International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
IJCS 2018; 6(6): 1090-1095

Received: 11-09-2018
Accepted: 15-10-2018

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Influence of silicon solubilizers on biochemical parameters and yield of rice genotypes

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Abstract
A Field experiment was conducted at Indian Institute of Rice Research (IIRR), Hyderabad during *Kharif* 2014 and *Kharif* 2015 to study the influence of silicon solubilizers on biochemical parameters and yield of eight rice genotypes. The treatments comprised of control (T_0), silixol @ 0.2% (T_1) and Imidazole @0.05% (T_2) and sprayed at tillering stage. The experiment was laid out in split plot design, replicated thrice. Biochemical parameters viz. total chlorophyll content, silicilic acid content, total sugar content and phenol content were measured at tillering, panicle initiation and grain filling stages and grain yield significantly increased under silicon solubilizer treatments compared to control. Among the genotypes PHB 71(V_5), PA6129 (V_2) and PA6201 (V_3) were maintained higher values under silicon solubilizer application as well as control conditions along with higher yield.

Keywords: rice, silicon, solubilizer, biochemical, parameters, genotypes, yield

Introduction
Rice (*Oryza sativa* L.) is one of the most important staple food crops in the world. India has the largest area among rice growing countries and stands second in production. Rice is one of the most effective silicon-accumulating plant and accumulate upto 10% of dry weight in the shoots, roots and contributes to enhance resistance to disease and insects (Ishiguru, 2001). Although silicon is the second largest element present in the soil it is not available for plants due to presence in the amorphous form. Plants absorb silicon from the soil solution in the form of monosilicic acid, also called orthosilicic acid [H_4SiO_4] (Lewin and Reimann, 1969) [9]. This molecule is highly unstable and readily becomes into non available form i.e. polymeric silicic acid or forms complex with other compounds to form metasilicates. Silicon nutrition in rice has low soil solubility, so the silicon solubilizers known to influence silicon uptake and accumulation in crop plants. Soluble Si has enhanced the growth, development and yield of several plant species including rice, sugarcane and most other cereals (Elawad and Green, 1979) [4]. Application of Si increased the uptake of P, Ca, Mg and the formation of carbohydrate (Islam and Saha, 1969) [8]. To enhance the production by decreasing yield losses through disease and pest infestation, lodging, and metal toxicity (Zhang *et al*., 2013) [21].

Materials and Methods
The present study was aimed at evaluating the relative performance of eight rice genotypes for biochemical efficiency and yield. These genotypes were evaluated in a field experiment, laid out in split plot design, treatments as main plots ((T_0) Control, (T_1) Silixol @ 0.2%, (T_2) Imidazole @ 0.05%) and rice genotypes as sub plots (DRRH 3(V_1), PA 6129(V_2), PA 6201 (V_3), PA6444 (V_4), PHB 71 (V_5), BPT 5204(V_6), CO 39 (V_7) and HR 12 (V_8)) and replicated thrice in *kharif* 2014 and 2015 at IIRR, Hyderabad. Prophylactic measures were taken for protecting the crop from pest and diseases. During crop growth period the silicon solubilizers sprayed at tillering stage. Data on total chlorophyll content, silicilic acid content, total sugar content and phenol content were measured at tillering, panicle initiation and grain filling stages and Grain yield recorded at harvest in both control and silicon solubilizer treatments. The data was statistically analyzed ad described by Panse and Sukhatme (1985) [11].

Results and Discussion

All the biochemical characters used for evaluating rice genotypes under silicon solubilizer treatments and control conditions *viz.*, total chlorophyll content, silicilic acid content, total sugar content and phenol content and yield significantly varied between silicon solubilizer treatments and genotypes at different intervals (Table1). All these parameters increased from tillering to Panicle initiation stage and then decreased at grain filling stage during both seasons of experiment. The rice genotypes differed in their response to silicon solubilizer treatments and control in terms of biochemical and yield traits.

