

Reducing Grain Sorghum (*Sorghum bicolor* L. Moench) Injury From Postemergence Application of Mesotrione With Dicamba

Taghi Bararpour¹, Gurbir Singh¹, Ralph R. Hale¹ & Gurpreet Kaur¹

¹ Delta Research and Extension Center, Mississippi State University, Stoneville, Mississippi, USA

Correspondence: Gurpreet Kaur, Delta Research and Extension Center, Mississippi State University, 82 Stoneville Rd., Stoneville, Mississippi 38776, USA. Tel: 1-662-686-9311. E-mail: gk340@msstate.edu

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Abstract

Weed management in grain sorghum is limited by the number of herbicide options. A two-year (2017-2018) field study was conducted at the Mississippi State University Delta Research and Extension Center, in Stoneville, MS to evaluate the response of grain sorghum to mesotrione application alone or when tank-mixed with dicamba at the two-leaf and four-leaf growth stage of sorghum. Mesotrione was applied at 0.07 and 0.105 kg ai ha⁻¹ alone or was tank-mixed with dicamba at 0.28 kg ae ha⁻¹. Significant injury to grain sorghum from all herbicide treatments was observed compared with the untreated check. Increase in mesotrione application rate increased injury to grain sorghum from 14 to 19% at two-leaf and from 10 to 24% at the four-leaf stage by 4 weeks after application (WAA) in 2017. Adding dicamba to mesotrione reduced grain sorghum injury in both years. At 4-leaf sorghum application stage, mesotrione applied at 0.07 kg ha⁻¹ resulted in greater grain yield than all other herbicide treatments, except mesotrione (0.105 kg ha⁻¹) + NIS in 2017. Our results indicate that adding dicamba to mesotrione safes grain sorghum from injury caused by mesotrione alone.

Keywords: callisto, clarity, plant height, heading, yield

1. Introduction

Grain sorghum (*Sorghum bicolor* L. Moench) is an important cereal crop grown in the United States. In 2019, U.S. harvested 4.6 million ha of grain sorghum (USDA-NASS, 2020). Cultural practices, like crop rotation, are important for weed control in grain sorghum along with incorporating herbicide programs (Brown, Al-Khatib, Regehr, Stahlman, & Loughin, 2004). Unlike corn (*Zea mays* L.), cotton (*Gossypium hirsutum* L.), or soybean (*Glycine max* L. Merr.), there are limited options for weed control in grain sorghum.

Amaranthus spp. are among the most troublesome weeds in grain sorghum. In a competition study, Knezevic, Horak, and Vanderlip (1997) reported a 47% yield reduction to grain sorghum when redroot pigweed (*Amaranthus retroflexus* L.) emerged once grain sorghum had reached the 2.6-leaf stage. In a different study, grain sorghum yield was reduced by 48% when one *Amaranthus* plant per 30 cm² was present (Shipley & Wiese, 1969). In addition, Palmer amaranth (*Amranthus palmeri* S.Wats.) present in grain sorghum fields caused increased moisture in grain and other foreign materials at the time of harvest (Moore, Murray, & Westerman, 2004). Since chemical control of troublesome weeds are important in grain sorghum production, there is a need for new herbicide options for control (Abit et al., 2009).

Preemergence weed control in sorghum can be achieved by using atrazine, S-metolachlor, dimethenamid-p, or alachlor and postemergence with 2,4-D, dicamba, or bromoxynil (Smith & Scott, 2010). Mesotrione is labeled to use in corn to control annual broadleaf and some grass weeds in corn (Janak & Grichar, 2016; Mitchell et al., 2001), including triazine-resistant Palmer amaranth, common waterhemp (*Amranthus rudis* Sauer), common lambsquarters (*Chenopodium album* L.), and black nightshade (*Solanum nigrum* L.), and ALS resistant weeds including *Amaranthus* spp., common cocklebur (*Xanthium strumarium* L.), and annual sowthistle (*Sonchus oleraceus* L.) (Abit et al., 2009; Sutton, Richards, Buren, & Glasgow, 2002). Mesotrione is labeled to use as preplant and preemergence for weed control in grain sorghum (Abit et al., 2009). However, its postemergence applications have been reported to cause injury to sorghum plants. Mesotrione applied at 70.5 g ai ha⁻¹ resulted in 20% chlorosis injury in grain sorghum but provided consistent weed control (Horky & Martin, 2004). In another study, Miller and Regehr (2002) reported early postemergence applications of mesotrione to grain sorghum exhibited 40-60% bleaching, but late postemergence applications exhibited less grain sorghum injury. Therefore, it

is possible that mixing mesotrione with other herbicides will alleviate the injury caused on sorghum plants by mesotrione.

