the Syngenta hybrids in this trial; however, since only the V6 growth stage was affected, and only at one of three locations, there is not enough evidence to generally speculate that the AB-01 seed treatment negatively interacts with the Syngenta germplasm. The AB-01 seed treatments reduced leaf greenness at the R3 growth stage overall, with all locations responding similarly (Table 28-30).

Plant biomass measurements reflect the amount of CO₂ fixation, water, and nutrients that the plants utilized and converted into plant mass. Overall, when averaged over all locations and hybrids, the AB-01 seed treatment had no effect on vegetative biomass accumulation, nor when averaged over all the hybrids at the Champaign location (Table 27 & 29). However, the AB-01

seed treatment promoted greater vegetative biomass accumulation at the Harrisburg location. In 2016, Harrisburg received twice the amount of precipitation in May as well as near average rainfall in June (Table 1). It is possible that the Harrisburg field had nitrogen loss that created a low-nutrient environment during the early vegetative growth stages. Strigolactones are positive regulators of root development in the presence of low-nutrient environments (Eshel and Beeckman, 2013). It is possible that the AB-01 seed treatment may have led to increased early root development, consequently resulting in increased vegetative biomass. This hypothesis cannot be corroborated as root measurements were only conducted in Champaign. Overall, hybrid selection and location individually and in combination significantly impacted both vegetative and R6 biomass accumulation (Table 27). At all locations, the Syngenta hybrids, G10T63-300GT and G11K47-GT, out-performed the Monsanto hybrids, DKC61-54RIB and DKC63-71RIB, for vegetative biomass accumulation (Tables 28 & 29), and this trend continued through the remainder of the growing season for both R6 stover and total biomass accumulation as well (Tables 28-30). Notably, both workhorse-type hybrids had greater vegetative and R6 biomass accumulation than the racehorse-type hybrid counterparts (Tables 28-30). There were no interactions found between the AB-01 seed treatment and any of the hybrids for either vegetative or R6 biomass accumulation (Tables 31-33). While racehorse-type hybrids respond with greater yield to intensified management inputs such as fertilizer and increased planting population, this study utilized a standard fertilizer rate of 202 kg N ha⁻¹ and a slightly increased planting density of 88,800 plants ha⁻¹; which is why the workhorse-type hybrids out-performed the racehorse-type hybrids for biomass accumulation, as workhorse-type hybrids are more tolerant to lower levels of fertility (Laue and Hicks, 2005). In contrast to Experiment A, where the plant roots responded to applications of the AB-01 seed treatment, the AB-01 seed treatment in this experiment had no

effect on root biomass accumulation at either the vegetative or the physiologically mature growth stage (Table 29). Also, in opposition to the stover and total biomass accumulation findings, on average, the racehorse-type hybrids, DKC63-71RIB and G11K47-GT, had greater root biomass than the workhorse-type hybrids, DKC61-54RIB and G10T63-3000GT, by 2.6 g plant⁻¹ (Table 27).

Grain Yield, Yield Components, and Grain Quality

When averaged over all hybrids and treatments, yields of 8.2, 12.1, and 11.9 Mg ha⁻¹ at Harrisburg, Champaign, and Yorkville, respectively, were measured (Table 34), with significant effects of both location and hybrid. When averaged over locations and treatments, hybrids yielded an average of 11.2, 11.1, 10.6, and 10.7 Mg ha⁻¹ for DKC61-54RIB, G10T63-3000GT, DKC63-71RIB, and G11K47-GT, respectively (Table 34). When averaged over treatments, the workhorse hybrids, DKC61-54RIB and G10T63-3000GT, out-performed the racehorse hybrids of DKC63-71RIB and G11K47-GT at both Harrisburg and Champaign (Tables 35 & 36), although hybrid selection had no effect on grain yield in Yorkville (Table 37). When averaged over all hybrids, AB-01 treatments did not affect grain yield at the Champaign or Yorkville locations; however, AB-01 significantly reduced yield at Harrisburg (Tables 35-37). While not significant, AB-01 treatments had no interaction with hybrid selection at any location; however, AB-01 tended to increase yield slightly when applied to DKC61-54RIB and G11K47-GT in Champaign, and tended to increase yield by 0.6 Mg ha⁻¹ when applied to G10T63-300GT in Yorkville (Tables 38-40). Since Davidson et al. (2015) reported yield increases in field trials located in Texas, we speculated that the AB-01 seed treatment could increase yield at the southern location of Harrisburg, this study does not support that hypothesis; however this study only utilized one site-year at the Harrisburg location and further testing is required to confirm these claims.

Similar to grain yield, the workhorse-type hybrids, DKC61-54RIB and G10T63-3000GT, had greater kernel number than the racehorse-type hybrids, DKC63-71RIB and G11K47-GT; however, the Syngenta hybrids also had greater kernel number than the Monsanto hybrids, when averaged over locations and AB-01 seed treatments (Table 34). Due to yield component compensation, the Syngenta hybrid's increased kernel number consequentially decreased kernel weight, with again the workhorse hybrids having greater kernel number than the racehorse hybrids. In no instance did the AB-01 seed treatment have any effect on either final kernel number or kernel weight at any of the locations (Table 35-37), in contradiction of earlier findings of increases in both kernel set and kernel mass in response to AB-01 treatments (Davidson et al. 2015). Following the near-significant yield increase from the AB-01 seed treatment in 2015, we speculated that the AB-01 seed treatment was increasing early vegetative growth, and subsequent ovule potential; however, the kernel number results of this study do not support that hypothesis.

When averaged over locations and AB-01 seed treatment, Syngenta hybrids, G10T63-3000GT and G11K47-GT, had significantly greater grain oil concentration than the Monsanto hybrids, DKC61-54RIB and DKC63-71RIB (Table 34). While there was no difference between the Monsanto hybrids for grain oil concentration, G11K47-GT had greater oil concentration than G10T63-3000GT (Table 34). Similarly to grain oil concentration, when averaged over locations and AB-01 seed treatments, Syngenta hybrids had greater grain protein concentration than Monsanto hybrids, except that this time G11K47-GT had more grain protein concentration than G10T63-3000GT and DKC61-54RIB had more grain protein concentration than DKC63-71RIB (Table 34). Conversely, the Monsanto hybrids had more grain starch concentration than the Syngenta hybrids. Overall, the AB-01 seed treatment significantly increased grain oil concentration, while having no effect on protein or starch concentrations (Table 34); however, AB-

01 seed treatments led to greater grain protein concentration at Champaign when applied to DKC63-71RIB and G11K47-GT (Table 39). When averaged over all hybrids, AB-01 seed treatments increased grain protein concentration at Champaign and Yorkville, but decreased grain starch concentration at Yorkville (Tables 39 & 40). At the Champaign location, there was a significant interaction for grain protein concentration between hybrid and the AB-01 seed treatment resulting in a significant increase in protein concentration when applied to both racehorse-type hybrids (Table 39). There was also a significant interaction for starch concentration between hybrid and the AB-01 seed treatment at the Yorkville location, which resulted in a significant decrease in starch concentration when applied to the G10T63-300GT and DKC63-71RIB hybrids (Table 40).

CONCLUSIONS

The two years of investigating the use of strigolactone for stress relief and increased grain production provided very similar growing conditions, as both 2015 and 2016 had near-average temperatures and above-average precipitation. The abundant amounts of precipitation likely caused nitrogen loss, and the increased cloud cover likely caused decreased photosynthetic activity, and possible reductions in kernel number and weight over all treatments. The supplemental 67 kg ha⁻¹ of N applied in 2015 likely mitigated the yield limiting effect from the nitrogen loss, allowing for the increase in yield at high population of 108,600 plants ha⁻¹.

Overall, in either year, strigolactone treatments did not significantly impact leaf greenness or above ground growth and development; however the AB-01 seed treatment did significantly affect root development in 2016. Although the AB-01 seed treatment had no impact on root biomass accumulation at the planting densities of 79,000 or 88,800 plant ha⁻¹, there was a significant increase in R6 root biomass accumulation in response to the AB-01 seed treatment when grown under the intensive management system that utilized a planting density of 108,600 plants ha⁻¹. While this response of root biomass cannot be attributed to planting population alone, it is possible that AB-01 can be an effective strategy to increase root growth under high planting populations. However, this study only contains one year of root data, and further testing is required before generalizing AB-01's interaction with planting densities on root growth and development.

While strigolactone treatments did significantly affect grain yield, in no instance, did AB-01 applications significantly increase grain yield in this study. While the AB-01 seed treatment did increase yield in 2015 when averaged over both planting densities, it was not a significant increase. In both years, applications of the AB-01 foliar spray tended to decrease yield at the Champaign location, with the reduction in yield being significant in 2016. This decrease in yield suggests that

the foliar formulation of AB-01 has little value in the absence of stressful growing conditions, which is what the weather 2015 and 2016 provided. The use of strigolactone may be beneficial to producers in less productive environments, as observed in previous trials in Texas.