Table 1: Influence of silicon solubilizers on total chlorophyll content (mg g^{-1} FW), Silicilic acid content (µmoles/100µlcellsap. 100 mg FW), Total sugars (mg g^{-1} DW) and Phenol content (mg 100 g^{-1} DW) of rice genotypes at panicle initiation stage during *Kharif* 2014 and 2015

***Kharif* 2014**	**total chlorophyll content**				**Silicilic acid content**				**Total sugars**				**Phenol content**			
Genotypes	**T_0**	**T_1**	**T_2**	**Mean**	**T_0**	**T_1**	**T_2**	**Mean**	**T_0**	**T_1**	**T_2**	**Mean**	**T_0**	**T_1**	**T_2**	**Mean**
DRRH 3 (V_1)	3.74	3.84	3.92	3.83	1.04	1.12	1.02	1.06	33.66	39.3	56.6	43.19	2.32	2.41	2.84	2.52
PA 6129 (V_2)	3.27	3.52	4.66	3.82	0.89	1.17	1.19	1.08	31.13	50.27	61.61	47.67	2.59	2.89	3.38	2.95
PA 6201 (V_3)	3.36	3.68	3.42	3.49	0.81	0.97	1.28	1.02	36.4	44.79	42.27	41.15	2.38	2.62	2.88	2.63
PA 6444 (V_4)	3.91	3.41	3.58	3.63	1.02	0.98	1.07	1.03	32.91	36.11	47.75	38.92	2.18	2.29	2.74	2.40
PHB 71 (V_5)	3.96	4.11	5.18	4.42	0.96	1.20	1.32	1.16	34.88	48.45	58.89	47.41	2.63	2.65	2.94	2.74
BPT 5204 (V_6)	2.77	3.50	3.68	3.32	0.88	0.97	1.14	0.99	32.41	39.16	42.42	38.00	2.16	2.37	2.53	2.35
CO 39 (V_7)	2.69	3.33	3.34	3.12	0.71	0.88	0.97	0.85	32.81	35.43	43.44	37.23	2.14	2.34	2.51	2.33
HR 12 (V_8)	2.81	2.31	3.09	2.74	0.80	0.83	0.86	0.83	30.8	35.26	36.32	34.13	2.12	2.20	2.23	2.18
Mean	3.31	3.46	3.86		0.89	1.01	1.11		33.13	41.10	48.66		2.32	2.47	2.76	
	T	G	T ×G		T	G	T ×G		T	G	T ×G		T	G	T ×G	
SE m ±	0.10	0.077	0.159		0.025	0.042	0.064		0.126	0.196	0.341		0.028	0.072	0.119	
CD (P=0.05)	0.402	0.22	0.529		0.099	0.120	0.217		0.506	0.560	1.03		0.112	0.205	NS	

Table 1: Continued

***Kharif* 2015**	**total chlorophyll content**				**Silicilic acid content**				**Total sugars**				**Phenol content**			
Genotypes	**T_0**	**T_1**	**T_2**	**Mean**	**T_0**	**T_1**	**T_2**	**Mean**	**T_0**	**T_1**	**T_2**	**Mean**	**T_0**	**T_1**	**T_2**	**Mean**
DRRH 3 (V_1)	2.13	2.68	2.49	2.43	0.85	0.90	1.04	0.93	40.15	42.93	46.17	43.08	2.10	2.27	2.50	2.29
PA 6129 (V_2)	2.28	3.21	3.07	2.85	0.93	1.04	1.04	1.00	47.43	50.58	54.68	50.90	2.23	2.38	2.85	2.49
PA 6201 (V_3)	2.34	2.90	3.12	2.79	1.00	1.01	1.15	1.05	41.14	54.52	54.56	50.07	2.12	2.62	2.67	2.47
PA 6444 (V_4)	2.07	2.28	2.68	2.34	0.99	0.99	0.92	0.97	44.65	46.65	47.75	46.35	2.20	2.33	2.59	2.37
PHB 71 (V_5)	2.47	2.98	3.58	3.01	1.18	1.11	1.33	1.21	49.24	51.39	59.67	53.43	2.32	2.51	2.89	2.57
BPT 5204 (V_6)	2.01	2.33	2.40	2.25	0.79	0.83	0.93	0.85	36.54	39.16	44.15	39.95	2.09	2.24	2.65	2.33
CO 39 (V_7)	1.97	2.31	2.37	2.22	0.73	0.69	0.88	0.77	34.79	37.09	40.75	37.54	2.01	2.21	2.27	2.16
HR 12 (V_8)	1.91	2.03	2.30	2.08	0.64	0.59	0.82	0.68	32.91	36.02	42.67	37.20	1.75	2.19	2.00	1.98
Mean	2.15	2.59	2.75		0.89	0.90	1.01		40.86	44.79	48.80		2.10	2.34	2.55	
	T	G	T ×G		T	G	T ×G		T	G	T ×G		T	G	T ×G	
SE m ±	0.001	0.097	0.001		0.001	0.036	0.072		0.026	0.001	0.026		0.018	0.068	0.111	
CD (P=0.05)	0.006	0.279	0.006		0.004	0.102	0.238		0.106	0.004	0.106		0.071	0.194	NS	

