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Exogenous application of sulphydryl compounds enhances growth, photosynthetic efficiency and yield of moth bean (*Vigna aconitifolia* L.) under water limiting environment

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ABSTRACT

A two year field experiment was conducted in hot arid region at Bikaner, Rajasthan to investigate the effects of application of sulphydryl compounds (thioglycollic acid, TGA; thiourea TU) on growth traits, photosynthetic efficiency, yield components and yield of moth bean under water deficit conditions. The experiment comprised seven treatments (water spray, TGA 200 mg L^{-1}, TGA 300 mg L^{-1}, TGA 400 mg L^{-1}, TU 500 mg L^{-1}, TU 750 mg L^{-1} and TU 1000 mg L^{-1}) and laid out in randomized block design with three replications. Application of sulphydryl compounds had significant effects on growth, photosynthetic traits, activities of anti-oxidant enzymes, and yield of moth bean. The sulphydryl compounds sprayed plants had 24-70, 13-40 and 13-20% higher activities of antioxidant enzymes (glutathione reductase, GR; gluthathione-s-transferase, GST), photosynthetic parameters (net photosynthetic rate, P_N; stomatal conductance, g_s; transpiration rate, E) and seed yield respectively compared to unsprayed plants. The results suggest that application of sulphydryl compounds mitigate moisture deficit induced negative effects on growth and photosynthetic parameters which lead to better seed yield of moth bean.

Key words: Antioxidant enzymes, Photosynthetic parameters, Seed yield, Sulphydryl compounds.

INTRODUCTION

Abiotic stresses such as drought, salinity, high temperature, low temperature adversely affect plant growth and agricultural productivity. Amongst the various abiotic stresses, drought is the most devastating stress limiting crop production and yield worldwide, particularly in arid and semi-arid regions (Araujo *et al*., 2015). It is estimated that 70% of crop yield loss can be attributed to abiotic stresses, especially drought. Growth and yield are functions of a large number of metabolic processes, which are affected by environmental and genetic factors. Studies of growth pattern and its understanding not only tell us how plant accumulates dry matter, but also reveals the events which can make a plant more or less productive individually or in population. In a crop the growth parameters like LAI and CGR at flowering have been identified as the major determinants of yield. The combination of these growth parameters explain different yields better than any individual growth variable. Tesfaye *et al.,* (2006) reported the attainment of high LAI that reduces soil water evaporation intercepts and converts radiation into dry matter efficiency and partitioning of the dry matter to the seed is the major requirement of a high seed yield in grain legumes in arid environment.

Bioregulators are considered as new generation agrochemicals after fertilizer, pesticides and herbicides, which enhance the crop yield. Application of bioregulators may modify morphological and physiological characteristics of plant to the environment which improves the growth dry matter production and yield (Pandey *et al*., 2013; Kaya *et al*., 2015). Numerous plant bio-regulators (PBR's) and other plant hormones have been recently tried to impart stress tolerance to crop under water deficit (Perveen *et al*. 2016; Ratnakumar *et al*., 2016; Wahid *et al*., 2017). Thiourea (TU) and thioglycollic acid (TGA) as the sulphydryl groups has diverse biological activities. It helps to improve phloem translocation of photosynthate in crop plants and thereby, induces drought, heat stress and salinity tolerance in cereals, pulses, legumes and oilseeds (Srivastava *et al*., 2008; Asthir *et al*., 2015; Jhanji and Dhingra, 2018; Nathawat *et al*., 2018).

Moth bean (*Vigna aconitifolia* jacq.) is an important legume crop of arid regions of Rajasthan (Rathore *et al*., 2009). It is cultivated on ~ 1 million hectares as a rainfed crop. Water deficit caused by erratic rainfall and dry atmosphere leads to the poor yield of moth bean in hot arid region (Burman *et al.,* 2002). Drawing on these insights, the present study was undertaken to assess the effects of exogenous application of sulphydryl compounds on growth, activities of antioxidant enzymes, photosynthetic traits and

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yield of moth bean under water limiting condition in a hot arid environment.