This study documents the interaction between the strigolactone seed treatment formulation and hybrid selection and how this interaction impacts grain yield. In no instance, at either location, did the AB-01 seed treatment significantly interact with workhorse or racehorse-type hybrids, nor significantly impact grain yield. While not significant, there was a tendency for the AB-01 seed treatment to decrease yield when applied to racehorse-type hybrids at the Yorkville location. This suggests that the use of strigolactones may not be appropriate for this hybrid-type; however this trend only occurred at one location, and further testing is required before we can generalize the AB-01 effect on hybrid selection.

Currently there is little information on how strigolactones affect plant responses under field conditions. Further research on the use of strigolactones to obtain increased productivity in high-yielding environments and their interactions with planting population, hybrids, and abiotic and biotic stresses using varying formulations, application rates, and application timings may help identify environments and/ or management practices where strigolactones will be beneficial. Further investigation into these interactions will provide a better understanding of the true value of implementing strigolactones into producer's management practices.

TABLES

Table 1. Monthly weather data between 1 April and 30 September for Harrisburg, Champaign, and Yorkville, IL in 2015 and 2016. Temperature (°C) is the average daily temperature and precipitation (cm) is the average monthly accumulated rainfall. Values were obtained from Illinois State Water Survey (1990-2010) and values in parentheses are the deviations from the 20-year average.

Year	Month					
	April	May	June	July	August	September
Harrisburg, IL						
2016						
Temperature, °C	9.2 (0.8)	15.3 (-0.3)	21.7 (+0.4)	23.5 (+0.4)	23.9 (+1.4)	19.8 (+1.5)
Precipitation, cm	6.7 (-2.9)	23.5 (+12.8)	10.3 (+0.4)	19.5 (+8.8)	9.4 (-0.8)	4.8 (-3.8)
Champaign, IL						
2015						
Temperature, °C	12.1 (+0.7)	18.6 (+1.6)	22.2 (-0.1)	23.0 (-0.7)	22.1 (-1.0)	21.0 (+1.8)
Precipitation, cm	9.2 (+0.1)	15.4 (+2.5)	23.3 (+12.5)	10.7 (-1.5)	8.0 (-1.9)	16.4 (8.4)
2016						
Temperature, °C	11.4 (0.0)	16.6 (-0.4)	23.3 (+1.0)	23.9 (+0.2)	24.4 (+1.3)	21.0 (+1.9)
Precipitation, cm	8.3 (-0.8)	9.6 (-3.3)	18.1 (+7.3)	11.3 (-0.9)	10.5 (+0.6)	14.0 (+6.0)
Yorkville, IL						
2016						
Temperature, °C	14.6 (+0.7)	17.6 (-1.5)	25.1 (+6.4)	25.6 (+0.1)	25.0 (-0.1)	21.9 (+1.1)
Precipitation, cm	14.8 (+3.3)	15.0 (+3.0)	4.7 (-6.8)	22.5 (+14.0)	16.0 (+8.2)	14.6 (+6.9)

Table 2. Treatment combinations designed to evaluate the strigolactone AB-01 PGR on corn growth and productivity at Champaign, IL in 2015. Treatments consisted of five chemical treatments each evaluated at two planting densities using the hybrid Stone 6148RIB

Chemical Treatment	Planting Density (plants ac⁻¹)
Untreated	32,000
AB-01 Seed Treatment (ST)	32,000
AB-01 Foliar Spray (FS) [†]	32,000
AB-01 ST + FS [†]	32,000
Headline AMP [†]	32,000
Untreated	44,000
AB-01 Seed Treatment (ST)	44,000
AB-01 Foliar Spray (FS) [†]	44,000
AB-01 ST + FS [†]	44,000
Headline AMP [†]	44,000

[†]Applied at the VT/R1 growth stage.

Table 3. Treatment combinations used in the evaluation of strigolactone, fungicide, and crop management systems influences on corn growth and yield at three locations in IL in 2016 ('Experiment A'). Four strigolactone treatments were each evaluated under two management systems and with or without a foliar fungicide using the corn hybrid DKC 62-77RIB.

Strigolactone	Management	Foliar Fungicide
Untreated	Standard	Untreated
Untreated	Standard	Headline AMP [†]
Untreated	Intensive	Untreated
Untreated	Intensive	Headline AMP [†]
AB-01 Seed Treatment (ST)	Standard	Untreated
AB-01 Seed Treatment (ST)	Standard	Headline AMP [†]
AB-01 Seed Treatment (ST)	Intensive	Untreated
AB-01 Seed Treatment (ST)	Intensive	Headline AMP [†]
AB-01 Foliar Spray (FS) [†]	Standard	Untreated
AB-01 Foliar Spray (FS) [†]	Standard	Headline AMP [†]
AB-01 Foliar Spray (FS) [†]	Intensive	Untreated
AB-01 Foliar Spray (FS) [†]	Intensive	Headline AMP [†]
AB-01 ST + FS [†]	Standard	Untreated
AB-01 ST + FS [†]	Standard	Headline AMP [†]
AB-01 ST + FS [†]	Intensive	Untreated
AB-01 ST + FS [†]	Intensive	Headline AMP [†]

[†] Applied at the VT/R1 growth stage.

Table 4. Treatment combinations used in the evaluation of hybrid characterization and strigolactone AB-01 influences on corn growth and yield at three locations in IL in 2016 ('Experiment B'). Four hybrids were each evaluated with or without a seed treatment.

Hybrid Characterization	Hybrid	Seed Treatment
Workhorse	DKC61-54RIB	Untreated
Workhorse	DKC61-54RIB	AB-01 Seed Treatment
Workhorse	G10T63-3000GT	Untreated
Workhorse	G10T63-3000GT	AB-01 Seed Treatment
Racehorse	DKC63-71RIB	Untreated
Racehorse	DKC63-71RIB	AB-01 Seed Treatment
Racehorse	G11K47-GT	Untreated
Racehorse	G11K47-GT	AB-01 Seed Treatment

Table 5. Effect of chemical treatments, planting population, and source of variation on leaf greenness at two growth stages, plant height, and ear height for corn grown at Champaign, IL in 2015 averaged.

Chemical Treatment	Leaf Greenness		Height	
	V5	R3	Plant	Ear
	— SPAD Units —		— cm —	
	79,000 Plants ha⁻¹			
Untreated	40.3	50.9	238.8	81.4
AB-01 Seed Treatment (ST)	40.8	56.4	242.3	82.4
AB-01 Foliar Spray (FS)	—	53.1	—	—
AB-01 ST + FS	—	54.3	—	—
Headline AMP	—	54.8	—	—
LSD ($\alpha = 0.10$)	NS	NS	NS	NS
	108,600 Plants ha⁻¹			
Untreated	40.2	51.8	235.7	83.6
AB-01 Seed Treatment (ST)	41.6	52.4	238.1	83.3
AB-01 Foliar Spray (FS)	—	50.7	—	—
AB-01 ST + FS	—	51.3	—	—
Headline AMP	—	51.2	—	—
LSD ($\alpha = 0.10$)	NS	NS	NS	NS
	Average of Populations			
Untreated	39.9	51.4	237.2	82.5
AB-01 Seed Treatment (ST)	40.8	54.4	240.2	82.9
AB-01 Foliar Spray (FS)	—	51.9	—	—
AB-01 ST + FS	—	52.8	—	—
Headline AMP	—	53.0	—	—
LSD ($\alpha = 0.10$)	NS	NS	NS	NS
Source of Variation	$P > F$			
Treatment (T)	0.2408	0.3935	0.1108	0.7828
Population (P)	0.8203	0.0210	0.0513	0.2249
T x P	0.7117	0.5815	0.7629	0.5856

Table 6. Effect of chemical treatments, planting population, and source of variation on grain yield, yield component, and grain quality for corn grown at Champaign, IL in 2015. Grain yield and kernel weight is presented at 0 % moisture.