(T_0): Control; (T_1): Silixol @ 0.2 %; (T_2): Imidazole @ 0.05 %

Among the genotypes, PHB 71(V_5), PA6129 (V_2) and PA6201 (V_3) recorded significantly higher values for all these parameters and higher yield, The genotypes HR 12 (V_8) and CO 39 (V_7) recorded lowest values for all these parameters under silicon solubilizer treatments as well as control.

At panicle initiation stage Imidazole (T_2) showed highest total chlorophyll content by 16.61%, 27.91%, silicilic acid content by 24.71% and 13.48%, total sugar content by 46.87%, 19.43%, Phenol content by 18. 96%, 21.45% and grain yield by 15.37%, 25.29% over control and silixol (T_2) increased the total chlorophyll content by 4.53%, 20.46 %, silicilic acid content by 13.48%, 1.12%, total sugar content by 24.05%, 9.61 %, phenol content by 6.46%, 11.42% and grain yield by 4.53%, 18.28% over control during *Kharif* 2014 and 2015, respectively. Imidazole (T_2) showed better performance compared to silixol (T_1) and control (T_0) at all growth stages in both seasons.

Silicon solubilizer significantly increased the chlorophyll content in leaves (Shen *et al.*, 2010 in soybean) [17]. Silicon may increase cell metabolic activity and promote the amino acid biosynthesis of chlorophyll. It was reported that Chl content is positively correlated with the photosynthetic rate (Thomas *et al.*, 2013) [19]. Silicon shortage can reduce the amount of chlorophyll (Agarie, 1993) [1]. Silicon treatment enhanced the levels of chlorophyll a, which indicates formation of new pigments, and maintenance of chlorophyll a previously existing (Lobato *et al.*, 2013) [10]. These enhancements in chlorophyll are defined by the fact that silicon is absorbed by the plant and it has been accumulated in the layer of the epidermis, which promotes positive changes in plant structure and better light capture by the leaf (Barbosa *et al*., 2015) [2].

]The increase in the silicilic acid content could be mainly attributed to additional supplement of Si fertilizer and genotype characters like root bearing ability and root architecture for more removal of nutrients. The increase in Si has also been attributed to its release from ferrosilicon complexes under reducing soil conditions (Savant *et al*., 1997b) [16].

Increasing the level of silicon in sunflower observed that the sugar content was increased as well as *amylase* content was decreased (Zahoor *et al.*, 2011) [20]. The application of silicon caused a reduction in the levels of total soluble carbohydrates. This effect was likely due to the silicon protecting the photosynthetic apparatus (Guntzer *et al.,* 2012) [6].

Rodrigues *et al.* (2004) [14]; Borel *et al.* (2005) [3] in wheat and Fawe *et al.* (2005) [5] in cucumber reported that silicon activates certain enzymes like chitinases, peroxidases, polyphenol oxidases and antifungal compounds like phytoalexins which reduce fungal attack in addition to the mechanical barrier.

The improvement in grain yield might be attributed to advantage gained in grain filling and grain weight because of better translocation of photosynthates (Rani and Narayanan (1994) [12] and Rani *et al*., 1997. The supply of silica resulting in physical environment leading to better aeration, root activity, nutrient absorption and the consequent complementary effect would have resulted in higher grain and straw yield of rice (Tanaka and Kawano, 1965) [18], plants become more resistant to fungal disease, by increase of cell wall thickness below the cuticle, imparting mechanical resistance to the penetration of fungi, and improvement of the leaf angle, making leaves more erect and enhanced carbohydrate translocation from vegetative part to grain or seeds (Sarma *et al*.,2017) [15].