MATERIALS AND METHODS

An experiment was conducted during two *kharif* seasons (July-October) in 2010 and 2011 at the ICAR-Central Arid Zone Research Institute, Regional Research Station, Bikaner (28°4′ N; 74°3′ E; 238.3 m above mean sea level), Rajasthan, India. The climate of the area is characterized as arid with hot and dry spring-summer from April to June, hot and humid summer from July to September. The average annual rainfall is about 287 mm, most of which is received during the monsoon period (July to September). The total amount of rainfall received during the crop seasons (from July to October) was 279 mm, and 340 mm in 2010 and 2011, respectively. The soil of the experimental field was sandy in texture having pH 8.4, with 0.16% organic carbon, 9.8 kg P ha^{-1} and 236.0 kg K ha^{-1}. The experiment comprised seven treatments *i.e.* water spray, TGA 200 mg L^{-1}, 300 mg L^{-1} and 400 mg L^{-1}, TU 500 mg L^{-1}, 750 mg L^{-1} and 1000 mg L^{-1} and laid out in a randomized complete block design with three replications. Two foliar sprays of the –SH compounds were applied at vegetative and pre-flowering stages of the crop. Size of plot was 5.0 × 4.0 m. After receiving adequate monsoon rain, the land was prepared by a tractor-drawn disc harrow. Moth bean (cultivar RMO-225) was sown on 1 August and 30 July during 2010 and 2011, respectively.

Dry matter accumulation

Ten plants were randomly taken from the central 2 × 2 -m area of each plot to determine dry matter (DM) accumulation per plant at 40, 50 and 60 days after sowing. The plants were oven dried at 65°C ± 5°C till constant dry weight.

Leaf area index (LAI)

Leaf area (LA) was measured at 40, 50 and 60 DAS by a leaf area meter. LAI was calculated by using the formula given by Watson (1947). LAI = Leaf area/Land area

Crop growth rate (g/m^2/d)

Dry matter (DM) accumulation was determined at 40, 50 and 60 DAS from each plot. Afterwards samples were dried in oven at 65°C ± 5°C till constant dry weight. Then dry weight per square meter was calculated and was used to estimate crop growth rate (CGR), as proposed by Hunt (1978). CGR expressed as g. m^{-2}.day^{-1}.

$$CGR = W_2\text{-}W_1 / t_2\text{-}t_1$$

Where

W_2 = dry weight per unit land area (g m^{-2}) at second harvest.

W_1 = dry weight per unit land area (g m^{-2}) at first harvest.

t_2 = time corresponding to second harvest.

t_1 = time corresponding to first harvest.

Relative growth rate (RGR)

The equation suggested by Causton (1991) was used to calculate RGR and expressed as mg $g^{-1}day^{-1}$:

$$RGR = Log_e W_2 - log_e W_1 / t_2 - t_1$$

Log_e is natural logarithms W_1 and W_2 are dry weight at time t_1 and t_2, respectively.

Net assimilation rate (NAR)

NAR was calculated by Williams (1948) and expressed as mg cm^{-2} day^{-1}.

$$NAR = W_2 - W_1 / t_2 - t_1 \times Log_e LA_2 - Log_e LA_1 / LA_2 - LA_1$$

LA_1 and LA_2 are the leaf area (cm^2) and W_1 and W_2 are total dry weight of a plant (g) at time interval t_1 and t_2 (days), respectively.

Determination of antioxidant enzyme activities

Leaf samples (0.5 g fresh weight) were homogenized in ice-cold 50 mM potassium phosphate buffer (pH 7.0) containing 0.1 mM ethylene diamine tetraaceatic acid (EDTA) and 1% (w/v) polyvinyl polypyrolidone (PVP). The homogenate was filtered through four layers of cheese cloth and then centrifuged at 4°C for 20 min at 15,000 × g. The supernatant was collected and an appropriate aliquot dilution of the crude extract was used for the following assays. The activity of glutathione reductase (GR) was measured as described by Shaedle and Bassham (1977) by following the decrease in absorbance at 340 nm (ε = 6.2 mM^{-1} cm^{-1}) for 1 min. The reaction mixture contained 50 mM Tris-HCl buffer (pH 7.5), 0.5 mM GSSG, 0.1 mM EDTA, 3 mM $MgCl_2$ and 0.15 mM NADPH. GR activity was expressed as µmol (NADPH oxidized) mg^{-1} (protein) min^{-1}. GST activity was measured as per Mannervik and Guthenberg (1981) by following the changes in the absorbance at 340 nm for 1 min in a mixture containing 100 mM sodium phosphate buffer (pH 6.5), 1 mM GSH and 1 mM 1-chloro-2, 4-dinitrobenzene. The activity of GST was expressed as µmol (2,4-dinitrophenyl glutathione formed) mg^{-1} (protein) min^{-1} (ε = 9.8 mM^{-1} cm^{-1}).