Chemical Treatment	Yield Mg ha ⁻¹	Yield Components		Grain Quality		
		Kernel Number number m ²	Kernel Weight mg seed ⁻¹	Protein	Oil %	Starch
79,000 Plants ha⁻¹						
Untreated	10.8	4392	247.1	6.46	3.75	73.26
AB-01 Seed Treatment (ST)	11.8	4846	243.0	6.31	3.57	73.83
AB-01 Foliar Spray (FS)	11.2	4644	241.0	6.39	3.69	73.49
AB-01 ST + FS	11.2	4560	246.2	6.34	3.56	72.86
Headline AMP	11.7	4771	245.6	6.36	3.58	72.68
LSD ($\alpha = 0.10$)	NS	NS	NS	NS	NS	NS
108,600 Plants ha⁻¹						
Untreated	11.6	5062	229.6	6.09	3.50	74.18
AB-01 Seed Treatment (ST)	11.6	4961	233.9	6.18	3.52	73.68
AB-01 Foliar Spray (FS)	11.2	4732	235.7	6.32	3.64	73.92
AB-01 ST + FS	11.1	4957	232.4	6.14	3.52	73.98
Headline AMP	12.3	5348	230.1	6.20	3.50	74.08
LSD ($\alpha = 0.10$)	NS	NS	NS	NS	NS	NS
Average of Populations						
Untreated	11.2	4727	238.4	6.27	3.62	73.72
AB-01 Seed Treatment (ST)	11.7	4903	238.4	6.25	3.54	73.75
AB-01 Foliar Spray (FS)	11.2	4688	238.3	6.36	3.67	73.70
AB-01 ST + FS	11.4	4759	239.3	6.24	3.54	73.92
Headline AMP	12.0	5059	237.8	6.28	3.54	73.88
LSD ($\alpha = 0.10$)	0.6	NS	NS	NS	NS	NS
Source of Variation	P > F					
Treatment (T)	0.1037	0.1469	0.9880	0.4652	0.5273	0.8939
Population (P)	0.1860	0.0007	<.0001	<.0001	0.1052	0.0467
T x P	0.5969	0.2873	0.2152	0.2471	0.7533	0.3721

Table 7. Effect of location, management, strigolactone, and source of variation on leaf greenness (NDVI), vegetative shoot and root biomass, and R6 root biomass for corn grown at three locations in IL in 2016.

Treatment factor	NDVI		Biomass		
	V6 [†]	V12	V8		R6
	NDVI Relative Units		Shoot	Root	Root
			g plant ⁻¹		
Location					
Harrisburg	0.23	0.69	35.9	—	—
Champaign	0.25	0.73	8.1	—	—
Yorkville	0.50	—	—	—	—
LSD ($\alpha = 0.10$)	0.02	0.01	0.9	—	—
Management					
Standard	0.29	0.70	20.3	1.4	13.3
Intensive	0.36	0.71	23.6	2.0	8.9
LSD ($\alpha = 0.10$)	0.01	0.01	0.9	0.4	0.6
Strigolactone					
Untreated	0.33	0.71	22.0	1.8	7.46
AB-01 Seed Treatment (ST)	0.32	0.71	21.9	1.6	7.50
LSD ($\alpha = 0.10$)	0.01	NS	NS	0.1	NS
Source of variation					
			<i>P > F</i>		
Location (L)	<.0001	<.0001	<.0001	—	—
Management (M)	<.0001	0.0023	<.0001	<.0251	0.0001
L x M	0.0762	<.0001	0.1252	—	—
Seed Treatment (ST)	0.0025	0.7763	0.7811	<.0444	0.3240
L x ST	0.7036	0.9878	0.0869	—	—
M x ST	0.3421	0.9879	0.8821	0.2373	0.0681
L x M x ST	0.0557	0.4072	0.3390	—	—

[†]V6 NDVI values are transformed.

Table 8. Effect of location, management, foliar fungicide, strigolactone, and source of variation on R3 ear-leaf greenness (SPAD) and R6 above ground stover and total biomass for corn grown at two locations in IL in 2016.

Treatment factor	SPAD	Biomass	
		Stover	Total
	Relative SPAD Units	g plant ⁻¹	
Location			
Harrisburg	55.1	86.7	185.8
Champaign	58.9	103.3	244.5
LSD ($\alpha = 0.10$)	2.5	5.4	7.0
Management			
Standard	57.2	105.6	236.1
Intensive	56.8	84.4	194.2
LSD ($\alpha = 0.10$)	NS	3.5	4.2
Foliar Fungicide			
Untreated	57.2	90.9	207.3
Headline AMP	56.8	99.0	223.0
LSD ($\alpha = 0.10$)	NS	3.3	3.4
Strigolactone			
Untreated	57.5	95.8	216.1
AB-01 Seed Treatment (ST)	57.1	95.0	217.2
AB-01 Foliar Spray (FS)	57.0	91.8	210.3
AB-01 ST + FS	56.4	97.2	217.1
LSD ($\alpha = 0.10$)	NS	NS	5.3
Source of variation			
		<i>P > F</i>	
Location (L)	0.0161	0.0002	<.0001
Management (M)	0.4015	0.0001	<.0001
L x M	0.7177	0.0539	0.7921
Foliar Fungicide (FF)	0.3789	0.0004	<.0001
L x FF	0.8798	0.0169	0.0002
M x FF	0.5270	0.0392	0.2435
L x M x FF	0.0472	0.6843	0.6649
Strigolactone (S)	0.3003	0.1699	0.0968
L x S	0.0074	0.0734	0.4506
M x S	0.2042	0.1885	0.3327
L x M x S	0.7693	0.2726	0.6202
FF x S	0.2129	0.6031	0.6839
L x F x S	0.0840	0.8829	0.9029
M x FF x S	0.5276	0.1201	0.3513
L x M x FF x S	0.1596	0.4254	0.4009

Table 9. Effect of management, strigolactone, and source of variation on leaf greenness (NDVI) and vegetative biomass (V10-V12) for corn grown at Harrisburg, IL in 2016.

Treatment factor	NDVI		Biomass
	V6	V12	Shoot
	NDVI Relative Units		g plant ⁻¹
Management			
Standard	0.42	0.69	34.7
Intensive	0.52	0.69	37.1
LSD ($\alpha = 0.10$)	0.02	NS	1.8
Strigolactone			
Untreated	0.47	0.69	36.3
AB-01 Seed Treatment (ST)	0.47	0.69	35.4
LSD ($\alpha = 0.10$)	NS	NS	NS
Source of variation			
	<i>P > F</i>		
Management (M)	<.0001	0.2120	0.0293
Seed Treatment (ST)	0.1815	0.8650	0.4339
M x ST	0.4114	0.6439	0.5504

Table 10. Effect of management, foliar fungicide, strigolactone, and source of variation on R3 ear-leaf greenness (SPAD) and R6 stover and total biomass for corn grown at Harrisburg, IL in 2016.

Treatment factor	SPAD	Biomass	
		Stover	Total
	Relative SPAD Units	g plant ⁻¹	
Management			
Standard	55.4	100.3	206.3
Intensive	54.7	75.0	165.2
LSD ($\alpha = 0.10$)	NS	5.6	7.3
Foliar Fungicide			
Untreated	55.2	79.9	173.6
Headline AMP	54.9	95.4	198.0
LSD ($\alpha = 0.10$)	NS	5.9	6.6
Strigolactone			
Untreated	55.6	91.1	188.9
AB-01 Seed Treatment (ST)	55.5	89.3	188.8
AB-01 Foliar Spray (FS)	55.8	81.1	186.9
AB-01 ST + FS	53.4	89.0	178.5
LSD ($\alpha = 0.10$)	1.3	NS	NS
Source of variation			
		<i>P > F</i>	
Management (M)	0.2212	<.0001	<.0001
Foliar Fungicide (FF)	0.3805	0.0007	<.0001
M x FF	0.1281	0.3303	0.7220
Strigolactone (S)	0.0069	0.1739	0.1363
M x S	0.2222	0.4979	0.6053
FF x S	0.2615	0.9161	0.8786
M x FF x S	0.3667	0.2846	0.2286

Table 11. Interaction of management and strigolactone seed treatment on leaf greenness (NDVI), and vegetative shoot biomass for corn grown at Harrisburg, IL in 2016.

Management	Strigolactone	NDVI		Biomass
		V6	V12	Shoot
		NDVI Relative Units		g plant ⁻¹
Standard	Untreated	0.42	0.69	34.8
	AB-01 Seed Treatment (ST)	0.42	0.69	34.6
Intensive	Untreated	0.53	0.69	37.8
	AB-01 Seed Treatment (ST)	0.52	0.69	36.3
LSD ($\alpha = 0.10$)		NS	NS	NS

Table 12. Interaction of management and strigolactone on R3 ear-leaf greenness (SPAD) and R6 stover and total biomass for corn grown at Harrisburg, IL in 2016 averaged over all foliar fungicide treatments.

Management	Strigolactone	SPAD Relative SPAD Units	Biomass	
			Stover	Total
			g plant ⁻¹	
Standard	Untreated	54.9	107.9	211.5
	AB-01 Seed Treatment (ST)	56.0	102.2	211.8
	AB-01 Foliar Spray (FS)	56.6	91.3	198.1
	AB-01 ST + FS	54.1	99.5	203.9
Intensive	Untreated	56.2	74.3	166.4
	AB-01 Seed Treatment (ST)	55.0	76.4	165.8
	AB-01 Foliar Spray (FS)	55.1	70.9	158.9
	AB-01 ST + FS	52.6	78.5	169.9
LSD ($\alpha = 0.10$)		NS	NS	NS

Table 13. Interaction of foliar fungicide and strigolactone on R3 ear-leaf greenness (SPAD) and R6 stover and total biomass for corn grown at Harrisburg, IL in 2016 averaged over all management.

