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LED grow lights alter sorghum growth and sugarcane aphid (Hemiptera: Aphididae) plant interactions in a controlled environment

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Abstract

Normal growth and production of plant tissues requires water, carbon dioxide, nutrients, and light. Light-emitting diodes (LED) are being used increasingly as a substitute for fluorescent or incandescent light sources in greenhouse horticulture because of their small size, durability, wavelength specificity, long operating life, and efficiency in offering photosynthetically active radiation at lowered energy costs compared to conventional lights. However, studies conducted to test the effects of these lights reveal that spectral properties of light-emitting diodes can have dramatic effects on plant morphology, nutrient uptake, and pathogen development when plants are grown under the incorrect light spectrums. We grew sorghum plants under a light-emitting diode grow panel, and compared it to plants grown under conventional fluorescent lighting within identical environmental chambers. Light-emitting diode lighting resulted in deleterious sorghum growth with fewer true leaves formed, reduced plant height, lower chlorophyll content, and an unusual pink to purple coloration of the plant tissue when compared to sorghum grown under conventional lighting. All 4 of the different sorghums grown under light-emitting diodes had 2× the amount of biomass measured as dry weights for upper (stems and leaves) and lower (root mass) when compared to the conventional lighting. When sorghums were infested with sugarcane aphid, *Melanaphis sacchari* (Zehntner) (Hemiptera: Aphididae), both light sources supported a similar number of aphids but plants grown under light-emitting diodes had higher damage ratings than those under conventional lights for both known resistant and susceptible sorghums. For future trials, sorghum should not be grown using the light-emitting diode lights when assessing host-plant resistance to aphid infestation.

Key words: plant-insect interactions; greenhouse; lighting

Resumen

El crecimiento normal y la producción de tejidos vegetales requieren agua, dióxido de carbono, nutrientes y luz. Se están utilizando los diodos emisores de luz (DEL) cada vez más como un sustituto para las fuentes de luz fluorescentes o incandescentes en la horticultura de invernadero debido a su pequeño tamaño, durabilidad, especificidad de longitud de onda, larga vida útil y eficiencia en el suministro de radiación fotosintéticamente activa a costos energéticos más bajos en comparación con luces convencionales. Sin embargo, los estudios realizados para probar los efectos de estas luces revelan que las propiedades espectrales de los diodos emisores de luz pueden tener efectos dramáticos en la morfología de la planta, la absorción de nutrientes y el desarrollo de patógenos cuando las plantas crecen bajo espectros de luz incorrectos. Cultivamos plantas de sorgo bajo un panel de cultivo de diodos emisores de luz, y las comparamos con plantas cultivadas bajo iluminación fluorescente convencional dentro de cámaras ambientales idénticas. La iluminación de diodos emisores de luz dio como resultado un crecimiento perjudicial del sorgo con menos hojas verdaderas formadas, una altura reducida de la planta, un menor contenido de clorofila y una inusual coloración rosa a púrpura del tejido de la planta en comparación con el sorgo que se cultiva bajo iluminación convencional. Todos los 4 diferentes clases de sorgo cultivados bajo diodos emisores de luz tenían 2× la cantidad de biomasa medida como peso seco de las partes superiores (tallos y hojas) e inferiores (masa de las raíces) en comparación con la iluminación convencional. Cuando las plantas de sorgo estaban infestadas con el áfido de la caña de azúcar, *Melanaphis sacchari* (Zehntner), ambas fuentes de luz soportaban un número similar de áfidos, pero las plantas cultivadas con diodos emisores de luz tenían índices de daño más altos que los de las luces convencionales para los sorgos resistentes y susceptibles conocidos. Para ensayos futuros, el sorgo no debe cultivarse con las luces de diodo emisor de luz cuando se evalúa la resistencia de la planta hospedera a la infestación de áfidos.

Palabras Clave: luces de crecimiento; diodos emisores de luz; interacciones planta-insecto; invernadero; iluminación

It has long been known that plants require water, carbon dioxide, nutrients, and light for normal growth and reproduction. However, recent advances in light-emitting diode (LED) technology has offered improved efficiency in both photosynthetically active radiation and lowered energy costs. Light-emitting diodes are characterized by relatively narrow-band spectra, and have been increasingly used in growth chambers, greenhouse horticulture, and are being researched for growing plants in space (Hogewoning et al. 2007; Massa et al. 2008; Trouwborst et al. 2010). Their small size, durability, long operating lifetime, wavelength specificity, relatively cool emitting surfaces, and linear photon output with electrical current input make these solid-state light sources desirable for use in many growing systems. Light-emitting

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diodes have been used to allow yr-round production by providing high intensity light during winter months in northern climate greenhouses, and can improve plant growth during overcast days in summer (Moe et al. 2005; Heuvelink et al. 2006).