Determination of gas exchange parameters

Gas exchange parameters, *i.e.* net photosynthetic rate (P_N), stomatal conductance (g_s) and transpiration rate (E) were measured in vivo with a portable photosynthesis system (TPS - 2 CO_2 Gas Analyzers, USA). Measurements were made on fully formed leaves located in the upper third part of the canopy. Measurements were done in sunny and clear weather, in the period between 0900 and 1100 hours.

Determination of growth, yield attributes and yield

Yield components, *i.e.* pod per square meter and 100-seed weight (SW) were recorded for all the plants from the central 2 × 2 -m area of each plot at harvest. At the maturity stage of the crop seed yield (SY) and total above-ground biomass (ABY) were determined on an area of 2 × 2 m from each plot by manual harvesting of plants 3 cm above the ground and allowed to dry in the field. Yields of seed and straw were determined by drying sub-samples in a convection oven at 65°C to a constant weight.

Statistical analysis

All measured parameters were tested for significant differences between treatments using analysis of variance

(ANOVA) for a randomized complete block design. Wherever significant, separation of treatment means was achieved by the procedure of least significant difference (LSD) as described by Gomez and Gomez (1984) at ά = 0.05.

RESULTS AND DISCUSSION

Growth attributes

Exogenous application of sulphydryl compounds had significant effects ($p \leq 0.05$) on DMA, LAI, NAR, RGR and CGR in moth bean (Table 1 and 2). Averaged across both the years, the -SH sprayed plants had 11.4 - 19.6, 18.0 - 27.2 and 24.1- 38.3% higher DMA than unsprayed plants measured at 40, 50 and 60 DAS, respectively. The LAI varied from 0.86 - 1.04, 0.97 - 1.41 and 1.35 - 2.01 at 40, 50 and 60 DAS respectively. Compared with unsprayed plants, the -SH treated plants had 14.1– 21.2, 21.3 - 28.4 and 23.6 - 33.2% higher LAI at 40, 50 and 60 DAS (Table 1). Among the tested treatments, TGA 400 mg L^{-1} treated plants had the highest DMA and LAI followed by plants treated with TU 1000 mg L^{-1} at 60 DAS (Table 1). Water stress induced reduction in LAI is ascribed to decline in cell wall turgor and photosynthesis. The better LAI of moth bean treated with –SH compounds may be explained by their ability to maintain higher cell turgor and photosynthesis under moisture deficit conditions. The higher LAI coupled with higher P_N might be responsible for enhanced DMA with sulphydryl compounds treated plants (Garg *et al*., 2006: Burman *et al.,* 2008 and Nathawat *et al*., 2018). During the different growth stages, growth indices mean value variation were recorded as : NAR between 0.60 – 80 and 7.7 - 10.1 mg.cm^{-2}.d^{-1}; RGR between 29.9 - 50.4 and 40.6 - 53.3 mg. g^{-1}.d^{-1}; CGR between 4.2 - 9.6 and 7.8 - 16.9 g. m^{-2}.d^{-1} during 40-50 DAS and 50 - 60 DAS growth interval, respectively. The foliar applied TGA 400 mg L^{-1} had highest NAR, RGR and CGR followed by TU 1000 mg L^{-1}, TGA 300 mg L^{-1} and TU 750 mg L^{-1} (Table 2).

