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Short communication

Bioefficacy and phytotoxicity of pre- and post-emergence herbicides in grain sorghum

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Grain sorghum [*Sorghum bicolor* (L.) Moench], an important cereal crop of semi-arid tropical regions of India is traditionally grown for food, animal feed and fodder; but is also used as an industrial feedstock, and for biofuels. Weeds are a major deterrent in increasing the sorghum productivity, especially during rainy season. Grain sorghum seedlings are comparatively small and grow slowly for the first 20-25 days (Vanderlip 1979) and consequently do not compete well with most weeds in the early stage of crop growth, resulting in a yield loss of 15-83% depending on crop cultivars, nature and intensity of weeds, spacing, duration of weeds infestation and environmental conditions (Mishra *et al*. 2012). Planting sorghum in wider rows to facilitate inter-row cultivation further increases the weed problems. Weed control in grain sorghum is a challenge because of the availability of limited number of herbicides to farmers (Fromme *et al*. 2012). Early competition, especially from grasses is critical to control to avoid yield loss.

Sorghum producers in semi-arid tropical regions of India rely on hand weeding and mechanical cultivation to control weeds. However, repeated cultivation can accelerate loss of soil organic matter, increases soil erosion and promotes the emergence of new weed flushes. Scarcity of labour for hand weeding, and high costs are the major limitations of hand weeding. Atrazine (as pre-emergence) is the most widely used herbicide for weed control in grain sorghum. However, the efficacy of pre-emergence herbicides is moisture dependent. Too little or excessive moisture after herbicide application can result in poor weed control (Tapia *et al*. 1997). However, it has a low effectiveness on grasses (Dan *et al*. 2011). Atrazine may also cause carry over effects in subsequent sensitive crops under some conditions, so alternative treatments are needed (Ishaya *et al*. 2007, Keeling *et al*. 2013). Sensitivity of grain sorghum to currently available post-emergence grass herbicides is one of the major concerns to manage grassy weeds that emerge after crop establishment (Archangelo *et al*. 2002). Hence, atrazine may be combined with the grassy herbicides such as pendimethalin, metolachlor or alachlor to broaden the weed control spectrum. Combinations of these products with atrazine as tank mixes or premixes applied as pre-emergence will control most seedling grasses and broadleaf weeds for three to four weeks. In general, controlling grassy weeds that emerge after crop establishment is difficult because post-emergence herbicide options to control grass weeds in grain sorghum are limited (Hennigh *et al*. 2010, Abit and Al-Khatib 2013). Hence, the present investigation was undertaken to evaluate the bio-efficacy and phytotoxicity of new herbicide molecules in grain sorghum during rainy season.

A field experiment was conducted during rainy season of 2014 at the ICAR-Indian Institute of Millets Research, Hyderabad to evaluate weed control and grain sorghum response to herbicides. The climate of the area is semi-arid and tropical, with an average annual rainfall of 618 mm (75-80% of which is received during June-September), minimum temperature of 8-10 ^{0}C in December, and maximum temperature of 40-42 ^{0}C in May. The total rainfall received during cropping season (June-October) was 887 mm. The soil was an Alfisol, Udic Rhodustalf, sandy loam (66% sand, 13% silt and 21% clay), with 7.42 pH, 0.18 dS/m electrical conductivity, 0.39% organic carbon, 1.63 g/cc bulk density, 7.34% available soil moisture; low in available N (163 kg/ha), medium in available P (29 kg P_2O_5/ha) and high in K (360 kg K_2O/ha) content. A randomized complete-block experimental design was used and treatments were replicated three times.

Herbicide treatments (Table 1) were pre-emergence tank mix application of atrazine + pendimethalin, pendimethalin + imazethapyr, ready

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Table 1. Effect of herbicides on weed density, weed dry weight and weed control efficiency in sorghum

Treatment	Weed population at harvest (no./m^2)*				Total weed dry weight (g/m^2)	WCE (%)
	Broad-leaf	Grasses	Sedges	Total		
Atrazine PE (500 g/ha)	1.58 (2)	2.92 (8)	3.35 (5)	3.95 (15)	6.47 (47)	78.3
Atrazine + pendimethalin (tank mix) PE(500+750g/ha)	1.90 (3)	2.35 (5)	3.35 (5)	3.72 (13)	4.93 (33)	84.7
Pendimethalin + imazethapyr (tank mix) PE(750+100g/ha)	4.55 (20)	3.67 (13)	2.92 (8)	6.45 (41)	10.8 (124)	42.8
Penoxsulam PE (25 g/ha)	2.35 (5)	2.12 (4)	2.15 (4)	3.77(13)	4.13 (17)	92.1
Pendimethalin+ imazethapyr ready mix PE (750 + 50 g/ha)	1.91 (3)	1.58 (2)	1.87 (3)	2.96 (8)	2.3 (7)	96.7
Imazethpyr + imazamox ready mix (70 g/ha)	1.59 (2)	2.74 (7)	2.55 (6)	3.98 (15)	5.94 (36)	83.4
Penoxsulam as post-emergence at 15 DAS (25 g/ha)	6.52 (42)	4.75 (22)	3.54 (12)	8.77 (76)	14.3 (207)	4.6
Atrazine as post- emergence at 15 DAS (500 g/ha)	3.94 (15)	4.31 (18)	3.54 (12)	6.74 (45)	11.2 (125)	42.4
Imazethapyr as post- emergence at 15 DAS(100 g/ha)	4.55 (20)	9.41 (70)	4.18 (17)	10.41 (107)	20.1 (405)	0
Imazethpyr + imazamox ready mix at 15 DAS (70 g/ha)	3.95 (15)	7.71 (59)	3.81 (14)	9.41 (88)	18.8 (355)	0
Weedy check	8.69 (75)	5.53 (30)	3.10(9)	10.72 (114)	14.5 (217)	0
LSD (P=0.05)	1.34	1.57	1.45	2.36	4.17	