Limited research has indicated that the use of some growth regulators, like 2,4-D or dicamba, may save some herbicides in causing injury. Brown et al. (2004) reported 2,4-D and dicamba in combination with metsulfuron or fluroxypyr exhibited less injury to grain sorghum compared to metsulfuron applied alone. Bararpour, Norsworthy, Hale, and Jones (2017) reported the lowest grain sorghum injury (23%) when mesotrione was applied with dicamba postemergence compared to the combination of mesotrione and atrazine (54%) at 2 wk after application (WAA); furthermore, grain sorghum recovered by 4 WAA with only 2% injury with mesotrione and dicamba and 7% injury with mesotrione and atrazine. A reduction in the injury level observed with mesotrione when added to dicamba may indicate that the addition of dicamba will safen mesotrione, but more research is needed to validate it for sorghum planted in Mid-South United States. Therefore, the objective of this research was to validate the claim that the addition of dicamba to applications of mesotrione will safen grain sorghum against injury when applied postemergence.

2. Materials and Methods

Field studies were conducted in 2017 and 2018 at the Mississippi State University Delta Research and Extension Center in Stoneville, MS. Experiments were conducted on Sharkey clay (very-fine, smectitic, thermic Chromic Epiaquerts) with 2.4% organic matter and pH 7.5. A hybrid grain sorghum variety Pioneer '84P80' (Corteva Agriscience, Indianapolis, IN) was planted on June 8 and May 31 in 2017 and 2018, respectively, at a seeding rate of 23 seeds m⁻¹ row length. This variety was selected for its high yielding characteristic and is commonly grown around the U.S. The plot size was 4 m wide by 6 m long. Row spacing was 102 cm and there were four rows of sorghum in each plot.

The experimental design was a randomized complete block with a factorial arrangement of treatments. Experiments contained two factors including the two-application timings of herbicides (2-leaf stage, 4-leaf stage) and nine herbicide treatments (Table 1). The trade names, site of action, chemical group, and manufacturer information for herbicides used in this study are listed in Table 2. Mesotrione was applied at two rates at 0.07 and 0.105 kg ai ha⁻¹ at 2- and 4-leaf stage of grain sorghum either alone or tank-mix with dicamba at 0.28 kg ae ha⁻¹. Herbicide treatments were applied on June 26, 2017 and June 28, 2018 for the 2-leaf stage of grain sorghum. For 4-leaf stage application timing, the herbicides were applied on July 7, 2017 and July 10, 2018. Environmental data at each application timing in 2017 and 2018 are listed in Table 3. A non-treated control was also included in the study. Herbicide applications were made using a CO₂-pressurized backpack sprayer calibrated to deliver 141 L ha⁻¹ at 276 kPa. The boom consisted of 51-cm nozzle spacing equipped with Turbo TeeJet (TeeJet Technologies, Springfield, IL) Induction (TTI) 110015 nozzles.

Table 1. Herbicide treatments and their application rate used in this study

Treatment	Herbicide	Application rate	Application timing
		kg ai ha ⁻¹	
M1	Mesotrione	0.07	2lf, 4lf [§]
M2	Mesotrione	0.105	2lf, 4lf
M1 + NIS [†]	Mesotrione + Induce (NIS)	0.07	2lf, 4lf
M2 + NIS	Mesotrione + Induce (NIS)	0.105	2lf, 4lf
M1 + C	Mesotrione + Dicamba	0.07 + 0.28 [‡]	2lf, 4lf
M2 + C	Mesotrione + Dicamba	0.105 + 0.28	2lf, 4lf
M1 + C + NIS	Mesotrione + Dicamba + Induce (NIS)	0.07 + 0.28	2lf, 4lf
M2 + C + NIS	Mesotrione + Dicamba + Induce (NIS)	0.105 + 0.28	2lf, 4lf
NTC	Nontreated Check	-	-

Note. [†] NIS = Non-ionic surfactant at 0.25% v/v. [‡] Clarity is in kg ae ha⁻¹. [§] lf = leaf.