Foliar Fungicide	Strigolactone	SPAD Relative SPAD Units	Biomass	
			Stover	Total
			g plant ⁻¹	
Untreated	Untreated	55.5	85.4	178.9
	AB-01 Seed Treatment (ST)	56.5	80.5	177.1
	AB-01 Foliar Spray (FS)	55.3	73.3	165.5
	AB-01 ST + FS	53.6	80.4	173.0
Headline AMP	Untreated	55.6	96.9	199.0
	AB-01 Seed Treatment (ST)	54.5	98.1	200.4
	AB-01 Foliar Spray (FS)	56.4	88.9	191.5
	AB-01 ST + FS	53.1	97.7	200.9
LSD ($\alpha = 0.10$)		NS	NS	NS

Table 14. Interaction of management, foliar fungicide, and strigolactone treatments on R3 ear-leaf greenness (SPAD) and R6 stover and total biomass for corn grown at Harrisburg, IL during 2016.

Management	Strigolactone	Biomass					
		SPAD		Stover		Total	
		- Foliar Fungicide	+ Foliar Fungicide	- Foliar Fungicide	+ Foliar Fungicide	- Foliar Fungicide	+ Foliar Fungicide
		-Relative SPAD Units -		g plant ⁻¹			
Standard	Untreated	54.8	55.0	104	112	201	222
	AB-01 Seed Treatment (ST)	58.1	54.0	90	114	196	227
	AB-01 Foliar Spray (FS)	56.5	56.7	90	93	192	205
	AB-01 ST + FS	54.1	54.1	93	106	190	218
Intensive	Untreated	56.2	56.2	67	82	157	176
	AB-01 Seed Treatment (ST)	55.0	55.1	71	82	158	174
	AB-01 Foliar Spray (FS)	54.0	56.1	57	85	139	178
	AB-01 ST + FS	53.1	52.1	67	90	156	184
	LSD ($\alpha = 0.10$)	NS		NS		NS	

Table 15. Effect of management, strigolactone, and source of variation on leaf greenness (NDVI), vegetative shoot and root biomass, and R6 root biomass for corn grown at Champaign, IL in 2016.

Treatment factor	NDVI		Biomass		
	V6	V12	V8	R6	R6
	NDVI Relative Units		Shoot	Root	Root
			g plant ⁻¹		
Management					
Standard	0.46	0.73	6.0	1.4	13.3
Intensive	0.54	0.74	10.1	2.0	8.9
LSD ($\alpha = 0.10$)	0.03	0.01	0.9	0.4	0.6
Strigolactone					
Untreated	0.50	0.73	8.6	1.8	7.46
AB-01 Seed Treatment (ST)	0.49	0.73	7.5	1.6	7.50
LSD ($\alpha = 0.10$)	NS	NS	0.6	0.1	NS
Source of variation			<i>P > F</i>		
Management (M)	0.0003	<.0001	<.0001	<.0251	0.0001
Seed Treatment (ST)	0.3184	0.7780	0.0042	<.0444	0.3240
M x ST	0.0368	0.3767	0.1903	0.2373	0.0681

Table 16. Interaction of management and strigolactone seed treatment on leaf greenness (NDVI), vegetative shoot and root biomass, and R6 root biomass for corn grown at Champaign, IL in 2016.

Management	Strigolactone	NDVI		Biomass		
		V6	V12	Shoot	Root	R6
		NDVI Relative Units		g plant ⁻¹		
Standard	Untreated	0.47	0.73	6.3	1.4	13.4
	AB-01 Seed Treatment (ST)	0.45	0.73	5.7	1.4	13.2
Intensive	Untreated	0.53	0.74	10.9	2.1	8.5
	AB-01 Seed Treatment (ST)	0.54	0.74	9.3	1.8	9.3
	LSD ($\alpha = 0.10$)	0.02	NS	NS	NS	0.7

Table 17. Effect of management, foliar fungicide, strigolactone, and source of variation on R3 ear-leaf greenness (SPAD) and R6 stover and total biomass for corn grown at Champaign, IL in 2016.

Treatment factor	SPAD	Biomass	
		Stover	Total
	Relative SPAD Units	g plant ⁻¹	
Management			
Standard	59.6	111.8	264.9
Intensive	58.8	94.8	223.3
LSD ($\alpha = 0.10$)	NS	2.2	4.5
Foliar Fungicide			
Untreated	59.4	101.8	240.1
Headline AMP	58.9	104.9	248.0
LSD ($\alpha = 0.10$)	NS	3.1	2.8
Strigolactone			
Untreated	59.8	100.4	242.7
AB-01 Seed Treatment (ST)	59.6	105.3	245.5
AB-01 Foliar Spray (FS)	59.5	102.2	240.6
AB-01 ST + FS	57.8	105.6	247.3
LSD ($\alpha = 0.10$)	NS	NS	NS
Source of variation			
		<i>P > F</i>	
Management (M)	0.5407	<.0001	<.0001
Foliar Fungicide (FF)	0.4682	0.0962	0.0002
M x FF	0.1659	0.0097	0.1209
Strigolactone (S)	0.1678	0.1782	0.2660
M x S	0.3308	0.0924	0.0758
FF x S	0.1063	0.6938	0.3325
M x FF x S	0.1086	0.4563	0.6900

Table 18. Interaction of management and strigolactone on R3 ear-leaf greenness (SPAD) and R6 stover and total biomass for corn grown at Champaign, IL in 2016 averaged over all foliar fungicide treatments.

Management	Strigolactone	SPAD Relative SPAD Units	Biomass	
			Stover	Total
			g plant ⁻¹	
Standard	Untreated	59.9	109.2	266.8
	AB-01 Seed Treatment (ST)	60.9	113.6	267.0
	AB-01 Foliar Spray (FS)	57.2	107.1	255.8
	AB-01 ST + FS	60.2	117.4	269.8
Intensive	Untreated	59.7	91.6	218.6
	AB-01 Seed Treatment (ST)	58.4	96.9	224.0
	AB-01 Foliar Spray (FS)	58.3	97.3	225.5
	AB-01 ST + FS	58.8	93.5	224.9
LSD ($\alpha = 0.10$)		NS	6.1	8.4

Table 19. Interaction of foliar fungicide and strigolactone on R3 ear-leaf greenness (SPAD) and R6 stover and total biomass for corn grown at Champaign, IL in 2016 averaged over all management treatments.

Foliar Fungicide	Strigolactone	SPAD Relative SPAD Units	Biomass	
			Stover	Total
			g plant ⁻¹	
Untreated	Untreated	58.7	100.7	239.6
	AB-01 Seed Treatment (ST)	60.3	103.4	244.7
	AB-01 Foliar Spray (FS)	58.0	99.4	233.2
	AB-01 ST + FS	60.8	103.6	242.9
Headline AMP	Untreated	61.0	100.1	245.9
	AB-01 Seed Treatment (ST)	58.9	107.2	246.4
	AB-01 Foliar Spray (FS)	57.6	105.0	248.1
	AB-01 ST + FS	58.2	107.3	251.7
LSD ($\alpha = 0.10$)		2.4	NS	NS

Table 20. Interaction of management, foliar fungicide, and strigolactone treatments on R3 ear-leaf greenness (SPAD) and R6 stover and total biomass for corn grown at Champaign, IL during 2016.

Management	Strigolactone	Biomass					
		SPAD		Stover		Total	
		- Foliar Fungicide	+ Foliar Fungicide	- Foliar Fungicide	+ Foliar Fungicide	- Foliar Fungicide	+ Foliar Fungicide
		-Relative SPAD Units -		g plant ⁻¹			
Standard	Untreated	58.3	61.5	114	104	267	267
	AB-01 Seed Treatment (ST)	62.1	59.7	112	115	268	266
	AB-01 Foliar Spray (FS)	55.5	59.0	107	108	249	262
	AB-01 ST + FS	61.3	59.0	118	116	265	275
Intensive	Untreated	59.0	60.4	87	96	212	225
	AB-01 Seed Treatment (ST)	58.6	58.2	94	99	221	227
	AB-01 Foliar Spray (FS)	60.4	56.2	92	102	217	234
	AB-01 ST + FS	60.2	57.4	89	98	221	228
	LSD ($\alpha = 0.10$)	3.5		NS		NS	

Table 21. Effect of location, management, foliar fungicide, strigolactone, and source of variation on grain yield, yield component, and grain quality for corn grown at two locations in IL in 2016. Grain yield and kernel weight is presented at 0 % moisture.