Because the output waveband of light-emitting diodes (single color, nonphosphor-coated) is much narrower than that of traditional electric lighting used for plant growth, one challenge in designing an optimum plant lighting system is to determine wavelengths essential for specific crops. Indeed, a number of studies have been conducted in greenhouses and growth chambers that have tested the effects of varied light sources, wavelengths, and plant species (Vänninen et al. 2010). These studies have revealed that, like other light sources, spectral quality of light-emitting diodes can have dramatic effects on plant anatomy and morphology, as well as nutrient uptake and even pathogen development (Massa et al. 2008). Foliar intumescence may develop in the absence of ultraviolet light spectra, and this and other less understood stimuli could seriously limit some crops lighted solely by narrow-band light-emitting diodes. For example, studies on rice (*Oryza sativa* L.) (Poaceae) have revealed dramatic effects on leaves depending on the spectra used (Matsuda et al. 2004).

The quality of light, including proper spectral distribution, can affect many characteristics of plants. For example, blue light spectra are vital for growth and development of higher plants, because photomorphogenesis is triggered by blue photoreceptors (Briggs & Huala 1999; Briggs & Christie 2002). Wheat, *Triticum aestivum* L. (Poaceae), grown under blue light-emitting diodes responds with higher photosynthetic rates and greater stomatal conductance, leading to increased biomass production (Goins et al. 1997; Vänninen et al. 2010). A combination of red and blue light-emitting diodes promotes production of many vegetable crops including pepper, *Capsicum* sp. (Solanaceae) (Brown et al. 1995), spinach *Spinacia oleracea* L. (Amaranthaceae), radish *Raphanus raphanistrum* L. (Brassicaceae), and lettuce *Lactuca sativa* L. (Asteraceae) (Yorio et al. 2001). Light spectra influence plant physiological systems including altering the ratio of chlorophyll *a*/*b* (Senger & Bauer 1987), and chlorophyll *a*/*b*-binding proteins (Leong & Anderson 1984) and per unit total protein content (Eskins et al. 1991). Although physiological, morphological, and genetic traits of plants grown under light-emitting diode lights have been characterized, very few studies have investigated the influence of the light-emitting diode lights on plant-insect interactions.

Herbivorous arthropods that feed on plants growing under artificial light are exposed to abnormally long photoperiods and light spectra that are different from sunlight (Vänninen et al. 2010). The plants often are provided high nutrient and optimal water conditions, and the environment is maintained at a near constant temperature. Because plants produce secondary plant compounds in response to herbivory, and because plants under optimal conditions often can tolerate more injury than plants that are stressed, characterizing insect-plant interactions in artificially lighted greenhouse conditions is important, especially in cases where greenhouse trials are used prior to large-scale field implementation. Recently, USDA has suggested the use of light-emitting diode grow panels in an effort to reduce energy costs. However, sorghum plants grown under these orange, blue, and red light-emitting diodes appeared different because they grew more leaves and exhibited some very discolored tissue compared to plants grown under sunlight in the greenhouse (JSA personal observation).

Two sorghums that were sugarcane aphids susceptible, and 2 resistant sorghums were grown under conventional fluorescent grow lights and under light-emitting diode grow lights to determine the effects on sorghum growth and aphid-sorghum interactions. The experiments were conducted under identical conditions in environmental chambers with the only difference being the light source. We report here the differences measured under these replicated experiments.

Materials and Methods

APHID CULTURE

Parthenogenic sugarcane aphids were collected from Matagorda County, Texas, in 2015 and maintained on a known susceptible sorghum hybrid, cv. 'TX 7000' (Armstrong et al. 2015). This clonal colony was transferred to new seedling plants every 2 wk in the greenhouse. Plants were maintained on greenhouse benches at temperatures between 21 °C and 31 °C, and grown under 2 T-8 fluorescent lights that provide supplemental light.

SORGHUM ENTRIES AND CULTURE

To test the effects of light on sorghum and plant-aphid interactions, 2 known resistant lines, 'TX 2783' and 'DKS 37-07,' and 2 known susceptible lines, 'MORHC 858' and 'WSH 117' were used. Two seeds of each genotype were planted in cone-tainers™ (model SC10, S7S Greenhouse Supply, Tangent, Oregon, USA) in a rich 3-layer media of potting soil, fritted clay, and sand (from bottom to top, respectively). The cones were fitted with a plastic transparent tube covered on the top with an organdy cloth. The cones were maintained in the growth chambers at constant temperature with a photoperiod of 14:10 (L:D) h. When the plants reached the 3-leaf stage, the most vigorous seedling was kept and the other was removed. The temperature of the growth chambers was maintained at 25 ± 2 °C for a duration of 21 d to test the effects of lighting on plant growth, and 21 d to test the effects on aphid reproduction and damage on plants grown under different light conditions.