Table 2. Herbicide treatments including their trade name, manufacturer, chemical family, group, and site of action used in the study

Herbicide Treatments (common name)	Trade Name	Manufacturer	Chemical family	Group	Site of action
Mesotrione	Callisto (4L)	Syngenta Crop Protection, LLC, Greensboro, NC 27,419	Triketone	27	4-hydroxyphenyl-pyruvatedioxygenase (4-HPPD) inhibitor
Dicamba	Clarity (4SL)	BASF Corporation, Research Triangle Park, NC 27,709	Benzoic acid	4	Synthetic Auxin

Table 3. Environmental data at the time of each application (2-leaf and 4-leaf stages of grain sorghum) in 2017 and 2018

	Herbicide application timing			
	2-leaf stage		4-leaf stage	
	2017	2018	2017	2018
Application date	26 June	28 June	7 July	10 July
Air temperature (°C)	31	28	27	27
% Relative humidity	69	78	78	77
Wind velocity (km hr ⁻¹)	4.8	4.0	6.4	3.2
Soil temperature (°C)	29	28	28	26

Visual injury assessments consisted of estimating treated plants that exhibited symptomologies such as bleaching (which is general symptomology of mesotrione application), stunting, necrosis, and/or chlorosis. Ratings were based on a scale of 0 to 100%, with 0% being no injury and 100% being complete crop death, relative to the nontreated check. Injury ratings were taken thrice after herbicide application and dates for injury rating assessment is provided in Tables 4 and 5. Data on plant height and percent heading in sorghum was also collected after final injury assessment. Grain sorghum was harvested using a Kincaid plot combine on October 17, 2017. Plots were not harvested in 2018 for yield due to untimely rain and high-intensity winds during harvesting season which led to grain loss.

All the collected data were analyzed using SAS statistical software (SAS Institute Inc., Cary, NC) using the GLIMMIX procedure. Prior to analysis, all data was analyzed for normality using the UNIVARIATE procedure in SAS. All of the data was normally distributed. The herbicide treatments and application timing were considered fixed effects, whereas treatment replication was considered as random. Data were analyzed separately for each year since there was a significant effect of the year. Means were separated using T-grouping ($\alpha = 0.05$).

3. Results and Discussion

3.1 Year 2017

In 2017, the injury to grain sorghum assessed on 1 August and 17 August was affected by the interaction of application timing and herbicide treatments as well as by the main effects of application timing and herbicide treatments (Table 4). First grain sorghum physical injury was evaluated four weeks after application (WAA). Averaged over herbicide treatments, grain sorghum showed greater injury to mesotrione application at 4-leaf growth stage (15%) than at 2-leaf growth stage (10%) (Figure 1A). This result may again indicate that grain sorghum is less sensitive to mesotrione application at 2-leaf than 4-leaf. Grain sorghum injury increased from 14% to 19% as mesotrione (alone) application rate at 2-leaf growth stage increased from 0.07 kg ha⁻¹ to 0.105 kg ha⁻¹ (Figure 1A). Similarly, increasing mesotrione (alone) application rate from 0.07 kg ha⁻¹ to 0.105 kg ha⁻¹ at 4-leaf growth stage increased injury to sorghum plants from 10% to 24%. Grain sorghum injury level was 16 and 15% from 0.07 and 0.105 kg ha⁻¹ mesotrione alone + NIS applications at 2-leaf growth stage, respectively. However, the application of dicamba with mesotrione to the tank at 2-leaf growth stage reduced grain sorghum injury 4 WAA (Figure 1A). This indicates that dicamba had safening effect on grain sorghum from mesotrione.

