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Selection for drought tolerance in sorghum using desiccants to simulate post-anthesis drought stress

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ABSTRACT

Late-season drought is a major limiting factor worldwide for rainfed sorghum [*Sorghum bicolor* (L.) Moench] production. Field screening of genotypes against post-anthesis drought is challenging as the stress is unpredictable and, when it happens, is often confounded with stalk diseases and lodging. In this study, we report on the results of tests on the use of desiccants in simulating post-anthesis drought effects in sorghum as aid in selection for late-season drought tolerance. First, we tested the efficacies of three desiccants KI, $NaClO_3$ and $KClO_3$. Each desiccant was applied at three concentrations: 0.4% w/v, 0.6% w/v and 1% w/v, and on three genotypes P89001, P898012 and TX7078, known for their drought responses. Genotypic grain yield (GY) and seed weight (SWT) differed significantly under each of these desiccants. Genotype P898012, tolerant to post-anthesis drought, had the highest GY and SWT, while TX7078 and P89001, known for their post-anthesis drought susceptibility, had the lowest values following treatment with desiccants. The desiccants had significantly different effects, with $NaClO_3$ inducing the most severe effect on GY and SWT while KI had the least effect. Observed genotypic differences were greater at 0.4% w/v for $NaClO_3$ and $KClO_3$, while KI had greater marked effect both at 0.6% w/v and 1% w/v. In the second experiment, we assessed the sensitivity of 18 diverse sorghum genotypes to KI (0.6% w/v). All genotypes tolerant to late-season drought had lower grain yield reduction (GYR), seed weight reduction (SWR) and stress susceptibility index (SSI), but a higher stress tolerance index (STI) than the susceptible genotypes. Remobilized total nonstructural carbohydrate was associated positively with STI's but negatively with SSI's. Results from this study suggested that desiccants simulated the effect of post-season drought stress, and that this technique could be used in assisting sorghum breeders to rapidly screen for post-anthesis drought tolerance under drought free environments.

1. Introduction

Drought stress remains a major constraint on crop production in arid and semi-arid climates. As a drought-tolerant crop, sorghum is widely grown in the more arid areas of the world (Ejeta and Knoll, 2007; Ramazanzadeh and Asgharipour, 2011; Reddy et al., 2008), although it also responds favorably to irrigation and higher rainfall. Drought stress has been shown to reduce grain yield significantly even in sorghum when it occurs both at pre- and post-anthesis growth stages (Blum, 2004; Rosenow and Ejeta, 1996; Rosenow and Clark, 1995; Tuinstra et al., 1997). Post-anthesis drought stress predisposes sorghum to diseases like charcoal rot and Fusarium stalk rot which cause significant lodging, reduced seed size and total yield loss (Rosenow and Clark, 1995; Tesso et al., 2004). Breeding efforts to address pre-anthesis drought have in the past led to development of early maturing sorghum genotypes that employ drought escape mechanism, including a few that combined both pre- and post-athesis drought tolerance (Ejeta and Rosenow, 1993; Ejeta, 1986; Leslie, 2008; Reddy et al., 2008; Wani et al., 2009).

Physiological grain yield reduction under post-anthesis drought stress is mainly a result of disruption in current photosynthesis (Budakli et al., 2007), a phenomenon that is very important in providing assimilates needed during grain filling (Blum, 1998). Consequently, it has been recognized that, delayed leaf senescence, a trait commonly known as 'stay green', is associated with tolerance to post-anthesis drought in sorghum. Several quantitative trait loci (QTLs) anchoring associated this trait have been mapped in sorghum (Crasta et al., 1999; Harris and Subudhi, 2007; Hash et al., 2003; Tao et al., 2000; Tuinstra and Grote, 1996; Tuinstra et al., 1998; Xu et al., 2000). The 'Stay green' trait has been found to be highly and positively correlated with resistance to charcoal rot and reduced lodging in sorghum, and as such used as an effective

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tool for indirect selection for charcoal rot resistance (Duncan et al., 1981; Rosenow, 1977).

Despite the importance of stay green in selection for post-anthesis drought tolerance, field evaluation of the ‘stay green’ trait can be difficult and unreliable where drought is not optimally expressed, especially, due to timing and intensity of moisture stress, and the presence of large genotype × environment interactions (Xu et al., 2000). An alternative approach to improving post-anthesis drought tolerance is to select for efficient stored reserve remobilization (Blum et al., 1997). When current photosynthates are disrupted due to moisture stress, plants attempt to remobilize stored reserves from other parts, especially from the stems and leaf sheaths, for grain filling. Stored reserve remobilization is thus an important indicator of drought adaptation (Blum, 1998; Blum et al., 1997). Previous studies have also shown that stem remobilization ability is under genetic control, making it possible to improve grain filling capacity using stem reserves (Beheshti and Behboodi, 2010; Blum, 1998; Blum et al., 1997). High yielding genotypes tend to have low stem storage reserves and therefore, suffer greater grain yield loss under post-anthesis drought compared to other potentially lower yielding cultivars (Blum, 1998). Incorporating the reserve remobilization trait into elite varieties could therefore improve yield performance under post-anthesis drought stress.