The significant enhancement in DMA due to application of sulphydryl compounds (Table 1) is a possible explanation for higher CGR, NAR and RGR compared to untreated control. The foliar application of thiourea on the abiotically stressed plants is much effective. Improvement in plant growth and development under different stresses due to application of thiourea has been observed in crops like maize (Perveen *et al*., 2016), wheat (Sahu and Singh, 1995; Kumar *et al*., 2013), pearl millet (D'Souza *et al*., 2009), chickpea (Vineeth *et al*., 2017) and cluster bean (Nathawat *et al*., 2016; Meena *et al*., 2017).

Thiol-mediated antioxidant enzymes

Exogenous application of sulphydryl compounds significantly enhanced activities of thiol-mediated antioxidant enzymes (GR and GST). The -SH treated plants recoded 23.7- 65.4% and 24.0 - 69.9% higher activities for GR and GST, respectively as compared to non-treated plants (Fig 1). The greatest increments in GR and GST were recorded with TU 1000 mg L^{-1} followed by TGA 400 mg L^{-1}, TGA 300 mg L^{-1}, TU 750 mg L^{-1}, TGA 200 mg L^{-1} and TU 500 mg L^{-1}. TU and TGA are thiol compounds and there are ample evidences to support the role of thiol compounds in abiotic tolerance in plants. The potential of thiol compounds in mitigation of water deficit stress in pearl millet is evident from experiments involving pre-sowing seed treatment with sulphydryl compounds such as dithiothreitol, thioglycollic acid and cysteine. These compounds could improve the activities of key enzymes of the superoxide scavenging system that involves superoxide dismutase, GR and GST (Ramaswamy *et al.,* 2007). Previous studies confirm that thiourea and thioglycollic acid increased the plant growth under water stress condition, which might be due to increase in antioxidant activities that alleviated the stress damage (D'Souza *et al*., 2009; Pandey *et al*., 2013; Nathawat *et al*., 2016).

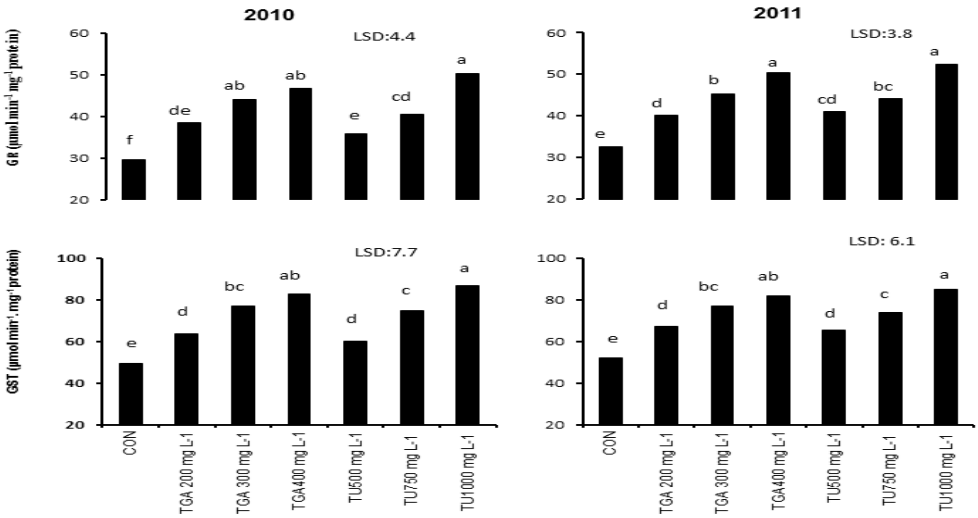


Fig 1: Effect of sulphydryl compounds application on activities of (A) glutathione reductase (µmol min^{-1} mg^{-1} protein) and (B) glutathione – S – trasferase (µmol min^{-1} mg^{-1} protein) in leaves of *Vigna aconitifolia*. Bars represents means ± SE, *n* = 3. Bars having different letters are significantly different ($P < 0.05$) according to the LSD test.

Table 1: Effect of foliar application of – SH compounds on leaf area index (LAI) and dry matter (DM) accumulation of *Vigna aconitifolia*.