GROW LIGHT COMPARISONS

Experiments were designed to study the effects of light-emitting diode grow lights (grow panel W2238, Sunshine Systems, Wheeling, Illinois, USA) on sorghum plant growth and interactions with sugarcane aphid infestation. The light-emitting diode light source was tested for the conventional lighting provided within growth chambers (Percival® Model E30B, Perry, Iowa, USA). The conventional growth chamber has 6 Philips (model 7866113, Philips Inc.Guadalajara, Jalisco, Mexico) fluorescent grow lights, and 2 clear 40-watt appliance lights bulbs (Sylvania, Wilmington, Massachusetts, USA). The light spectrum at the plant growth level in the conventional growth chamber was measured at 8,007.0 lux (15 s avg.) with a photometric sensor, and 195.4 µmol (15 s avg.), whereas the growth chamber fitted with the light-emitting diode grow light provided 1269.5 lux (15 s avg.) with the photometric sensor, and 36.90 µmol (15 s avg.). Because the light emission spectrum is so different for the light-emitting diode grow lamps (Sunshine Systems, Wheeling, Illinois), the spectrum was also measured using a 0.3 m spectrometer with a 150 groove per mm diffraction grating and a thermoelectrically cooled CCD camera. Light was coupled into the spectrometer using a 100 µm diam optical fiber (Fig. 1).

SORGHUM GROWTH EXPERIMENTS

Four different sorghum cultivars were used in flat screen trials where 15 replications of each cultivar were grown under light-emitting diode grow lights and conventional lights. Plant height and the number of leaves were measured every 48 h. Chlorophyll content was measured using a SPAD 502 chlorophyll meter (Minolta, Ramsey, New Jersey, USA) after 7 and 16 d post emergence. Wet and dry weights were taken at the conclusion of the experiment for dry weight biomass comparisons. The upper portion of the plant from the soil line up were clipped and weighed, as was the root system, then the tissues were labeled and dried in a drying oven at 50 °C for 72 h, before being reweighed.

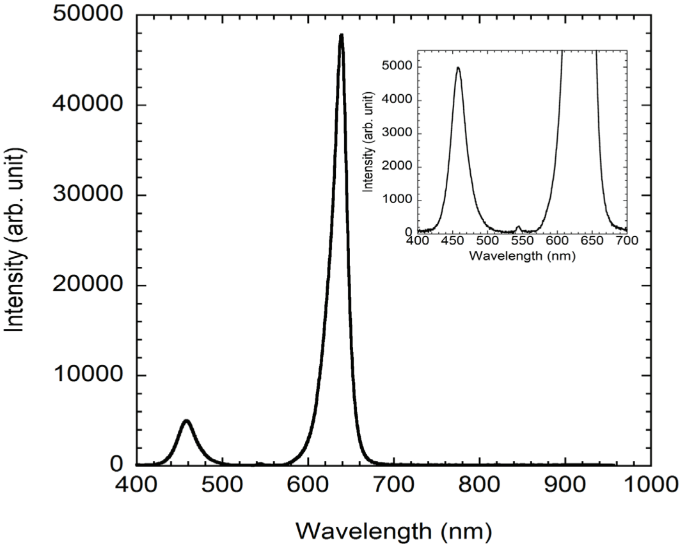

Fig. 1. Light emission spectrum of the W2238 LED grow panel over the visible spectrum and into the near infrared. The inset spectrum is zoomed vertically to show details of any weaker emissions.

SORGHUM-SUGARCANE APHID EXPERIMENT

A second trial was designed to measure sugarcane aphid reproduction and damage under light-emitting diode grow lights and conventional lighting. The same 4 cultivars of sorghum were used with 11 replications of each cultivar planted in cone-tainers™. Two separate trays were prepared and placed into separate growth chambers, 1 with the grow lights and the other for conventional lights. Each plant was infested with leaf cuttings that had 5 adult females transferred to each sorghum entry at the 3-leaf stage, 8 d post emergence. After 2 wk of being infested, the plants were evaluated for plant height and the number of true leaves, but not counting the cotyledon leaf. Chlorophyll content was measured with the SPAD 502 chlorophyll meter followed by counting the number of nymphs and winged adults on each plant. Damage ratings were made using damage rating based on a scale of 1 to 5, where 1 = 0 to 20%, 2 = 21 to 40%, 3 = 41 to 60%; 4 = 61 to 80%, and 5 = 81 to 100% damage.