Selection for improved stem reserves that support high grain filling under drought stress can be done by subjecting the materials to actual stress conditions in the field. However, it has been argued that optimal level of drought stress for drought selection is very difficult to achieve during grain filling when dealing with diverse genotypes with range of maturity and morphology (Blum, 1998). This difficulty is particularly evident and paramount in imposing stress when working with a large breeding population in the field. The more popular approaches to imposing drought stress under field conditions often involve carefully managed drought stress experiments, requiring precise irrigation control or constructing cumbersome and costly rain-out shelters for deriving stress treatments. Trait expressions in drought stress environments often exhibit low genetic variation (Bidinger et al., 1994; Singh et al., 1995). Dry environments are highly variable due to the unpredictable and highly variable seasonal rainfall. Heritability tends to be low under such highly variable environmental conditions (Dabholkar, 2006), leading to the slow progress in genetic improvement of sorghum yields in dry areas as compared to favorable environments or where irrigation is available (Eid, 2009).

The use of chemical desiccants allows selection for drought stress response to be made in favorable environments, making it possible to exploit better genetic variation and attain improved selection efficiency. The application of chemical desiccants or use of senescence-inducing agents has been proposed as a means for inhibiting current photosynthesis and thus revealing the capacity for grain filling by stem reserves (Beheshti and Behboodi, 2010; Blum, 1998). Desiccation treatment is not meant to simulate the actual drought stress physiology, but rather the effect of stress on yield and component traits. Previously, Haley and Quick, (1993) reported the use of $NaClO_3$, applied at 2% w/v, to achieve early generation selection of wheat (*Triticum aestivum* L.) for post-anthesis drought tolerance. Significant kernel weight reduction was reported among wheat varieties under $NaClO_3$ desiccation stress, and this response was correlated with reactions to late season drought (Cseuz et al., 2002). Herrett et al. (1962) reported that KI was a better desiccant for field use due its low toxicity and efficacy to induce senescence. More recently, Dogan and Kacar, (2012) created post-anthesis drought stress in triticale (×*Triticosecale Wittm. ex A.* Camus) using 4% $KClO_3$ and identified lines with a high capacity for stem reserves remobilization to grain filling. In sorghum, Beheshti and Behboodi, (2010) observed an increase in dry matter remobilization when plants were stressed with KI. Limited information exists in literature on an elaborate assessment of how well chemical desiccants can mimic the effect of drought to stress in sorghum. In our study, we utilized sorghum genotypes with known reactions to post-anthesis drought (i) evaluate the efficacy of chemical desiccants in inducing post-anthesis drought-like stress in sorghum, (ii) determine reactions of the known post-anthesis drought tolerant and susceptible sorghum genotypes to desiccation stress (iii) assess the role of stored stem reserve remobilization in sustaining yield under post-anthesis stress in sorghum.

2. Materials and methods

The study was conducted at Purdue University Agronomy Center for Research and Education (ACRE) near West Lafayette (40 33′ 36″ N, 86 55′ 48″ W), Indiana, during the summers of 2012 and 2013. The experiments were conducted in an area which was previously planted with soybeans and has long been managed under sorghum-soybean rotation. The soil at the sites is classified as Fine-loamy, mixed, superactive, mesic Aquic Argiudolls (USDA, 1998). Mean temperature and total precipitation during the growing periods (May-November) were 17.4 °C and 514.4 mm in 2012 respectively, while in 2013, the mean temperature and total precipitation were 16.9 °C and 557.0 mm respectively.

2.1. Dosage experiment

This study was aimed at testing the efficacy of three chemical desiccants in mimicking the effect of post-anthesis drought stress in sorghum. It was a factorial experiment composed of 27 treatment combinations with three genotypes, three desiccants, each with three dosage levels. The treatments were arranged in a randomized complete-block design, replicated three times in 2012 and two replicates in 2013. The three genotypes selected for the experiment were P89001, TX7078 and P898012. The first two genotypes are known to be primarily tolerant to pre-flowering drought but susceptible to post-flowering drought, while P898012 is tolerant to both pre-and-post flowering drought (Leslie, 2008; Wani et al., 2009). Untreated control (not sprayed with the desiccants) of the same three genotypes were also included in the trial as checks. The desiccants and the doses used included potassium iodide (KI), sodium chlorate ($NaClO_3$), and potassium chlorate ($KClO_3$), all applied at the following concentrations: (0.4% w/v), (0.6% w/v), and (1% w/v). Previously, these desiccants have been used to screen wheat and barley (*Hordeum vulgare* L. cv. Gustoe) for post-flowering drought responses (Blum, 1998; Budakli et al., 2007; Cseuz et al., 2002; Nicolas and Turner, 1993), and in sorghum for plant growth analysis under impaired photosynthesis (Ramazanzadeh and Asgharipour, 2011). These literatures informed our choice of the desiccant concentration levels. Desiccants were sprayed using a seven-liter hand-held pressure pump sprayer. Grams of each salt desiccants, determined based on the aforementioned concentrations were dissolved in water, and sprayed at an approximate rate of 2500 L/ha. During spraying, effort was made to ensure that the upper leaf surfaces were completely saturated. Care was also taken by shielding neighboring rows next to the one being sprayed to protect them from random sprays and to ensure that each plot was treated with the right desiccant (Fig. 1). Due to differences in genotype maturity, the application of desiccants was scheduled at 10–14 days after anthesis for each genotype, accordingly. At maturity, data were collected on the effect of the induced stress on grain yield (g) and 100 seed weight (g).