Correlation study with yield

Total chlorophyll content showed strong positive correlation with yield for silixol (T_1) treatment (R^2 = 0.5533 and R^2 = 0.8958) and imidazole (T_2) treatment (R^2 = 0.502 and R^2 = 0.8084) as depicted in Fig. 4.6 (a, b) and 4.7 (a,b) during both *Kharif* 2014 and 2015, respectively.

Silicilic acid content showed strong positive correlation with yield for silixol (T_1) treatment (R^2 = 0.6544 and R^2 = 0.7146) and imidazole (T_2) treatment (R^2 = 0.5814 and R^2 = 0.7565) as depicted in Fig. 4.8 (a, b) and 4.9 (a, b) during both *Kharif* 2014 and 2015 respectively.

Total sugar content showed strong positive correlation with yield for silixol (T_1) treatment (R^2 = 0.5066 and R^2 = 0.677) and for imidazole (T_2) treatment (R^2 = 0.5975 and R^2 = 0.8753) as depicted in Fig. 4.12 (a, b) and 4.13 (a,b) during both *Kharif* 2014 and 2015 respectively.

Phenol content showed strong positive correlation with yield for silixol (T_1) treatment (R^2 = 0.4757 and R^2 = 0.3952) and imidazole (T_2) treatment (R^2 = 0.7212 and R^2 = 0.8088) as depicted in Fig. 4.14 (a, b) and 4.15 (a, b) during both *Kharif* 2014 and 2015, respectively.

Table 2: Influence of silicon solubilizers on Grain Yield (Kg/ha) of rice genotypes at harvest during *kharif* 2014 and 2015

	Kharif 2014				*Kharif* 2015			
Genotypes	**T_0**	**T_1**	**T_2**	**Mean**	**T_0**	**T_1**	**T_2**	**Mean**
DRRH3(V1)	**8583.33**	**8850.00**	**9773.33**	**9068.89**	**6733.33**	**7583.33**	**7993.33**	**7436.66**
PA 6129(V2)	8056.67	9433.33	10456.67	9315.56	5663.33	10910.00	9233.33	8602.22
PA6201(V3)	9201.67	9163.33	9416.67	9260.56	7783.33	8173.00	9236.67	8397.67
PA6444(V4)	8945.00	9013.33	9600.00	9186.11	7166.67	7166.67	7780.00	7371.11
PHB 71(V5)	9943.33	9146.67	10036.67	9708.89	8013.33	8763.33	9353.33	8710.00
BPT 5204(V6)	6876.67	7323.33	8916.67	7705.56	5596.67	6296.67	7196.67	6363.34
CO 39(V7)	5270.56	5786.67	6530.37	5862.53	4886.67	5780.00	6530.00	5732.22
HR 12(V8)	4670.28	5620.12	6278.21	5522.87	4660.00	5063.33	5953.33	5225.56
Mean	7693.44	8042.10	8876.07		6312.92	7467.04	7909.58	
	T	G	T ×G		T	G	T ×G	
SE m ±	91.829	189.729	320.819		38.65	106.87	177.411	
CD (P=0.05)	370.22	543.390	949.616		155.85	306.08	517.96	

(T_0) Control, Silixol (T_1), Imidazole (T_2)

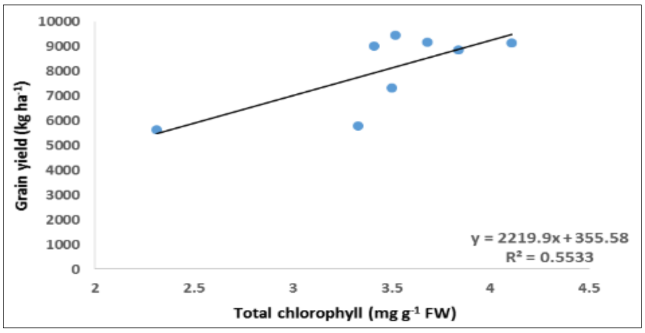

Fig 1.1a: Correlation between total chlorophyll and grain yield in rice genotypes under silixol (T_1) application during *Kharif* 2014 at panicle initiation stage