Treatment factor	Yield Mg ha ⁻¹	Yield Components		Grain Quality		
		Kernel Number number m ⁻²	Kernel Weight mg seed ⁻¹	Oil	Protein	Starch
				———— % ————		
Location						
Harrisburg	9.2	—	—	3.66	7.42	71.35
Champaign	12.9	—	—	3.85	7.53	71.39
LSD ($\alpha = 0.10$)	0.2	—	—	0.03	0.09	NS
Management						
Standard	10.6	4540	268.3	3.89	7.40	71.23
Intensive	11.5	5387	251.4	3.62	7.55	71.51
LSD ($\alpha = 0.10$)	0.2	59	3.9	0.05	0.08	0.18
Foliar Fungicide						
Untreated	10.8	4983	254.2	3.69	7.52	71.43
Headline AMP	11.3	4944	265.5	3.82	7.43	71.30
LSD ($\alpha = 0.10$)	0.1	NS	3.2	0.04	0.05	0.11
Strigolactone						
Untreated	11.1	5017	260.3	3.70	7.46	71.46
AB-01 Seed Treatment (ST)	11.1	4914	261.1	3.76	7.50	71.37
AB-01 Foliar Spray (FS)	11.0	4972	257.8	3.75	7.41	71.38
AB-01 ST + FS	11.1	4951	260.1	3.80	7.54	71.27
LSD ($\alpha = 0.10$)	NS	NS	NS	0.06	0.06	NS
Source of variation						
		———— <i>P > F</i> ————				
Location (L)	<.0001	—	—	<.0001	0.0511	0.6353
Management (M)	<.0001	<.0001	<.0001	<.0001	0.0053	0.0132
L x M	<.0001	—	—	0.8715	0.1432	0.4886
Foliar Fungicide (FF)	<.0001	0.2706	<.0001	<.0001	0.0116	0.0440
L x FF	0.2438	—	—	0.0413	0.0003	0.6663
M x FF	0.6559	0.7334	0.9493	0.2293	0.4105	0.5629
L x M x FF	0.2332	—	—	0.0020	0.2404	0.0012
Strigolactone (S)	0.1502	0.2199	0.3287	0.0577	0.0046	0.2125
L x S	0.1354	—	—	0.0233	0.1961	0.0842
M x S	0.3306	0.7314	0.8131	0.2694	0.0544	0.4503
L x M x S	0.3362	—	—	0.1908	0.1472	0.3933
FF x S	0.4604	0.1390	0.5523	0.3044	0.2445	0.5318
L x F x S	0.3478	—	—	0.3770	0.9297	0.6654
M x FF x S	0.1669	0.3002	0.6327	0.8298	0.0872	0.7504
L x M x FF x S	0.0756	—	—	0.9391	0.2374	0.8042

Table 22. Effect of management, foliar fungicide, strigolactone, and source of variation on grain yield and grain quality for corn grown at Harrisburg, IL in 2016. Grain yield is presented at 0 % moisture.

Treatment factor	Yield Mg ha ⁻¹	Grain Quality		
		Oil	Protein	Starch
		%		
Management				
Standard	8.9	3.78	7.29	71.24
Intensive	9.5	3.53	7.53	71.46
LSD ($\alpha = 0.10$)	0.3	0.08	0.12	NS
Foliar Fungicide				
Untreated	8.9	3.57	7.50	71.40
Headline AMP	9.5	3.77	7.32	71.30
LSD ($\alpha = 0.10$)	0.1	0.06	0.08	NS
Strigolactone				
Untreated	9.2	3.55	7.38	71.52
AB-01 Seed Treatment (ST)	9.2	3.64	7.46	71.41
AB-01 Foliar Spray (FS)	9.1	3.67	7.29	71.33
AB-01 ST + FS	9.2	3.79	7.50	71.13
LSD ($\alpha = 0.10$)	NS	0.09	0.12	0.20
Source of variation				
		<i>P > F</i>		
Management (M)	0.0009	0.0013	0.0061	0.1218
Foliar Fungicide (FF)	<.0001	0.0002	0.0012	0.2424
M x FF	0.2759	0.0043	0.7042	0.0450
Strigolactone (S)	0.6663	0.0004	0.0274	0.0157
M x S	0.2886	0.2135	0.2842	0.3914
FF x S	0.5210	0.6206	0.3379	0.8072
M x FF x S	0.9293	0.5516	0.2586	0.7255

Table 23. Interaction of management, foliar fungicide, and strigolactone treatments on grain yield, yield components, and grain quality for corn grown at Harrisburg, IL during 2016. Grain yield and kernel weight is presented at 0% moisture.

Management	Strigolactone	Grain Quality							
		Yield		Oil		Protein		Starch	
		- FF	+ FF	- FF	+ FF	- FF	+ FF	- FF	+ FF
		— Mg ha ⁻¹ —		%					
Standard	Untreated	8.5	9.1	3.70	3.75	7.23	7.15	71.33	71.43
	AB-01 Seed Treatment (ST)	8.8	9.3	3.68	3.77	7.49	7.18	71.36	71.45
	AB-01 Foliar Spray (FS)	8.7	9.0	3.80	3.85	7.38	7.10	71.10	71.15
	AB-01 ST + FS	8.7	9.3	3.85	3.90	7.60	7.40	71.00	71.10
Intensive	Untreated	9.2	9.9	3.23	3.53	7.81	7.35	71.76	71.58
	AB-01 Seed Treatment (ST)	9.1	9.7	3.44	3.68	7.68	7.49	71.58	71.25
	AB-01 Foliar Spray (FS)	9.2	9.8	3.41	3.63	7.48	7.30	71.58	71.49
	AB-01 ST + FS	9.1	9.9	3.46	3.85	7.54	7.58	71.50	70.93
LSD ($\alpha = 0.10$)		NS		NS		NS		NS	

FF indicates the application of the foliar fungicide Headline AMP.

Table 24. Effect of management, foliar fungicide, strigolactone, and source of variation on grain yield, yield component, and grain quality for corn grown at Champaign, IL in 2016. Grain yield and kernel weight is presented at 0 % moisture.

Treatment factor	Yield Components			Grain Quality		
	Yield	Kernel Number	Kernel Weight	Oil	Protein	Starch
	Mg ha ⁻¹	number m ⁻²	mg seed ⁻¹	%		
Management						
Standard	12.5	4540	268.3	3.98	7.49	71.21
Intensive	13.4	5387	251.4	3.72	7.57	71.57
LSD ($\alpha = 0.10$)	0.5	59	3.9	0.05	NS	0.31
Foliar Fungicide						
Untreated	12.7	4983	254.2	3.82	7.51	71.47
Headline AMP	13.2	4944	265.5	3.89	7.55	71.31
LSD ($\alpha = 0.10$)	0.2	NS	3.2	0.06	NS	0.16
Strigolactone						
Untreated	13.1	5017	260.3	3.85	7.53	71.40
AB-01 Seed Treatment (ST)	13.0	4914	261.1	3.88	7.53	71.33
AB-01 Foliar Spray (FS)	12.8	4972	257.8	3.83	7.50	71.43
AB-01 ST + FS	12.9	4951	260.1	3.84	7.57	71.41
LSD ($\alpha = 0.10$)	0.2	NS	NS	NS	NS	NS
Source of variation						
		$P > F$				
Management (M)	0.0014	<.0001	<.0001	<.0001	0.2786	0.0610
Foliar Fungicide (FF)	0.0001	0.2706	<.0001	0.0398	0.2003	0.1017
M x FF	0.6738	0.7334	0.9493	0.1112	0.0922	0.0120
Strigolactone (S)	0.006	0.2199	0.3287	0.7712	0.4805	0.8434
M x S	0.0167	0.7314	0.8131	0.1554	0.1802	0.4517
FF x S	0.2672	0.1390	0.5523	0.1101	0.5516	0.4383
M x FF x S	0.0204	0.3002	0.6327	0.9517	0.5463	0.8236

Table 25. Effect of management and strigolactone on grain yield, yield components, and grain quality for corn grown at Champaign, IL during 2016 averaged over all foliar fungicide treatments. Grain yield and kernel weight is presented at 0% moisture.