STATISTICAL ANALYSIS

The variables of plant height, number of leaves on a sorghum entry, wet and dry mass, chlorophyll content, numbers of sugarcane aphid nymphs, and damage ratings were subjected to Proc Mixed analysis (SAS 9.3, SAS Institute 2010), with the degrees of freedom calculated using Kenward-Roger degrees of freedom approximation method. Means were compared ($\alpha = 0.05$) using least squared means pairwise comparisons procedure.

Results

LIGHT SPECTRUM MEASUREMENTS

Light-emitting diodes produced 2 primary emissions that were centered near 457 nm (blue) and 636 nm (red). Both emission peaks had similar widths, with full width at half maximum (FWHM) values of roughly 24 nm and 20 nm for the blue and red emissions, respectively (Fig. 1). There was an additional peak centered at 544 nm, although it was very weak in intensity compared to the red and blue emission. The light intensity within the growth chamber that has six 17-watt Phillips fluorescent lights, and two 40-watt light bulbs measured with a LI-COR light meter (model LI-250, LI-COR, Lincoln, Nebraska, USA) resulted in 8,007 lux (15 s avg.) with the photometric sensor, and 195.44 µmol (15 s avg.) with a quantum sensor.

PLANT GROWTH

The difference in visual appearance of the plants growing under the 2 different spectra was striking with sorghum grown under light-emitting diode lights having stunted height, chlorotic, and pink to purple leaves, and other differences in tissue color (Fig. 2). One cultivar, MORHC 858, turned completely pink, and the second cultivar DKS 37-07 showed 70 to 80% of pink color with leaf chlorosis (Fig. 2), whereas the other 2 cultivars, TX 2783 and WSH 117, were not as pink but turned light green to yellow or white in some cases. Plant morphology also differed with sorghum grown under light-emitting diode lights producing more leaves, and leaves that were broader as compared to the same cultivars grown under conventional light (Fig. 2).

The number of leaves on a sorghum plant (df = 55, 839; $F = 15.40$; $P = < 0.001$) were significantly greater for those grown under conventional lighting compared to those under light-emitting diodes lights, as was for entry ($F = 4.4$; $P = < 0.005$), light source ($F = 31.8$; $P = < 0.001$), date of evaluation ($F = 124.6$; $P = < 0.001$), entry by light source ($F = 3.7$; $P = < 0.012$), and finally light source by date ($F = 4.7$; $P = < 0.001$) (Fig. 3). However, on the last evaluation date of 8 Jun, 2016 sorghum entries TX 2783, MORCH 858, and WSH 117 grown under light-emitting diode lights had higher numbers of leaves compared to the remaining entries in the evaluation.

Even though the models for numbers of leaves were highly significant when compared for light source, plant height (df = 55, 839; $F = 70.3$; $P = < 0.001$) measured across the same dates differentiated itself by light source ($F = 1{,}546.5$; $P = < 0.001$), date of evaluation ($F = 291.3$; $P = < 0.001$), entry by light source ($F = 5.6$; $P = < 0.001$), and light source by date ($F = 81.09$; $P = < 0.001$), with each evaluation date increasing steadily for entries grown under conventional lights (Fig. 4). The only evaluation date plant height was not significantly higher for all entries grown under conventional lights was on the first 27 May, 2016 evaluation. On the closing date of plant height measurements of 8 Jun, there was an average of 20 cm increase across sorghums grown under conventional lighting. Light source was the most impactful influence on plant height.

Dry matter weights for the upper stems and leaves (df = 7,111; $F = 3.7$; $P > F = 0.001$) were significantly higher for light-emitting diode grown sorghums (df = 1, 92; $F = 28.5$; $P > F = 0.001$), but not for entry within light source (df = 3, 91; $F = 0.06$; $P > F = 0.98$) (Table 1). Root dry weight trends were similar to the upper parts based on the means across entries, as shown in Table 1; the light-emitting diode sorghums had 3× more root dry weight contrasted with those grown in a conventional growth chamber. When total dry weights (upper parts plus the roots) were compared, only the light source (df = 1, 97; $F = 9.9$; $P < 0.002$) was the significant factor that was of influence. Dry weights for upper and lower sorghum parts were from 2 to 3× higher for light-emitting diode grown lights as opposed to conventional lights (Table 1).