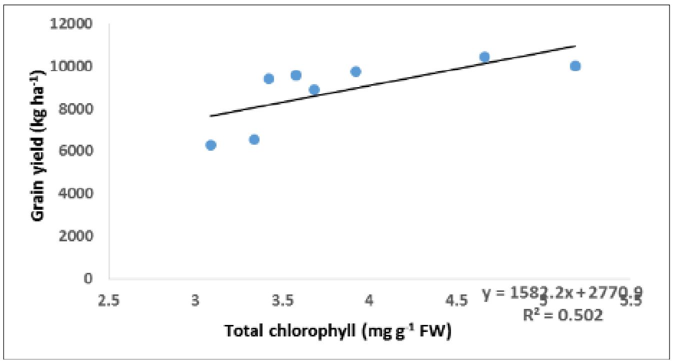

Fig 1.1b: Correlation between total chlorophyll and grain yield in rice genotypes under imidazole (T_2) application during *Kharif* 2014 at panicle initiation stage

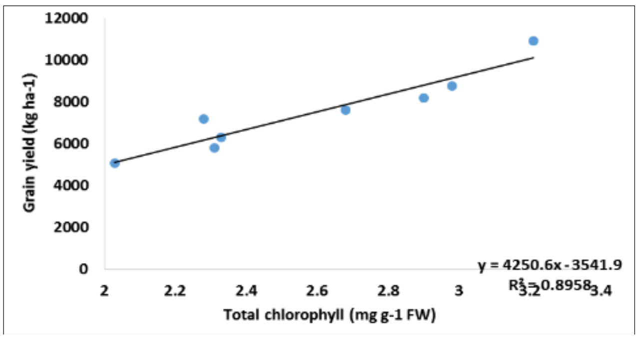

Fig 1.2a: Correlation between total chlorophyll and grain yield in rice genotypes under silixol (T_1) application during *Kharif* 2015 at panicle initiation stage

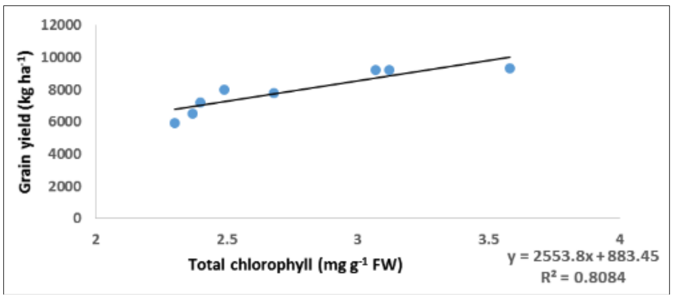

Fig 1.2b: Correlation between total chlorophyll and grain yield in rice genotypes under imidazole (T_2) application during *Kharif* 2015 at panicle initiation stage

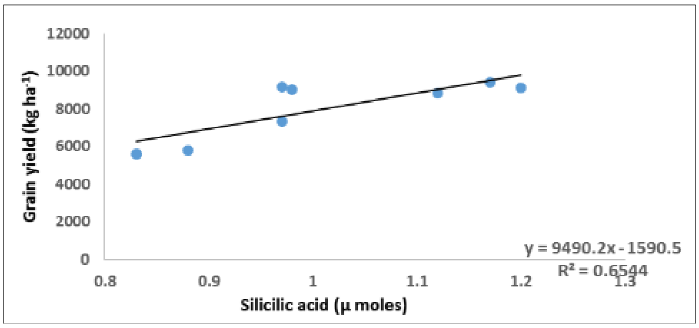

Fig 2.1a: Correlation between silicilic acid content and grain yield in rice genotypes under silixol (T_1) application during *Kharif* 2014 at panicle initiation stage