Management	Strigolactone	Yield	Yield Components		Grain Quality		
			Kernel Number	Kernel Weight	Oil	Protein	Starch
		Mg ha ⁻¹	number m ⁻²	mg seed ⁻¹	%		
Standard	Untreated	12.8	4624	267.8	3.95	7.46	71.28
	AB-01 Seed Treatment (ST)	12.5	4494	270.1	4.04	7.54	71.07
	AB-01 Foliar Spray (FS)	12.2	4527	266.1	4.02	7.44	71.18
	AB-01 ST + FS	12.3	4514	269.1	3.93	7.52	71.31
Intensive	Untreated	13.4	5409	252.9	3.75	7.60	71.51
	AB-01 Seed Treatment (ST)	13.5	5334	252.2	3.72	7.53	71.58
	AB-01 Foliar Spray (FS)	13.4	5417	249.6	3.64	7.55	71.69
	AB-01 ST + FS	13.4	5387	251.1	3.76	7.59	71.51
	LSD ($\alpha = 0.10$)	0.4	NS	NS	NS	NS	NS

Table 26. Interaction of management, foliar fungicide, and strigolactone treatments on grain yield, yield components, and grain quality for corn grown at Champaign, IL during 2016. Grain yield and kernel weight is presented at 0% moisture.

Management	Strigolactone	Yield Components						Grain Quality					
		Yield		Kernel Number		Kernel Weight		Oil		Protein		Starch	
		- FF	+ FF	- FF	+ FF	- FF	+ FF	- FF	+ FF	- FF	+ FF	- FF	+ FF
		— Mg ha ⁻¹ —		— number m ⁻² —		— mg seed ⁻¹ —		%					
Standard	Untreated	12.6	12.9	4601	4646	264.5	271.1	3.91	3.99	7.40	7.51	71.44	71.13
	AB-01 Seed Treatment (ST)	12.4	12.6	4634	4354	264.2	276.0	3.91	4.18	7.49	7.60	71.41	70.73
	AB-01 Foliar Spray (FS)	11.8	12.6	4514	4540	259.5	272.6	4.00	4.04	7.44	7.45	71.36	71.00
	AB-01 ST + FS	11.9	12.8	4464	4564	261.9	276.3	3.88	3.98	7.43	7.61	71.48	71.15
Intensive	Untreated	13.2	13.6	5443	5375	247.7	258.0	3.79	3.71	7.64	7.56	71.30	71.73
	AB-01 Seed Treatment (ST)	13.1	13.8	5373	5295	245.0	259.4	3.63	3.80	7.55	7.50	71.60	71.56
	AB-01 Foliar Spray (FS)	13.2	13.6	5427	5406	245.0	254.2	3.67	3.60	7.54	7.56	71.70	71.68
	AB-01 ST + FS	13.2	13.6	5406	5369	245.5	256.7	3.73	3.79	7.58	7.61	71.49	71.54
LSD ($\alpha = 0.10$)		0.5		NS		NS		NS		NS		NS	

FF indicates the application of the foliar fungicide Headline AMP.

Table 27. Effect of location, hybrid, strigolactone seed treatment, and source of variation on leaf greenness and plant biomass accumulation (V8-12 and R6) for corn grown at three locations in IL in 2016 averaged.

Treatment factor	Leaf Greenness			Biomass				
	V6	V12	R3	V8-V12		R6		
	–NDVI Units –		SPAD Units	Shoot	Root	Stover	Total	Root
			g plant ⁻¹					
Location								
Harrisburg	0.46	0.67	55.8	29.3	—	97.0	189.9	—
Champaign	0.44	0.71	57.0	6.3	—	114.8	247.2	—
Yorkville	0.70	—	55.8	—	—	119.5	253.7	—
LSD ($\alpha = 0.10$)	0.02	0.01	0.7	1.1	—	5.7	8.6	—
Hybrid								
DKC61-54RIB	0.53	0.70	53.2	13.2	1.3	103.4	223.4	9.6
G10T63-3000GT	0.55	0.69	54.0	15.5	1.7	124.6	248.7	10.0
DKC63-71RIB	0.51	0.69	57.3	11.7	1.1	96.5	214.3	12.6
G11K47-GT	0.54	0.69	60.3	14.2	1.5	117.2	234.6	12.2
LSD ($\alpha = 0.10$)	0.01	0.01	0.8	1.0	0.2	5.5	6.9	1.0
Strigolactone								
Untreated	0.54	0.69	56.5	13.4	1.4	109.2	228.5	11.1
AB-01 Seed Treatment	0.53	0.69	55.8	13.7	1.4	111.6	232.0	11.1
LSD ($\alpha = 0.10$)	NS	NS	0.6	NS	NS	NS	NS	NS
Source of variation								
	$P > F$							
Location (L)	<.0001	<.0001	0.0087	<.0001	—	<.0001	<.0001	—
Hybrid (H)	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
L x H	0.0002	0.4818	0.0020	0.0013	—	0.0073	0.0614	—
Strigolactone (S)	0.3344	0.3211	0.0592	0.1568	0.4734	0.2988	0.2439	0.8720
L x S	0.9478	0.3471	0.4202	0.1527	—	0.9159	0.9655	—
H x S	0.4531	0.2995	0.3343	0.1971	0.7634	0.2083	0.6910	0.7413
L x H x S	0.0430	0.6835	0.6593	0.8666	—	0.3374	0.2799	—

Table 28. Effect of hybrid, strigolactone seed treatment, and source of variation on leaf greenness and plant biomass accumulation (V10-12 and R6) for corn grown at Harrisburg, IL in 2016.

Treatment factor	Leaf Greenness		Biomass			
	V6	V12	R3	V10-V12	R6	Total
	—NDVI Units—		SPAD Units	g plant ⁻¹		
Hybrid						
DKC61-54RIB	0.45	0.68	51.3	28.4	92.1	187.7
G10T63-3000GT	0.49	0.67	54.5	33.2	112.9	210.9
DKC63-71RIB	0.44	0.67	57.4	26.9	77.7	166.5
G11K47-GT	0.47	0.66	60.0	29.7	105.0	194.4
LSD ($\alpha = 0.10$)	0.01	0.01	1.8	1.9	10.9	12.4
Strigolactone						
Untreated	0.46	0.67	56.4	28.8	96.2	188.7
AB-01 Seed Treatment	0.46	0.67	55.1	30.3	97.7	191.0
LSD ($\alpha = 0.10$)	NS	NS	1.3	1.4	NS	NS
Source of variation	$P > F$					
Hybrid (H)	<.0001	0.0163	<.0001	<.0001	<.0001	<.0001
Strigolactone (S)	0.5290	0.9611	0.0958	0.0718	0.7425	0.6551
H x S	0.2229	0.3059	0.4293	0.7080	0.2452	0.3374

Table 29. Effect of hybrid, strigolactone seed treatment, and source of variation on leaf greenness and plant biomass accumulation (V8-10 and R6) for corn grown at Champaign, IL in 2016.

Treatment factor	Leaf Greenness			Biomass				
	V6	V12	R3	V8-V10		R6		
	—NDVI Units —		SPAD Units	Shoot	Root	Stover	Total	Root
				g plant ⁻¹				
Hybrid								
DKC61-54RIB	0.43	0.72	55.3	6.1	1.3	101.9	235.2	9.6
G10T63-3000GT	0.46	0.71	53.5	7.4	1.7	121.9	257.9	10.0
DKC63-71RIB	0.42	0.70	58.4	5.1	1.1	109.8	237.7	12.6
G11K47-GT	0.45	0.71	60.7	6.9	1.5	125.6	257.7	12.2
LSD ($\alpha = 0.10$)	0.02	0.01	1.3	0.3	0.2	8.2	10.3	1.0
Strigolactone								
Untreated	0.44	0.71	57.1	6.4	1.4	112.3	245.1	11.1
AB-01 Seed Treatment	0.44	0.71	56.9	6.4	1.4	116.7	249.2	11.1
LSD ($\alpha = 0.10$)	NS	NS	NS	NS	NS	NS	NS	NS
Source of variation								
	P > F							
Hybrid (H)	<.0001	0.0163	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Strigolactone (S)	0.5505	0.2494	0.6751	0.8458	0.4734	0.2758	0.3407	0.8720
H x S	0.0968	0.5440	0.2816	0.1977	0.7634	0.4767	0.6841	0.7413

Table 30. Effect of hybrid, strigolactone seed treatment, and source of variation on leaf greenness and R6 plant biomass accumulation for corn grown at Yorkville, IL in 2016.

Treatment factor	Leaf Greenness		Biomass	
	V6 NDVI Units	R3 SPAD Units	Stover g plant ⁻¹	Total
Hybrid				
DKC61-54RIB	0.71	53.0	116.1	247.2
G10T63-3000GT	0.70	54.0	138.6	272.4
DKC63-71RIB	0.69	56.0	102.1	238.6
G11K47-GT	0.71	60.3	120.5	250.9
LSD ($\alpha = 0.10$)	0.01	1.1	9.6	10.3
Strigolactone				
Untreated	0.70	56.1	118.4	251.3
AB-01 Seed Treatment	0.70	55.6	120.2	252.8
LSD ($\alpha = 0.10$)	NS	NS	NS	NS
Source of variation				
	<i>P > F</i>			
Hybrid (H)	0.0023	<.0001	<.0001	<.0001
Strigolactone (S)	0.6714	0.2823	0.6463	0.3407
H x S	0.4337	0.9991	0.2695	0.6841

Table 31. Interaction of hybrid and strigolactone seed treatment on leaf greenness and plant biomass accumulation (V10-12 and R6) for corn grown at Harrisburg, IL in 2016.