Table 4. Probability values for year 2017 data generated from statistical model associated with injury ratings, plant height, sorghum heading and sorghum grain yield determined for herbicide treatments and application timing

Source of variation	df	Injury rating (2017)			Plant height (cm)	Heading (%)	Grain yield (kg ha ⁻¹)
		1 August	17 August	29 August			
----- p-value -----							
Herbicide Treatment (HT)	8	<0.0001	0.0017	0.0867	<0.0001	0.0051	0.0582
Application Timing (AT)	1	<0.0001	0.0314	0.1245	0.5078	0.1657	0.0037
HT × AT	8	<0.0001	0.0367	0.8595	0.2328	0.9953	0.0003

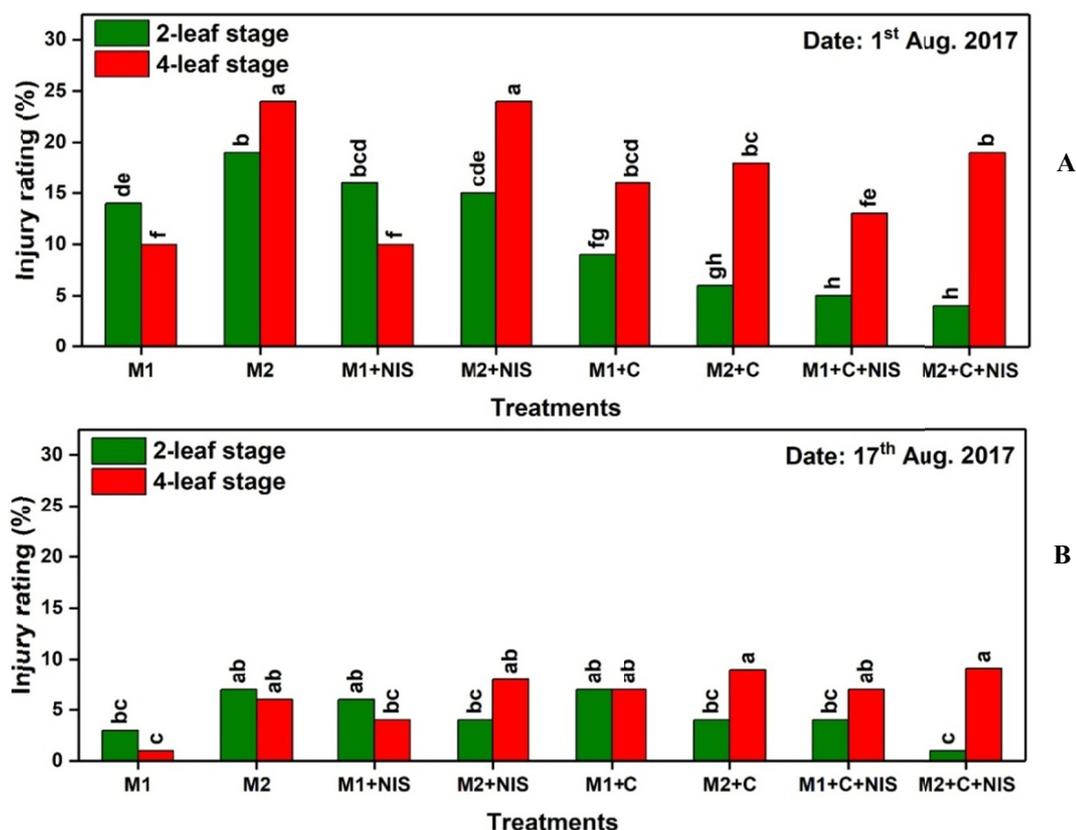


Figure 1. Injury due to herbicide treatments to grain sorghum in 2017 evaluated at 2-leaf and 4-leaf growth stage 4 weeks (A) and 7 weeks (B) after applications. The same letter on bars indicate no significant differences at $p < 0.05$. Abbreviations: M1, Mesotrione at 0.07 kg ai ha⁻¹; M2, Mesotrione at 1.05 kg ai ha⁻¹; C, Dicamba at 0.28 kg ae ha⁻¹; NIS, Non-ionic surfactant at 0.25% v/v

Grain sorghum recovered from mesotrione applications over time by 7 WAA for injury ratings assessed on 17 August 2017 (Figure 1B). Seven weeks after herbicide applications, grain sorghum physical injury showed that grain sorghum was more sensitive at 4-leaf growth stage (6%) than 2-leaf growth stage (4%) from mesotrione applications (Figure 1B). Application of dicamba with mesotrione (0.105 kg ha⁻¹) reduced grain sorghum injury when compared to the application of mesotrione alone at 0.105 kg ha⁻¹ at 2-leaf growth stage. Adding of dicamba to mesotrione reduced grain sorghum injury when application was made at 2-leaf grain sorghum (Figure 1A). Also, addition of dicamba + mesotrione + NIS tank-mix reduced grain sorghum injury when application was made at 2 leaf grain sorghum but not at 4 leaf grain sorghum.