*Data subjected to square root transformation ($\sqrt{x+0.5}$). Values in parentheses are original; PE=Pre-emergence (1 DAS); DAS=Days after sowing

mix application of pendimethalin+ imazethapyr, imazethpyr + imazamox, penoxsulam, and post-emergence application of penoxsulam, atrazine, imazethapyr and imazethpyr + imazamox. A non-treated control (weedy check) and standard pre-emergence herbicide atrazine were included for comparison. The sorghum hybrid '*CSH 16*' was sown manually in rows at 45 x 15 cm on 8 July 2014 and was later thinned to one plant per stand at 15 days after sowing (DAS). Herbicides, as per treatments, were applied in 500 l/ha spray volume with knapsack sprayer fitted with flat-fan nozzle. Pre-emergence herbicides were applied next day after sowing and post-emergence herbicides were applied at 15 DAS. Fertilizer (80 kg N, 40 kg P_2O_5 and 40 kg K_2O/ha) was applied as recommended for grain sorghum in the area. All the phosphorus as single super phosphate and potassium as muriate of potash were applied as basal on the day of planting. Nitrogen as urea was applied in 2 splits, 50% at sowing and remaining at 35 DAS. Sorghum crop injury was estimated by visual rating on a scale of 0 (no injury) to 100% (crop death) at 2 weeks after post-emergence herbicide application. Sorghum grain was manually harvested from middle 6 rows of each plot, weighed, and grain yield was adjusted to 14% moisture content. Weed count, for estimating weed density, and total weed dry weight were recorded at crop maturity with the help of a quadrate (0.50 m x 0.50 m) placed randomly at four spots in each plot. The data on weed dry weight were subjected to square root transformation ($\sqrt{x+0.5}$) before statistical analysis.

The experimental field was infested with mixed weed flora comprised of broad-leaved, grasses and sedges. The relative density of broad-leaved weeds was higher (65.8%) compared to grasses (26.3%) and sedges (7.9%). The dominant broad-leaf weeds were day flower (*Commelina benghalensis* L.), horse purslane (*Trianthema portulacastrum* L.), tridax daisy (*Tridax procumbens* L.), Indian borage [*Trichodesma indicum* (L.) R. Br.], and Parthenium (*Parthenium hysterophorus* L.); grass weed species include jungle rice [*Echinochloa colona* (L.) Link.], Indian goosegrass [*Eleusine indica* (L.) Gaertn.], viper grass [*Dinebra retroflexa* (Vahl) Panzer], common crab grass [*Digitaria sanguinalis* (L.) Scop.], and crowfoot grass [*Dactyloctenium aegyptium* (L.) Willd.]; and sedges such as rice flatsedge (*Cyperus iria* L.) and purple nutsedge (*Cyperus rotundus* L.).

Application of herbicides except imazethapyr and imazethpyr + imazamox applied at 15 DAS significantly reduced the weed density at harvest as compared to weedy check (Table 1). Post-emergence application of these herbicides caused complete mortality of both sorghum plants and weeds at 2 weeks after herbicide application. However, the second flush of weeds emerged, but no sorghum plants. In absence of competition from crop, weeds germinated in large numbers, grew profusely and accumulated higher dry matter even more than that of weedy check. New herbicide molecules, *viz*. penoxsulam, Pendimethalin+ imazethapyr, and imazethpyr + imazamox were very effective in controlling weeds. Penoxsulam at 15 DAS was less effective in reducing the density and dry weight of weeds as compared to its pre-emergence application. Application of herbicides significantly influenced the growth, yield attributes and yield of grain sorghum (Table 2). Leaf area index was significantly lower in penoxsulam and atrazine when applied at 15 DAS as compared to their pre-emergence applications. Pre-emergence application of imazethpyr + imazamox

Table 2. Effect of herbicides on growth, yield attributes and yields of grain sorghum