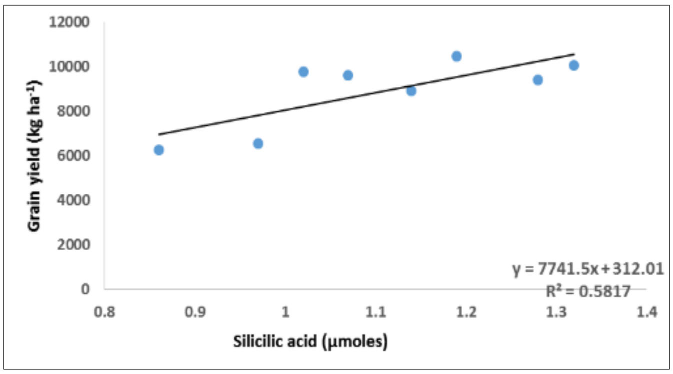

Fig 2.1b: Correlation between silicilic acid content and grain yield in rice genotypes under imidazole (T_2) application during *Kharif* 2014 at panicle initiation stage

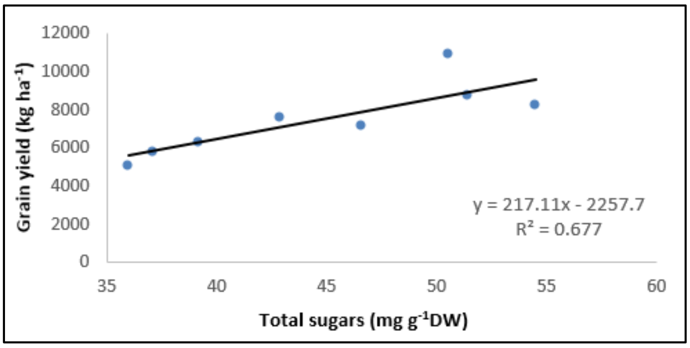

Fig 3.2a: Correlation between total sugars and grain yield in rice genotypes under silixol (T_1) application during *Kharif* 2015 at panicle initiation stage

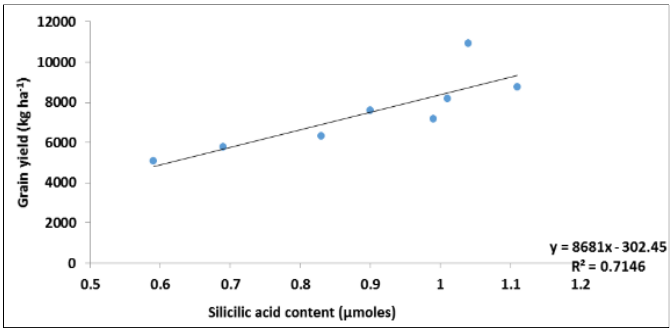

Fig 2.2a: Correlation between silicilic acid content and grain yield in rice genotypes under silixol (T_1) application during *Kharif* 2015 at panicle initiation stage

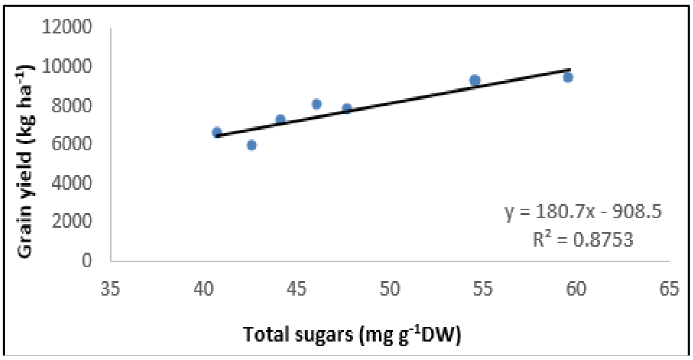

Fig 3.2b: Correlation between total sugars and grain yield in rice genotypes under imidazole (T_2) application during *Kharif* 2015 at panicle initiation stage

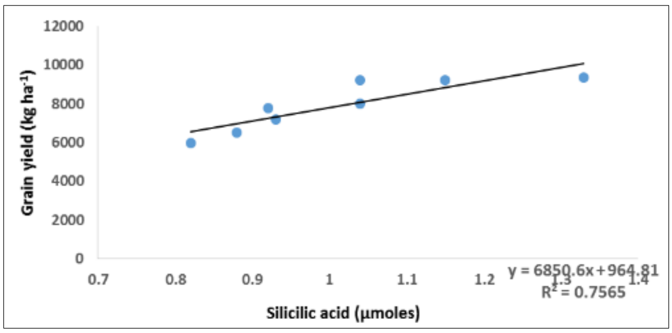

Fig 2.2b: Correlation between silicilic acid content and grain yield in rice genotypes under imidazole (T_2) application during *Kharif* 2015 at panicle initiation stage