Grain sorghum plant heights were affected by the main effects of herbicide treatments in 2017 (Table 4). Sorghum plant height was 123 cm in non-treated check, which was significantly higher than plant heights in all other herbicide treatments except in mesotrione (0.105 kg ha⁻¹) + NIS (121 cm) (Figure 2). Application of dicamba with mesotrione reduced plant height when compared to the application of mesotrione alone, irrespective of the application rate of mesotrione in 2017.

Similar to plant heights, percent grain sorghum heading was significantly affected by the main effect of herbicide treatments. Percent grain sorghum heading ranged from 97 to 99% regardless of herbicide treatments or grain sorghum growth stages, whereas the percent heading in nontreated check was 100% (Figure 2).

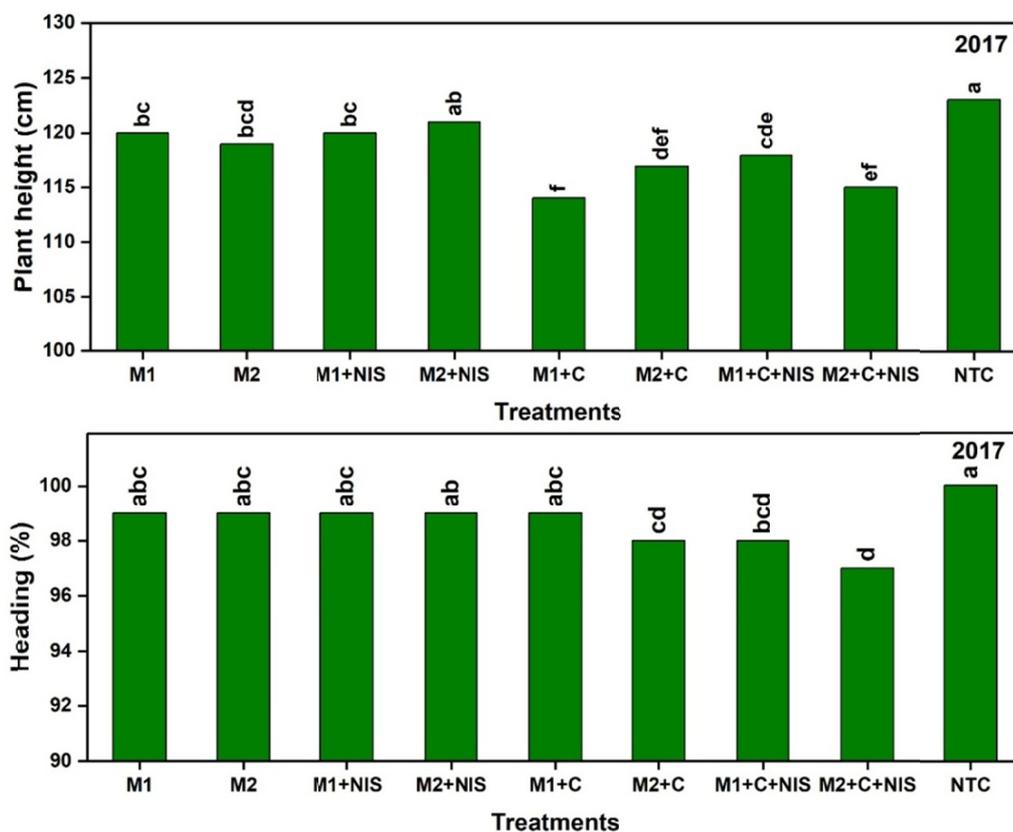


Figure 2. Difference in plant height and grain sorghum heading due to herbicide treatments in 2017. The same letter on bars indicate no significant differences between treatments at $p < 0.05$. Abbreviations: M1, Mesotrione at $0.07 \text{ kg ai ha}^{-1}$; M2, Mesotrione at $1.05 \text{ kg ai ha}^{-1}$; C, Dicamba at $0.28 \text{ kg ae ha}^{-1}$; NIS, Non-ionic surfactant at $0.25\% \text{ v/v}$; NTC, Nontreated check