Hybrid	Strigolactone	Leaf Greenness			Biomass		
		V6	V12	R3	V10-V12	R6	Total
		–NDVI Units –		SPAD Units	g plant ⁻¹		
DKC61-54RIB	Untreated	0.50	0.69	52.0	28.3	91.0	187.2
	AB-01 Seed Treatment	0.48	0.68	50.6	28.6	93.3	188.1
G10T63-3000GT	Untreated	0.47	0.67	55.3	32.7	119.9	216.9
	AB-01 Seed Treatment	0.47	0.67	53.7	33.6	106.0	205.0
DKC63-71RIB	Untreated	0.45	0.66	57.1	25.6	74.7	159.0
	AB-01 Seed Treatment	0.44	0.67	57.8	28.1	80.7	174.0
G11K47-GT	Untreated	0.44	0.66	61.4	28.5	99.2	191.6
	AB-01 Seed Treatment	0.43	0.67	58.5	30.9	110.8	197.1
LSD ($\alpha = 0.10$)		NS	NS	NS	NS	NS	NS

Table 32. Interaction of hybrid and strigolactone seed treatment on leaf greenness and plant biomass accumulation (V8-10 and R6) for corn grown at Champaign, IL in 2016.

Hybrid	Strigolactone	Leaf Greenness			Biomass				
		V6	V12	R3	V8-V10		R6		
		–NDVI Units –		SPAD Units	Shoot	Root	Stover	Total	Root
DKC61-54RIB	Untreated	0.47	0.72	55.6	6.2	1.3	99.0	231.3	9.4
	AB-01 Seed Treatment	0.46	0.72	55.0	6.1	1.4	104.7	239.2	9.8
G10T63-3000GT	Untreated	0.46	0.70	52.8	7.6	1.7	119.9	256.8	10.4
	AB-01 Seed Treatment	0.44	0.71	54.2	7.1	1.7	123.9	259.1	9.6
DKC63-71RIB	Untreated	0.43	0.71	58.6	5.0	1.1	112.3	239.5	12.5
	AB-01 Seed Treatment	0.43	0.70	58.3	5.2	1.1	107.3	235.8	12.7
G11K47-GT	Untreated	0.42	0.71	61.5	6.8	1.4	120.4	252.6	12.4
	AB-01 Seed Treatment	0.40	0.71	60.0	7.0	1.5	130.8	262.8	12.1
LSD ($\alpha = 0.10$)		0.02	NS	NS	NS	NS	NS	NS	NS

Table 33. Interaction of hybrid and strigolactone seed treatment on leaf greenness and R6 plant biomass accumulation for corn grown at Yorkville, IL in 2016.

Hybrid	Strigolactone	Leaf Greenness		Biomass	
		V6	R3	Stover	Total
		NDVI Units	SPAD Units	g plant ⁻¹	
DKC61-54RIB	Untreated	0.71	53.3	118.0	250.1
	AB-01 Seed Treatment	0.71	52.7	114.2	244.4
G10T63-3000GT	Untreated	0.71	54.2	134.1	269.6
	AB-01 Seed Treatment	0.71	53.8	143.1	275.1
DKC63-71RIB	Untreated	0.71	56.2	106.2	242.4
	AB-01 Seed Treatment	0.70	55.7	97.9	234.7
G11K47-GT	Untreated	0.69	60.6	115.1	244.8
	AB-01 Seed Treatment	0.69	60.0	125.8	257.0
LSD ($\alpha = 0.10$)		NS	NS	NS	NS

Table 34. Effect of location, hybrid, strigolactone seed treatment, and source of variation on grain yield, yield component, and grain quality for corn grown at three locations in IL in 2016. Grain yield and kernel weight is presented at 0 % moisture.

Treatment factor	Yield Components			Grain Quality		
	Yield	Kernel Number	Kernel Weight	Oil	Protein	Starch
	Mg ha ⁻¹	number m ⁻²	mg seed ⁻¹	%		
Location						
Harrisburg	8.2	3866	212.4	3.84	6.76	71.67
Champaign	12.1	4955	244.6	3.73	7.06	72.01
Yorkville	11.9	4759	250.1	3.75	7.76	72.07
LSD ($\alpha = 0.10$)	0.2	79	3.7	0.05	0.10	0.16
Hybrid						
DKC61-54RIB	11.2	4480	242.5	3.60	7.23	72.30
G10T63-3000GT	11.1	4717	231.9	3.87	7.34	71.77
DKC63-71RIB	10.6	4337	240.7	3.59	6.72	72.36
G11K47-GT	10.7	4573	227.8	4.02	7.48	71.23
LSD ($\alpha = 0.10$)	0.2	86	2.5	0.07	0.10	0.19
Strigolactone						
Untreated	10.9	4543	235.5	3.74	7.18	71.97
AB-01 Seed Treatment	10.9	4510	235.9	3.80	7.21	71.85
LSD ($\alpha = 0.10$)	NS	NS	NS	0.05	NS	NS
Source of variation						
	<i>P > F</i>					
Location (L)	<.0001	<.0001	<.0001	0.0011	<.0001	0.0001
Hybrid (H)	<.0001	0.0005	0.0650	<.0001	<.0001	<.0001
L x H	0.4274	0.0047	0.0016	0.0006	0.0024	0.5202
Strigolactone (S)	0.3335	0.4378	0.7400	0.0636	0.5111	0.1305
L x S	0.8093	0.9974	0.4471	0.2377	0.1223	0.1552
H x S	0.9184	0.4518	0.8295	0.8409	0.2487	0.7136
L x H x S	0.8782	0.1848	0.9707	0.2907	0.2881	0.1851

Table 35. Effect of hybrid, strigolactone seed treatment, and source of variation on grain yield, yield component, and grain quality for corn grown at Harrisburg, IL in 2016. Grain yield and kernel weight is presented at 0 % moisture.

Treatment factor	Yield Components			Grain Quality		
	Yield	Kernel Number	Kernel Weight	Oil	Protein	Starch
	Mg ha ⁻¹	number m ⁻²	mg seed ⁻¹	%		
Hybrid						
DKC61-54RIB	8.6	3826	221.8	3.64	6.94	71.97
G10T63-3000GT	8.6	4128	208.9	4.10	6.76	71.44
DKC63-71RIB	8.1	3743	215.1	3.57	6.26	72.13
G11K47-GT	7.9	3863	204.0	4.06	6.94	71.12
LSD ($\alpha = 0.10$)	0.2	113	3.8	0.12	0.24	0.33
Strigolactone						
Untreated	8.4	3904	213.4	3.85	6.74	71.62
AB-01 Seed Treatment	8.2	3876	211.5	3.84	6.71	71.72
LSD ($\alpha = 0.10$)	0.1	NS	NS	NS	NS	NS
Source of variation	<i>P > F</i>					
Hybrid (H)	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Strigolactone (S)	0.0826	0.5689	0.2380	0.8019	0.8052	0.4994
H x S	0.8152	0.5007	0.8593	0.8228	0.8313	0.8110

Table 36. Effect of hybrid, strigolactone seed treatment, and source of variation on grain yield, yield component, and grain quality for corn grown at Champaign, IL in 2016. Grain yield and kernel weight is presented at 0 % moisture.

Treatment factor	Yield Components			Grain Quality		
	Yield	Kernel Number	Kernel Weight	Oil	Protein	Starch
	Mg ha ⁻¹	number m ⁻²	mg seed ⁻¹	%		
Hybrid						
DKC61-54RIB	12.4	4934	249.8	3.55	7.00	72.49
G10T63-3000GT	12.3	5241	234.6	3.90	7.19	71.79
DKC63-71RIB	11.8	4591	257.3	3.60	6.67	72.38
G11K47-GT	12.0	5055	236.7	3.95	7.38	71.36
LSD ($\alpha = 0.10$)	0.3	135	4.5	0.14	0.10	0.31
Strigolactone						
Untreated	12.1	4971	243.2	3.71	7.01	72.10
AB-01 Seed Treatment	12.1	4939	245.9	3.79	7.11	71.91
LSD ($\alpha = 0.10$)	NS	NS	NS	NS	0.07	NS
Source of variation	$P > F$					
Hybrid (H)	0.0061	<.0001	<.0001	<.0001	<.0001	<.0001
Strigolactone (S)	0.7932	0.5773	0.1647	0.1763	0.0357	0.1451
H x S	0.9095	0.8241	0.2817	0.6952	0.0900	0.6019

Table 37. Effect of hybrid, strigolactone seed treatment, and source of variation on grain yield, yield component, and grain quality for corn grown at Yorkville, IL in 2016. Grain yield and kernel weight is presented at 0 % moisture.