APHID REPRODUCTION

Sugarcane aphid reproduction was most significantly affected by the sorghum entry (df = 3, 69; $F = 43.3$; $P = < 0.001$) as opposed to the light source (df = 1, 69; $F = 3.1$; $P = < 0.031$), and the model for entry by light source (df = 3, 69; $F = 1.1$; $P = < 0.340$) substantiated that factor (Table 3). All 4 entries under conventional lighting separated statistically, and this can be explained in part by the known degrees

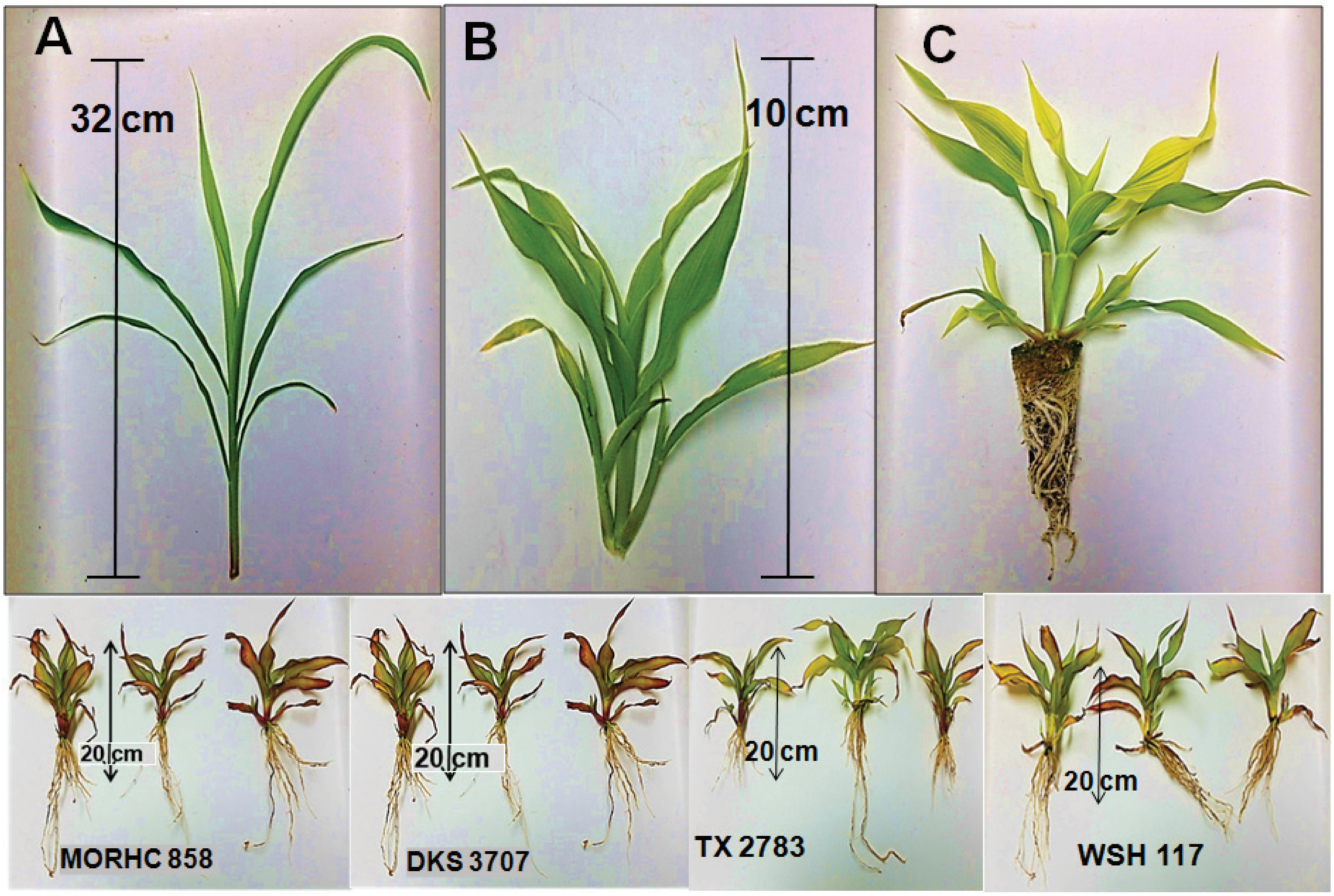

Fig. 2. Growth characteristics of grain sorghum grown under conventional lighting (A) from within an environmental chamber, fitted with a W2238 LED grow panel (B and C, see Fig. 1 for light spectrum measured), and for sorghum cv MORHC 858, DKS 37-07, TX 2783, and WSH117 after 21 d in a growth chamber fitted with a W2238 LED grow panel.

of resistance that have been documented for sugarcane aphids and these sorghums. TX 2783 is known as highly tolerant, where aphid reproduction occurs but the plant is not impacted, as opposed to DKS 37-07 that expresses more antibiosis, where aphid numbers are reduced due to reduced reproduction (Armstrong et al. 2015), which explains the disparity between the 2 resistant sorghums grown under conventional lights. A general, although not significant, trend for the 4 entries grown under light-emitting diode lights were that there were fewer sugarcane aphid nymphs across the entries, as compared to conventional lights in all cases (Table 3); however, the resistant entries TX 2783 and DKS 37-07 were similar in expression of resistance, as opposed to the susceptibles MORCH 858 and WSH 117. The known susceptible WSH 117 produced the most aphids under conventional light and considerably less under the light-emitting diodes.