Grain sorghum yield was affected by the main effects of herbicide application timing and interaction of herbicide application timing and herbicide treatments (Table 4 and Figure 3). At 2-leaf application timing for herbicide treatments, the mesotrione at 0.07 kg ha^{-1} + dicamba + NIS had 4444 kg ha^{-1} greater sorghum yield than Mesotrione at 0.105 kg ha^{-1} + NIS. At 4-leaf sorghum application stage, mesotrione applied at 0.07 kg ha^{-1} resulted in greater grain yield than all other herbicide treatments, except mesotrione (0.105 kg ha^{-1}) + NIS. Addition of dicamba to the mesotrion (0.07 kg ha^{-1}) plus NIS numerically increased grain sorghum yield when application was made at 2-leaf grain sorghum stage probably due safening (reduced injury) effect of dicamba.

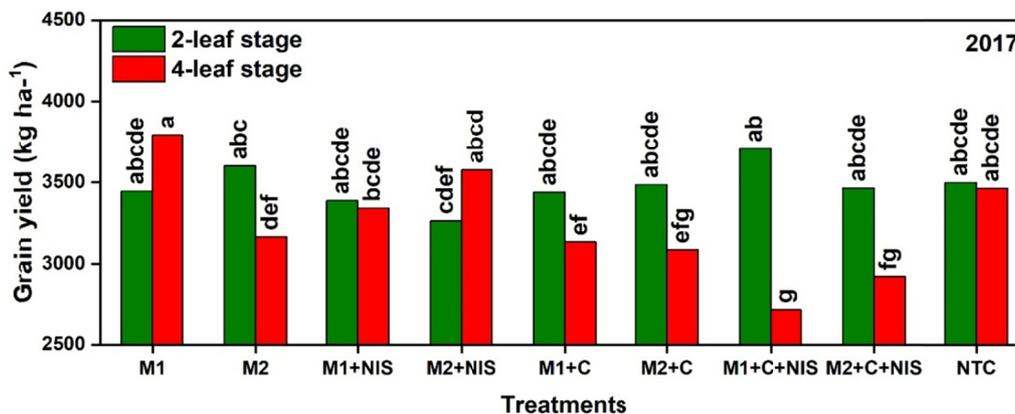


Figure 3. Grain sorghum yield due to herbicide treatments in 2017. The same letter on bars indicate no significant differences between treatments at $p < 0.05$. Abbreviations: M1, Mesotrione at $0.07 \text{ kg ai ha}^{-1}$; M2, Mesotrione at $1.05 \text{ kg ai ha}^{-1}$; C, Dicamba at $0.28 \text{ kg ae ha}^{-1}$; NIS, Non-ionic surfactant at $0.25\% \text{ v/v}$; NTC, Nontreated check

3.2 Year 2018

There were no significant differences in grain sorghum injury based on herbicide treatments or application timing from mesotrione applications on 9 July and 2 August evaluations (data not shown) (Table 5). However, grain sorghum injury was significantly different based on mesotrione applications on 7th August evaluations (Figure 4). Mesotrione application alone at 0.07 and 1.05 kg ha^{-1} caused a 6% injury to sorghum plants. Adding dicamba to the mesotrione tank-mix reduced the level of grain sorghum injury by 1 to 2%, indicating safening effect of dicamba in terms of grain sorghum injury from mesotrione application. However, the addition of NIS with dicamba and mesotrione did not reduce injury to sorghum plants. Plant height and percent heading were not significantly affected by the herbicide treatments or application timing in 2018 (Table 5) (data not shown).

Table 5. Probability values for year 2018 data generated from the statistical model associated with injury ratings, plant height, sorghum heading, and sorghum grain yield determined for herbicide treatments and application timing

Source of variation	df	Injury rating (2018)			Plant height (cm)	Heading (%)
		19 July	2 August	7 August		
		p-value				
Herbicide Treatment (HT)	8	0.3250	0.4805	0.0064	0.5192	0.8318
Application Timing (AT)	1	0.0724	0.3961	0.7690	0.6943	0.3382
HT × AT	8	0.4777	0.6904	0.2509	0.7596	0.9957