Treatment	2010						2011					
	LAI			DM (g plant^{-1})			LAI			DM (g plant^{-1})		
	40 DAS	50 DAS	60 DAS	40 DAS	50 DAS	60 DAS	40 DAS	50 DAS	60 DAS	40 DAS	50 DAS	60 DAS
Control	0.86±0.03^{b}	1.10±0.02^{b}	1.53± 0.07^{b}	4.91±0.2^{c}	7.34±0.5^{c}	11.4±0.7^{c}	0.83± 0.03^{c}	0.97±0.03^{b}	1.35±0.06^{c}	4.81±0.2^{d}	6.65±0.3^{c}	10.0±0.6^{d}
TGA $_{200\ mg\ L^{-1}}$	0.99±0.03^{a}	1.33±0.06^{a}	1.89± 0.10^{a}	5.46±0.1^{b}	8.90±0.5^{b}	14.8±0.6^{b}	0.94± 0.04^{b}	1.18±0.05^{a}	1.67±0.08^{b}	5.37±0.1^{c}	7.63±0.2^{bc}	11.8±0.3^{c}
TGA $_{300\ mg\ L^{-1}}$	1.02±0.02^{a}	1.36±0.06^{a}	1.95± 0.09^{a}	5.69±0.2^{ab}	9.37±0.3^{ab}	15.7±1.0^{ab}	0.98±0.04^{ab}	1.22±0.05^{a}	1.73±0.10^{ab}	5.62±0.2^{abc}	7.93±0.3^{ab}	12.4±0.4^{abc}
TGA $_{400\ mg\ L^{-1}}$	1.03±0.03^{a}	1.40±0.04^{a}	2.01± 0.10^{a}	5.79±0.2^{a}	9.64±0.4^{a}	16.4±0.8^{a}	0.99±0.04^{ab}	1.25±0.04^{a}	1.82±0.09^{a}	5.75±0.1^{ab}	8.19±0.2^{a}	13.2±0.6^{a}
TU $_{500\ mg\ L^{-1}}$	1.01±0.03^{a}	1.33±0.06^{a}	1.88±0.09^{a}	5.55±0.2^{ab}	9.02±0.4^{ab}	15.0±0.9^{ab}	0.95±0.03^{ab}	1.20±0.03^{a}	1.69±0.06^{ab}	5.43±0.2^{bc}	7.72±0.3^{abc}	12.1±0.5^{bc}
TU $_{750\ mg\ L^{-1}}$	1.02±0.03^{a}	1.39±0.07^{a}	1.98 ± 0.08^{a}	5.68±0.1^{ab}	9.31±0.5^{ab}	15.7±1.0^{ab}	0.97±0.02^{ab}	1.21±0.04^{a}	1.76±0.04^{ab}	5.70±0.2^{abc}	8.08±0.3^{ab}	12.3±0.4^{abc}
TU $_{1000\ mg\ L^{-1}}$	1.04±0.04^{a}	1.41±0.04^{a}	2.04 ± 0.08^{a}	5.83±0.2^{a}	9.66±0.3^{a}	16.4±0.9^{a}	1.01±0.03^{a}	1.25±0.05^{a}	1.80±0.06^{ab}	5.79±0.1^{a}	8.11±0.2^{ab}	13.0±0.6^{ab}
LSD $_{(0.05)}$	0.060	0.084	0.158	0.32	0.71	1.54	0.057	0.077	0.138	0.34	0.50	0.95

† Values followed by the different letters in each column are significantly different at $p \leq 0.05$ according to LSD.

TGA: Thioglycollic acid; TU: Thiourea; LAI: leaf area index; DM: dry matter accumulation.

Table 2: Effect of foliar application of – SH compounds on net assimilation rate (NAR), relative growth rate (RGR) and crop growth rate (CGR) of *Vigna aconitifolia*.