CHLOROPHYLL CONTENT

The chlorophyll content was significant for entry (entry df = 3, 211; F = 4.6; P = < 0.004) and light source df = 1, 211; F = 306.9; P = < 0.001), where there was 2 to 3× less content in sorghum under light-emitting diode lights as compared to conventional lights (Table 2), which could be one of the reasons for the decline in aphid reproduction (Table 3). When row means are compared for entry by light source by infested versus not infested (df = 4, 211; F = 17.5; P = < 0.001), there appear 2 co-factors reducing the chlorophyll content, and that is the light source and whether the plants are infested with sugarcane aphids. The means decrease across the rows for these 2 factors (Table 2).

The actual feeding injury caused by sugarcane aphids, and the discoloration of plants grown under light-emitting diodes could not be differentiated, so damage was assessed as a combination of the 2 factors. Table 4 shows that both resistant and susceptible entries (i.e., TX 2783 and DKS 37-07 versus MORCH 858 and WSH 117, respectively) maintain lower damage ratings under conventional lights as opposed to higher damage ratings when grown under light-emitting diode lighting. The damage ratings for the resistant entries grown in conventional lighting were no greater than 1.5, as opposed to those of the susceptible entries grown under LED that were almost 100% for MORCH 858, with an average of 4.8 and WSH 117 that averaged a 4.9 (Table 4).

Discussion

In greenhouse trials using both susceptible and resistant sorghum lines, substantial differences in plant growth forms were observed when sorghum was grown under pink light-emitting diode lights compared to sorghum grown under conventional lighting. When sorghums were infested with aphids, those grown under light-emitting diode lights had lowered chlorophyll content and significantly reduced plant

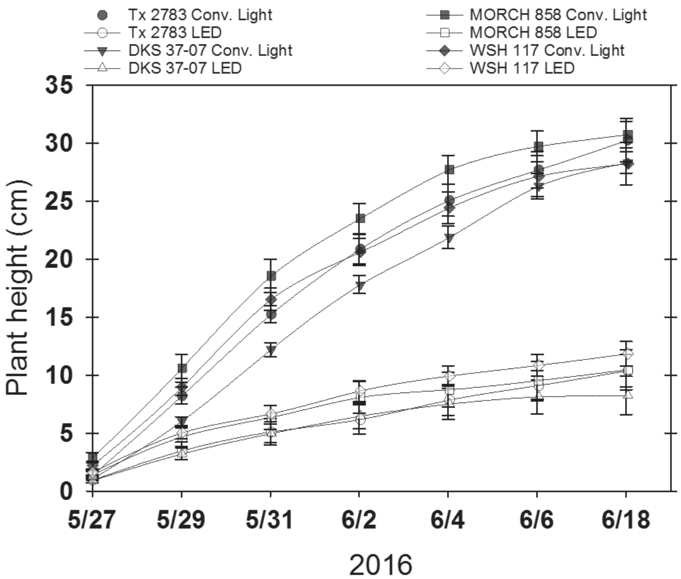

Fig. 4. Plant height (cm) for 2 different sorghum entries grown under conventional and LED light sources.

height, whereas WSH 117 and TX 2783 had significantly higher damage ratings when infested with sugarcane aphids than the same plants grown under conventional lights. However, it must be stated that TX 2783 is a tolerant sorghum that will allow aphids to reproduce. It is difficult to differentiate the damage from aphid feeding, and damage caused by altered plant color that is created by light-emitting diodes. The results of this study show that damage ratings for both a resistant and a tolerant sorghum are increased when grown under the incorrect light spectrum created by the light-emitting diode lights. Because greenhouse trials are conducted to identify potential resistance prior to field trials (Armstrong et al. 2017), the influence of light-emitting diode lighting on the results is notable. Differences in sorghum growth are attributed to the variation in different light sources and spectrum.