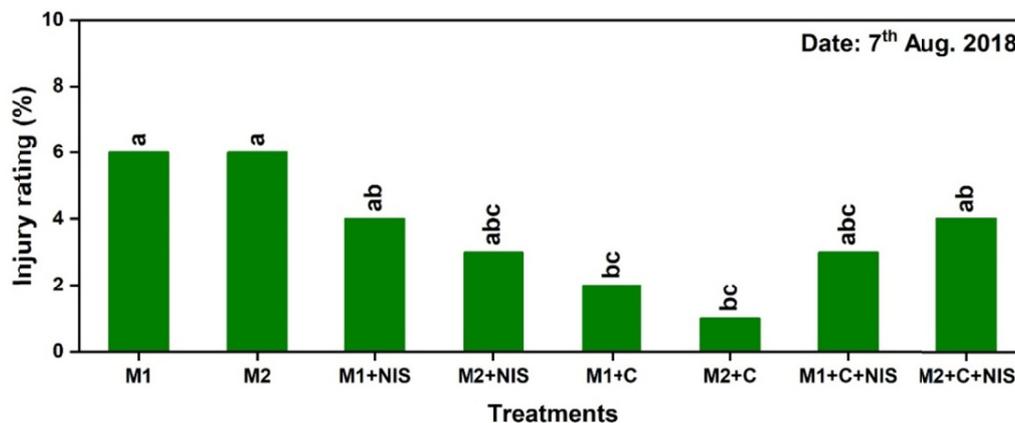


Figure 4. Injury due to herbicide treatments to grain sorghum in 2018. The same letter on bars indicate no significant differences between treatments at $p < 0.05$. Abbreviations: M1, Mesotrione at $0.07 \text{ kg ai ha}^{-1}$; M2, Mesotrione at $1.05 \text{ kg ai ha}^{-1}$; C, Dicamba at $0.28 \text{ kg ae ha}^{-1}$; NIS, Non-ionic surfactant at $0.25\% \text{ v/v}$

Mesotrione inhibits the hydroxyphenylpyruvate dioxygenase (HPPD) enzyme, which disrupts carotenoid biosynthesis and results in inhibition of plastoquinone synthesis (Duke, Dayan, Romagni, & Rimando, 2000; Wichert, Townson, Bartlett, & Foxon, 1999). Plastoquinone is a cofactor for phytoene desaturase, a necessary enzyme for carotenoid synthesis and it is also involved in the phosphorylation process. In our study, injury to sorghum plants was observed due to mesotrione applications. Similar to our study, Horkey and Martin (2005) reported 20% chlorosis on sorghum plants due to mesotrione when it was applied post-emergence at $70.5 \text{ g ai ha}^{-1}$. Miller and Regehr (2002) observed that early POST application of mesotrione caused severe plant injury, such as 40 to 60% bleaching, but less injury was caused with late POST applications.

Yield reduction due to mesotrione alone application at a lower rate was not present when mesotrione was applied at the 2-leaf stage in our study. Similarly, Abit, Al-Khatib, Stahlman, and Geier (2012) did not find any significant yield reductions in spite of severe mesotrione injury to grain sorghum. The authors reported that yield reduction was not well correlated with the visible mesotrione injury. Adding dicamba to the tank mix with mesotrione resulted in lowering physical injury to sorghum plants in our study indicating the safening effect of dicamba to mesotrione applications in sorghum. Similarly, Brown et al. (2004) also reported that dicamba safened grain sorghum from metsulfuron injury. However, adding dicamba also reduced yield of grain sorghum when mesotrione was applied at a lower rate of 0.07 kg ha^{-1} at later timing (4-leaf growth stage). The use of dicamba with mesotrione also reduced plant height in 2017. This indicates that dicamba should be avoided to be used with mesotrione at later application timing (4-leaf stage of grain sorghum).

4. Conclusions

The presence of weeds can result in severe yield losses in grain sorghum. There are limited herbicide options for weed management in grain sorghum. Mesotrione is labeled for preemergence application in grain sorghum since its post-emergence application can cause leaf injury in grain sorghum. Our study evaluated the use of dicamba with mesotrione in a tank mix to safen grain sorghum from injury. Our study results indicate that adding dicamba to mesotrione (postemergence) safens grain sorghum from injury caused by mesotrione alone. Therefore, mesotrione could be an option to use for as postemergence application for weed management in grain sorghum.

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