Treatment	2010						2011					
	NAR (mg. cm^{-2}. d^{-1})		RGR (mg. g^{-1}. d^{-1})		CGR (g. m^{-2}. d^{-1})		NAR (mg. cm^{-2}. d^{-1})		RGR (mg. g^{-1}. d^{-1})		CGR (g. m^{-2}. d^{-1})	
	40-50 DAS	50-60 DAS	40-50 DAS	50-60 DAS	40-50 DAS	50-60 DAS	40-50 DAS	50-60 DAS	40-50 DAS	50-60DAS	40-50 DAS	40-50 DAS
Control	0.62±0.046^{b}	7.7±0.44^{c}	40.5±1.6^{c}	43.6±1.6^{b}	6.1 ± 0.53^{b}	10.0 ± 0.86^{c}	0.60±0.023^{c}	7.4 ± 0.35^{c}	29.9±1.5^{d}	40.6±1.4^{c}	4.2 ±0.22^{d}	7.8 ± 0.85^{d}
TGA $_{200\ mg\ L^{-1}}$	0.75±0.042^{a}	9.2 ±0.38^{b}	49.0±1.9^{ab}	50.8 ±1.9^{a}	8.6 ± 0.77^{a}	14.7± 0.92^{ab}	0.72±0.018^{b}	8.8 ± 0.39^{b}	36.3±0.9^{bc}	47.4±2.4^{b}	5.5±0.29^{bc}	10.4±0.68^{a}
TGA $_{300\ mg\ L^{-1}}$	0.78±0.037^{a}	9.7± 0.45^{ab}	50.0±2.0^{ab}	51.7± 2.0^{a}	9.2 ± 0.50^{a}	15.8± 1.07^{ab}	0.75±0.029^{ab}	9.5±0.46^{ab}	37.6±0.8^{abc}	50.4±1.6^{ab}	5.8±0.34^{abc}	11.6±0.64^{ab}
TGA $_{400\ mg\ L^{-1}}$	0.80±0.020^{a}	10.1±0.38^{a}	51.0±1.7^{a}	53.3 ±1.5^{a}	9.6 ± 0.68^{a}	16.9 ± 0.96^{a}	0.78±0.034^{a}	9.9 ± 0.34^{a}	39.0±1.4^{a}	51.4±0.8^{a}	6.2±0.20^{a}	12.2 ±0.80^{a}
TU $_{500\ mg\ L^{-1}}$	0.75±0.038^{a}	9.5 ±0.45^{ab}	48.7 ±1.2^{b}	51.0 ±1.2^{a}	8.7 ± 0.59^{a}	15.0± 0.93^{ab}	0.71±0.028^{a}	8.9 ± 0.23^{b}	35.6 ± 1.8^{c}	48.3±1.7^{ab}	5.4 ± 0.30^{c}	10.7±0.55^{bc}
TU $_{750\ mg\ L^{-1}}$	0.76±0.035^{a}	9.6± 0.41^{ab}	49.4±1.8^{ab}	52.1 ±1.8^{a}	9.1 ± 0.79^{a}	15.9± 0.96^{ab}	0.74±0.021^{a}	9.3±0.36^{ab}	37.2±1.6^{abc}	49.6±2.1^{ab}	5.9±0.40^{abc}	11.5±0.38^{abc}
TU $_{1000\ mg\ L^{-1}}$	0.79±0.039^{a}	9.8 ±0.47^{ab}	50.4±1.7^{a}	52.9 ±1.7^{a}	9.6 ± 0.70^{a}	16.8 ±1.15^{a}	0.77±0.035^{a}	9.7 ± 0.45^{a}	38.5 ±1.1^{a}	50.8±1.1^{a}	6.1±0.44^{a}	12.2 ±0.72^{a}
LSD $_{(0.05)}$	0.055	0.73	3.5	3.2	0.97	1.85	0.049	0.70	2.6	3.2	0.57	1.30

† Values followed by the different letters in each column are significantly different at $p \leq 0.05$ according to LSD.

TGA: Thioglycollic acid; TU: Thiourea; NAR: net assimilation rate; RGR: relative growth rate; CGR: crop growth rate.