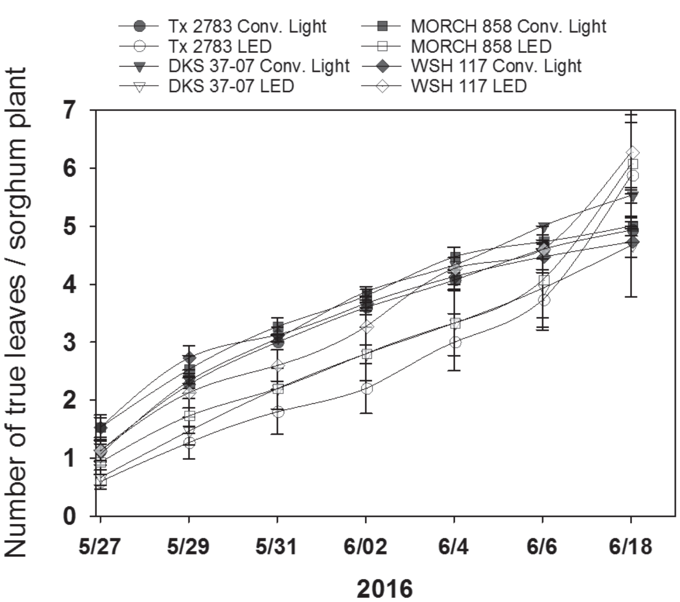

Fig. 3. Number of true leaves on 4 different sorghum entries grown under conventional and LED light sources.

This study concludes that pink light affects sorghum growth and response to aphids, and that the particular model of grow lights used in this study should not be used when evaluating sorghum for insect trials.

The light-emitting diode light source used in this study has a label that describes the color as "Red: Blue: Orange, 7:1:1." Based on the data and results obtained here, this is incorrect since only 2 primary emissions were observed (Fig. 1). The intensity ratio of the red emission to that of the blue emission was 6.9, which is close to the value of 7.0 on the label. The problem is that the quantum efficiency of the camera can vary quite substantially for different wavelengths of light. According to the manufacturer of the camera, the quantum efficiency near the blue emission is likely close to 50%, and the quantum efficiency near the red emission is likely closer to 85%. However, the spectrum should be corrected for the response of the specific system (spectrometer and camera) with the use of a known broadband emission before intensity ratios are considered accurate.

The irradiance spectrum to which plants are exposed causes different effects on plants during growth. In plant research and greenhouse horticulture, growth lamps with different spectral outputs have been used for more than a century, although at high energy cost and with increases in temperature because of inefficiency. More recently, light-emitting diodes which are characterized by relatively narrow-band spectra have become increasingly used in growth chambers, on an experimental basis in greenhouse horticulture, and in research aimed at growing plants in space (Hogewoning et al. 2007; Massa et al. 2008; Trouwborst et al. 2010). Hogewoning et al. (2007) previously reported lettuce to be physically very different when grown under pink lights compared to white light. Because pink light affected plant physiology of both sorghum and lettuce, which are C4 plants, it is possible that the C4 photosynthetic cycle is more affected by the pink light-emitting diode lights than C3 plants.

Overall the trends observed for the height and number of leaves of the lettuce grown under light-emitting diodes were similar to our results for sorghum. In addition, the dry weights for plants grown with light-emitting diodes were greater than the differences in leaf length and number of leaves, because leaves grown under light-emitting diode lights were thicker and hence heavier per length unit (Hogewoning et al. 2007).

To date, only a few studies have examined the effects of light-emitting diode lights on herbivore or tritrophic interactions (Vanninen et al. 2010), and more research is warranted as light-emitting diode technology replaces conventional lighting technology. In addition, the results of previous trials examining sorghum resistance to sugarcane aphid where pink light-emitting diode lights were used should be confirmed.

Acknowledgments

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Table 1. Dry matter weights (mg) for 2 resistant and 2 susceptible sorghums grown under conventional and light emitting diodes (LEDs).

Sorghum Type	Upper Stems and leaves[a]		Roots		Total Dry Matter	
	Conventional	LED	Conventional	LED	Conventional	LED
TX 2783	140.0 ± 18.8 A	246.9 ± 44.3 B	48.7 ± 7.6 A	157.7 ± 33.0 B	188.0 ± 25.8 A	404.6 ± 71.8 B
DKS 37-07	163.3 ± 14.9 A	283.6 ± 46.1 B	58.7 ± 5.2 A	150.8 ± 28.5 B	222.0 ± 19.1 A	379.2 ± 78.0 B
MORHC 858	158.0 ± 21.3 A	295.0 ± 59.6 B	54.0 ± 7.3 A	181.4 ± 34.3 B	212.0 ± 27.9 A	476.6 ± 90.0 B
WSH 117	113.3 ± 14.1 A	240.7 ± 35.9 B	49.3 ± 7.5 A	164.0 ± 32.4 B	162.3 ± 20.8 A	388.7 ± 67.8 B
All entries	143.7 ± 17.3 A	266.6 ± 46.5 B	52.7 ± 6.9 A	163.5 ± 32.1 B	196.1 ± 23.4 A	412.3 ± 76.9 B