Treatment factor	Yield Components			Grain Quality		
	Yield	Kernel Number	Kernel Weight	Oil	Protein	Starch
	Mg ha ⁻¹	number m ⁻²	mg seed ⁻¹	%		
Hybrid						
DKC61-54RIB	12.0	4613	253.8	3.61	7.76	72.45
G10T63-3000GT	11.9	4723	252.2	3.70	8.21	72.06
DKC63-71RIB	11.5	4603	249.8	3.61	7.08	72.56
G11K47-GT	11.9	4898	242.9	4.02	8.02	71.21
LSD ($\alpha = 0.10$)	NS	NS	5.5	0.14	0.11	0.36
Strigolactone						
Untreated	11.9	4747	249.9	3.69	7.72	72.20
AB-01 Seed Treatment	11.8	4671	249.4	3.78	7.82	71.93
LSD ($\alpha = 0.10$)	NS	NS	NS	NS	0.08	0.25
Source of variation	<i>P > F</i>					
Hybrid (H)	0.4924	<.1197	<.0099	<.0001	<.0001	<.0001
Strigolactone (S)	0.7712	0.4235	0.8228	0.1419	0.0456	0.0769
H x S	0.2745	0.1543	0.8341	0.4348	0.2187	0.0905

Table 38. Interaction of hybrid and strigolactone seed treatment on grain yield, yield components, and grain quality for corn grown at Harrisburg, IL during 2016. Grain yield and kernel weight is presented at 0% moisture.

Hybrid	Strigolactone	Yield Mg ha ⁻¹	Yield Components		Grain Quality		
			Kernel Number number m ⁻²	Kernel Weight mg seed ⁻¹	Oil	Protein	Starch
			%				
DKC61-54RIB	Untreated	8.7	3877	223.2	3.61	6.91	71.03
	AB-01 Seed Treatment	8.5	3774	220.5	3.67	6.98	71.91
G10T63-3000GT	Untreated	8.7	4174	209.1	4.10	6.79	71.41
	AB-01 Seed Treatment	8.5	4083	208.6	4.10	6.73	71.48
DKC63-71RIB	Untreated	8.1	3705	215.4	3.61	6.23	72.04
	AB-01 Seed Treatment	8.1	3781	214.8	3.53	6.29	72.23
G11K47-GT	Untreated	8.0	3859	205.9	4.07	7.03	71.00
	AB-01 Seed Treatment	7.8	3867	202.1	4.05	6.86	71.24
LSD ($\alpha = 0.10$)		NS	NS	NS	NS	NS	NS

Table 39. Interaction of hybrid and strigolactone seed treatment on grain yield, yield components, and grain quality for corn grown at Champaign, IL during 2016. Grain yield and kernel weight is presented at 0% moisture.

Hybrid	Strigolactone	Yield Mg ha ⁻¹	Yield Components		Grain Quality		
			Kernel Number number m ⁻²	Kernel Weight mg seed ⁻¹	Oil	Protein	Starch
			%				
DKC61-54RIB	Untreated	12.3	4951	246.5	3.50	6.98	72.65
	AB-01 Seed Treatment	12.5	4917	253.2	3.60	7.03	72.34
G10T63-3000GT	Untreated	12.3	5215	235.7	3.90	7.23	71.78
	AB-01 Seed Treatment	12.3	5268	233.5	3.90	7.16	71.81
DKC63-71RIB	Untreated	11.8	4618	257.2	3.51	6.55	72.59
	AB-01 Seed Treatment	11.7	4564	257.4	3.69	6.79	72.18
G11K47-GT	Untreated	11.9	5101	233.6	3.93	7.30	71.40
	AB-01 Seed Treatment	12.0	5008	239.7	3.97	7.45	71.31
LSD ($\alpha = 0.10$)		NS	NS	NS	NS	0.14	NS

Table 40. Interaction of hybrid and strigolactone seed treatment on grain yield, yield components, and grain quality for corn grown at Yorkville, IL during 2016. Grain yield and kernel weight is presented at 0% moisture.

Hybrid	Strigolactone	Yield	Yield Components		Grain Quality		
			Kernel Number	Kernel Weight	Oil	Protein	Starch
		Mg ha ⁻¹	number m ⁻²	mg seed ⁻¹	%		
DKC61-54RIB	Untreated	11.9	4684	254.7	3.65	7.80	72.27
	AB-01 Seed Treatment	12.0	4541	252.8	3.58	7.73	72.27
G10T63-3000GT	Untreated	11.6	4579	253.7	3.63	8.14	72.18
	AB-01 Seed Treatment	12.2	4867	250.6	3.77	8.27	71.95
DKC63-71RIB	Untreated	11.8	4727	249.6	3.57	7.00	72.81
	AB-01 Seed Treatment	11.2	4480	249.9	3.65	7.16	72.30
G11K47-GT	Untreated	12.1	5000	241.6	3.93	7.95	71.56
	AB-01 Seed Treatment	11.8	4796	244.1	4.12	8.10	70.86
	LSD ($\alpha = 0.10$)	NS	NS	NS	NS	NS	0.50

FIGURE

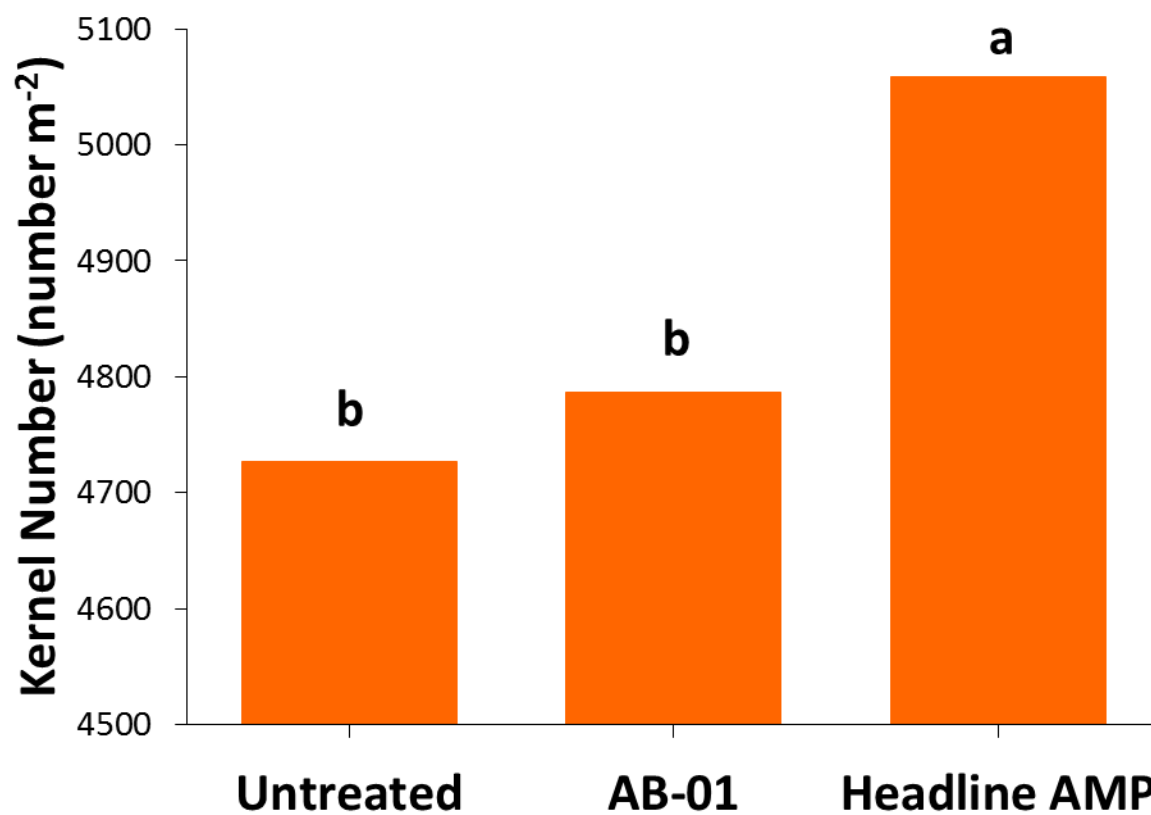


Figure 1. The effect of AB-01 and Headline AMP applications on kernel number. Values are averaged over the two planting populations. Different letters indicate significant differences between groups ($P \leq 0.1$).

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