Gas exchange parameters

Foliar application of sulphydryl compounds enhanced gas exchange parameters (P_N, g_s and E) (Table 3). Averaged across the years, the sulphydryl compounds sprayed plants had 17.1 - 34.1% greater P_N, 19.3 - 39.1% higher g_s and 12.9 - 26.8% higher E than unsprayed plant at post- flowering stage. Among –SH compounds tested, the TGA 400 mg L^{-1} treated plants had the highest P_N in the both years. The mean values for g_s and E varied from 314.7 - 561 mmol m^{-2} S^{-1} and 5.0 -7.5 mmol m^{-2} S^{-1}, respectively (Table 3). The plant treated with 400 TGA mg L^{-1} had maximum g_s and E followed by 1000 TU mg L^{-1}, 300 TGA mg L^{-1} and 750 TU mg L^{-1}. During drought stress, foliar application of thiourea improved net photosynthesis and chlorophyll content in cluster bean (Burman *et al*., 2008; Nathawat *et al*., 2016). Thiourea may be a nutrient supplement or may act as scavenger of reactive oxygen species (Pandey *et al*., 2013). Among other physiological impacts of thiourea, leaf gas exchange and improved photosynthetic pigment contents are amongst the pronounced and favorable changes produced by thiourea in quite a few plant species regardless of the stress applied (Garg *et al*., 2007; Perveen *et al*., 2016).

Yield attributes and yield

Application of -SH compounds had significant effects on yield components and yields (Table 4). Averages across both the years, sulphydryl compounds treated plants had 12.5 - 20.9% higher pods per sqare meter than untreated plants. The -SH application had significant effects on number of pods and the effects for 100-seed weight were not significant. Seed yield (SY) varied from 0.86 - 1.05 ton ha^{-1} and 0.84 - 1.01 ton ha^{-1} during 2010 and 2011 respectively. Application of -SH compounds significantly ($p \leq 0.05$) increased seed yield in both the years. Averaged across the years, application of sulphydryl compounds gave to 13.2 - 20.4% higher SY compared to control plants (Table 4). The SY was recorded highest with 400 TGA mg L^{-1} followed by 1000 TU mg L^{-1}, 300 TGA mg L^{-1}, and 750 TU mg L^{-1}. Above ground biomass yield (ABY) varied from 3.52 ton ha^{-1} to 4.48 ton ha^{-1}. Averaged across both the years, -SH compounds treated plants had 13.5 to 21.1% higher ABY. The plant treated with 1000 TU mg L^{-1} had the greater ABY followed by 400 TGA mg L^{-1} (Table 4). The beneficial role of PBR's in enhancing the crop yields through the regulation of physiological processes and plant-water relationships

Table 3: Effect of exogenous –SH compounds applications on net photosynthetic rate, stomatal conductance and transpiration rate of *Vigna aconitifolia* at post-flowering stage.

Treatment	2010			2011		
	Net photosyn-thetic rate (µ mol m^{-2} s^{-1})	Stomatal conductance (m mol/m^2/s)	Transpiration rate (m mol/m^2/s)	Net photosyn-theticrate (µ mol m^{-2} s^{-1})	Stomatal conductance (m mol/m^2/s)	Transpiration rate (m mol/m^2/s)
Control	7.3 ± 0.33^{d}	314.7±19.4^{d}	5.0±0.29^{b}	8.0 ± 0.22^{c}	438.0±17.6^{c}	5.7±0.38^{d}
TGA $_{200\ mg\ L^{-1}}$	9.0 ± 0.37^{c}	385.1±31.2^{c}	5.6±0.30^{ab}	9.0 ± 0.21^{b}	508.8±14.8^{b}	6.7±0.27^{c}
TGA $_{300\ mg\ L^{-1}}$	9.2 ± 0.57^{bc}	423.1±33.7^{bc}	5.7±0.18^{a}	9.2 ± 0.24^{ab}	529.2±19.2^{ab}	7.0±0.30^{abc}
TGA $_{400\ mg\ L^{-1}}$	10.2± 0.49^{a}	472.7±23.1^{a}	6.1±0.24^{a}	9.7 ± 0.21^{a}	561.0±16.9^{a}	7.5±0.27^{a}
TU $_{500\ mg\ L^{-1}}$	8.8 ± 0.56^{c}	395.4±19.2^{bc}	5.5±0.26^{ab}	9.1 ± 0.29^{b}	503.3±20.3^{b}	6.6±0.25^{c}
TU $_{750\ mg\ L^{-1}}$	9.2 ± 0.45^{bc}	401.2±19.6^{bc}	5.5±0.34^{ab}	9.2 ± 0.23^{ab}	540.2±15.4^{ab}	7.1±0.241^{abc}
TU $_{1000\ mg\ L^{-1}}$	11.0± 0.59^{a}	436.6±18.0^{ab}	6.1±0.19^{a}	9.4 ± 0.19^{ab}	551.7±22.0^{a}	7.2 ±0.25^{a}
LSD $_{(0.05)}$	0.93	49.2	0.50	0.506	38.0	0.53

† Values followed by the different letters in each column are significantly different at $p \leq 0.05$ according to LSD.