[a]Large cap letters designate mean differences across columns for light source by sorghum entry. Column means by light source are not provided because the models for upper stems and leaves, roots, and total dry matter were not significant. Stems and leaves by entry, df = 3, 104; *F* = 0.90; *P* > *F* = 0.45; light source df = 1, 104; *F* = 23.24; *P* > *F* = < 0.001; entry × light source df = 3, 104; *F* = 0.08; *P* > *F* = 0.99. Roots dry matter by entry, df = 3, 100; *F* = 0.29; *P* > *F* = 0.83; light source df = 1, 100; *F* = 0.38; *P* > *F* = 0.89; entry × light source df = 3, 93; *F* = 0.30; *P* > *F* = 0.83. Total dry matter by entry, df = 3, 97; *F* = 0.65; *P* > *F* = 0.59; light source df = 1, 97; *F* = 38.0; *P* > *F* = 0.001; entry × light source df = 3, 97; *F* = 0.07; *P* > *F* = 0.97.

Table 2. Total chlorophyll content (µmol m^{-2}) for resistant and susceptible sorghums that were infested or not infested with sugarcane aphids under conventional florescent lights or light emitting diodes (LEDs).

Sorghum Entry	Conventional Not Infested	Conventional Infested	LED Not Infested	LED Infested
TX 2783	30.5 ± 6.1 A	25.3 ± 2.3 A	19.5 ± 2.3 B	13.9 ± 0.8 C
DKS 37-07	30.0 ± 0.6 A	27.9 ± 1.4 A	20.7 ± 1.3 B	12.7 ± 0.4 C
MORHC 858	29.9 ± 1.7 A	27.1 ± 1.5 B	17.8 ± 1.6 C	10.9 ± 0.4 D
WSH 117	29.1 ± 1.2 A	23.7 ± 1.8 B	15.9 ± 1.6 C	11.5 ± 0.5 D

[a]Large cap letters designate mean differences across columns for light source by sorghum entry by infested or not infested. Chlorophyll content for entry, df = 3, 211; *F* = 4.55; *P* = < 0.004; light source df = 1, 211; *F* = 306.9; *P* = < 0.001; infested vs. not infested df = 1, 211; *F* = 0.29; *P* = 0.59; entry × infested, df = 3, 211; *F* = 1.26; *P* = 0.288; entry × light source df = 3, 211; *F* = 0.14; *P* = 0.93; entry*light source*infest df = 4, 211; *F* = 17.48; *P* = < 0.001.

Table 3. Mean number (± SE.) of sugarcane aphid nymphs recovered after 3 wk from 2 resistant and 2 susceptible sorghums that were grown under conventional lights or light emitting diodes (LEDs).

Sorghum Entry	Lighting Source		Conventional vs. LED
	Conventional[a]	LED	*alpha* = *P* < 0.05
TX 2783 (R)	182.0 ± 30.9 c	150.6 ± 18.6 b	0.38
DKS 37-07 (R)	14.1 ± 2.8 d	15.9 ± 5.9 c	0.96
MORHC 858 (S)	257.1 ± 36.9 b	244.8 ± 22.7 a	0.74
WSH 117 (S)	312.0 ± 33.0 a	228.4 ± 31.0 a	0.02

[a]Small cap letters down the column designate mean differences for light source by sorghum entry. Nymphs by entry, df = 3, 69; *F* = 43.39; *P* = < 0.001; light source df = 1, 69; *F* = 3.13; *P* = < 0.031; entry × light source df = 3, 69; *F* =1.13; *P* = < 0.34.

Table 4. Damage Ratings (1–5 scale) for 2 resistant and 2 susceptible sorghums that were either infested with sugarcane aphids and grown under conventional florescent lights or light emitting diodes (LEDs) for 3 wk.

Sorghum Entry	Lighting Source		Conventional vs. LED
	Conventional[a]	LED	*alpha* = *P* < 0.05
TX 2783 (R)	1.5 ± 0.2 cA	2.5 ± 0.2 bB	> 0.01
DKS 37-07 (R)	1.2 ± 0.1 dA	1.0 ± 0.0 cA	= 0.68
MORHC 858 (S)	3.5 ± 0.6 aA	4.8 ± 0.5 aB	> 0.001
WSH 117 (S)	2.5 ± 0.2 bA	4.9 ± 0.3 aB	> 0.001

[a]Small cap letters down the columns designate mean differences for light source by sorghum entry. Large cap letters designate mean differences across columns for light source by sorghum entry. Damage rating by entry, df = 3, 70; *F* = 43.5; *P* = < 0.001; light source df = 1, 70; *F* = 26.6; *P* = < 0.001; entry × light source *F* = 5.60; *P* = < 0.002.

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