Treatment	LAI at 60 DAS	Plant height at harvest (cm)	Number of panicles/m^2	Panicle length (cm)	Grains/ panicle	100-grain weight (g)	Grain yield (t/ha)	Dry fodder yield (t/ha)
Atrazine PE (500 g/ha)	4.72	205	13.93	32.0	1146	3.64	5.81	12.89
Atrazine + pendimethalin (tank mix) PE (500+750g/ha)	5.12	204	12.03	31.3	1595	3.09	5.87	13.33
Pendimethalin + imazethapyr (tank mix) PE (750+100g/ha)	5.20	197	11.83	31.4	1120	3.43	3.72	11.55
Penoxsulam PE (25 g/ha)	4.60	203	13.40	31.9	1152	3.07	4.35	10.22
Pendimethalin+ imazethapyr ready mix) PE(750 + 50 g/ha)	4.60	200	13.11	33.7	1059	3.26	4.72	8.67
Imazethpyr + imazamox ready mix (70 g/ha)	4.37	209	14.52	32.6	631	3.39	3.10	10.67
Penoxsulam (Granite 21.7%)15 DAS(25 g/ha)	3.53	207	13.49	31.5	888	3.63	4.01	8.09
Atrazine 15 DAS (500 g/ha)	3.93	209	12.47	30.3	1012	3.53	4.46	11.55
Imazethapyr 15 DAS (100 g/ha)	0	0	0	0	0	0	0	0
Imazethpyr + imazamox ready-mix at 15 DAS (70 g/ha)	0	0	0	0	0	0	0	0
Weedy check	3.01	209	11.17	31.5	970	3.08	3.70	9.78
LSD (P=0.05)	0.79	11	1.06	2.58	398	0.50	1.06	2.92

*values in parentheses are original

ready mix and post-emergence application of penoxsulam produced the lower number of grains/ panicle as compared to other herbicides. Although pre-emergence application of pendimethalin + imazethapyr ready mix resulted in higher weed control efficiency (96.77%), the maximum grain yield of sorghum (5.87 t/ha) was recorded with tank mix application of atrazine + pendimethalin (500+750 g/ha) applied as pre-emergence. Atrazine as post-emergence produced lower grain yield (4.46 t/ha) as compared to its pre-emergence application (5.81 t/ha) due to lower efficacy on weeds. Tank mix pre-emergence application of pendimethalin + imazethapyr caused significant reduction in plant population (data not shown) and number of panicles/ m^2 compared to atrazine alone. This has resulted in significant reduction in grain yield. Although visual injury on sorghum plants with pre-emergence ready mix application of pendimethalin+ imazethapyr (Velore) and imazethpyr + imazamox (Odessey), and post-emergence application of penoxsulam was less severe and slight yellowing on leaves was observed, which recovered at harvest, but these herbicides produced lower grain yield due to reduction in number of grains/panicle. The lowest grain yield (3.1 t/ha) was recorded with pre-emergence application of imazethpyr + imazamox. Infestation of weeds throughout the cropping season caused 37 % reduction in grain yield. The yield components most reduced by weed competition are number of heads per plant, panicle size, and numbers of seeds per panicle or head (Hwang *et al.*, 2015). Similarly, penoxsulam applied as pre-emergence caused significant reduction in population and dry matter accumulation of weeds and produced higher grain yield as compared to its post-emergence application. Pre-emergence ready mix application of pendimethalin + imazethapyr (750 + 50 g/ha) was more effective in controlling weeds and increasing grain sorghum yield than its tank mix application (750 + 100 g/ha), due to phytotoxicity of higher dose of imazethapyr (100 g) in the tank mix, which resulted in lower plant population (data not shown) and number of panicles/m^2. Lower plant population of sorghum in tank mix application might have allowed more weeds to emerge and accumulate higher dry matter.

The study showed that tank mix application of atrazine + pendimethalin (500 + 750 g/ha) as pre-emergence effectively controlled the weeds and increased grain sorghum yields. New herbicide molecules *viz.*, penoxsulam, pendimethalin+ imazethapyr and imazethpyr+ imazamox, though effectively controlled the weeds but reduced the grain yield due to reduction in number of grains/panicle. Post-emergence application of imazethapyr and odessey was highly phytotoxic to sorghum.

SUMMARY

Bio-efficacy and phytotoxicity of pre-emergence tank mix application of atrazine + pendimethalin, pendimethalin + imazethapyr, ready mix application of pendimethalin+ imazethapyr (Velore), imazethpyr + imazamox (Odessey), penoxsulam, and post-emergence application of penoxsulam, atrazine, imazethapyr and imazethpyr +

imazamox along with standard pre-emergence herbicide atrazine were evaluated at ICAR-Indian Institute of Millet Research, Hyderabad during rainy season of 2014. The field was dominated with broad-leaved weeds (65.8%) followed by grasses (26.3%) and sedges (7.9%). Infestation of weeds throughout the cropping season caused 37 % reduction in grain yield. Post-emergence (15 DAS) application of imazethapyr and velore herbicides was highly phytotoxic and caused complete mortality of both sorghum plants and weeds at 2 weeks after herbicide application. Tank mix application of atrazine + pendimethalin (500 + 750 g/ha) as pre-emergence was safe and most effective in sorghum. Atrazine as post-emergence was less effective than its pre-emergence application. New herbicide molecules *viz*., penoxsulam, velore and odessey, though effectively controlled the weeds but reduced the grain yield due to reduction in number of grains/panicle.

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