TGA: Thioglycollic acid; TU: Thiourea.

Table 4: Effect of foliar application of sulphydryl compounds on yield components and yield of *Vigna aconitifolia.*

Treatment	2010				2011			
	NP (m^{-2})	100 - seed weight (g)	SY (ton ha^{-1})	ABY (ton ha^{-1})	NP (m^{-2})	100 - seed weight (g)	SY (ton ha^{-1})	ABY (ton ha^{-1})
Control	1141±33^{c}	3.21 ±0.028	0.86 ±0.043^{c}	3.64 ±0.12^{d}	1230 ± 42	2.91 ±0.06^{a}	0.84 ±0.033^{c}	3.52 ±0.10^{d}
TGA $_{200\ mg\ L^{-1}}$	1258±20^{b}	3.24 ±0.051	0.98±0.037^{b}	4.20 ±0.18^{bc}	1367 ± 67	2.97 ±0.05^{a}	0.95 ±0.023^{b}	3.93±0.06^{c}
TGA $_{300\ mg\ L^{-1}}$	1279±26^{ab}	3.24 ±0.030	1.02±0.031^{ab}	4.35 ±0.17^{bc}	1457 ± 70	2.97 ±0.04^{a}	0.98 ±0.020^{ab}	4.05±0.10^{abc}
TGA $_{400\ mg\ L^{-1}}$	1298±27^{ab}	3.28 ±0.041	1.05±0.033^{a}	4.46 ±0.15^{ab}	1413 ± 30	3.07 ±0.05^{a}	1.01 ±0.022^{a}	4.17±0.09^{ab}
TU $_{500\ mg\ L^{-1}}$	1300±27^{ab}	3.24 ±0.036	0.99 ±0.038^{b}	4.17 ±0.13^{c}	1411± 42	2.95 ±0.04^{a}	0.95 ±0.026^{b}	3.96±0.11^{bc}
TU $_{750\ mg\ L^{-1}}$	1320±30^{a}	3.25±0.033	1.01 ±0.034^{ab}	4.35 ±0.16^{bc}	1483 ± 37	2.98 ±0.04^{a}	0.97 ±0.021^{ab}	4.05±0.12^{abc}
TU $_{1000\ mg\ L^{-1}}$	1325±35^{a}	3.31 ±0.022	1.04 ±0.037^{ab}	4.48 ±0.14^{a}	1435± 47	3.09 ±0.06^{a}	1.00 ±0.024^{ab}	4.20±0.09^{a}
LSD $_{(0.05)}$	56	NS	0.06	0.26	61	NS	0.06	0.21

†Values followed by the different letters in each column are significantly different at $p \leq 0.05$ according to LSD.

TGA: Thioglycollic acid; TU: Thiourea; NP: pod per square meter; SY: seed yield; ABY: aboveground biomass yield.

recently been elaborated through several reports (Vineeth *et al*., 2017; Wakchaure *et al*., 2016). The protective mechanism of PBR's regulates the root growth for improving plant water/nutrient status, photosynthetic efficiency and source–sink homeostasis resulting enhanced yield and metabolism for overall improvement in plant growth (Srivastava *et al*., 2016; Nathawat *et al*., 2016; Wahid *et al*., 2017).

CONCLUSION

In the present study, exogenous application of sulphydryl compounds led to significantly higher number of pods, seed yield and biomass yield compared with untreated plants. Significant improvement in SY and ABY with - SH compounds in the present study could be attributed to significant improvement in yield attributes due to greater photosynthetic efficiency and partitioning of photosynthates. Thus, increased seed yield of moth bean due to TU and TGA was a result of improved leaf area development, growth attributes, antioxidant defence mechanism and photosynthetic efficiency.

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