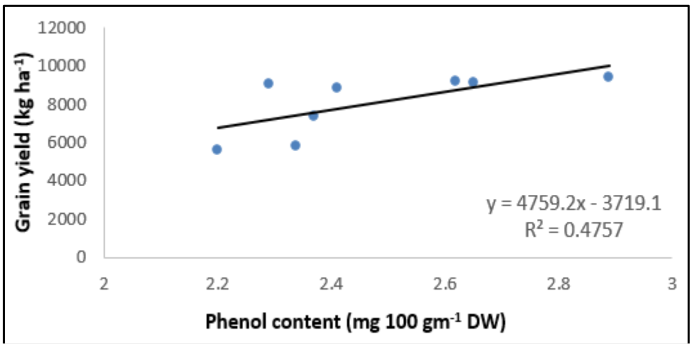

Fig 4.1a: Correlation between phenol content and grain yield in rice genotypes under silixol (T_1) application during *Kharif* 2014 at panicle initiation stage

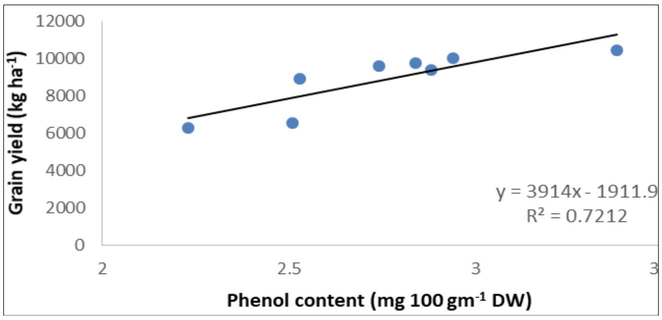

Fig 4.1b: Correlation between phenol content and grain yield in rice genotypes under imidazole (T_2) application during *Kharif* 2014 at panicle initiation stage

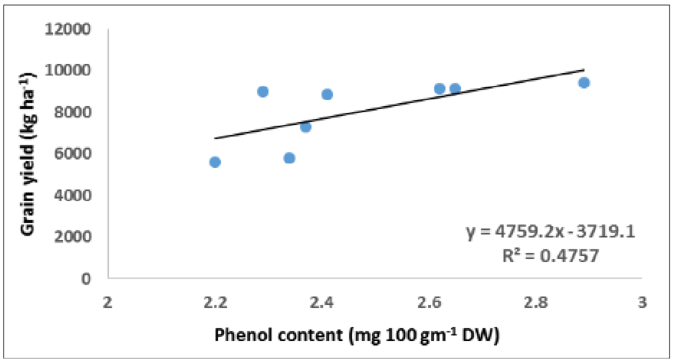

Fig 4.2a: Correlation between phenol content and grain yield in rice genotypes under silixol (T_1) application during *Kharif* 2015 at panicle initiation stage

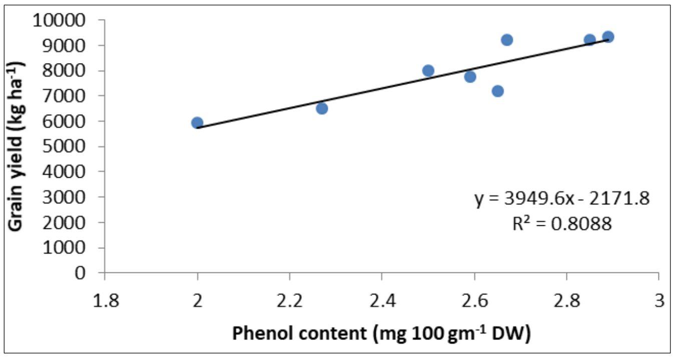

Fig 4.2b: Correlation between phenol content and grain yield in rice genotypes under imidazole (T_2) application during *Kharif* 2015 at panicle initiation stage

Table 2: Influence of silicon solubilizers on Grain Yield (Kg/ha) of rice genotypes at harvest during *kharif* 2014 and 2015

	Kharif 2014				*Kharif* 2015			
Genotypes	**T_0**	**T_1**	**T_2**	**Mean**	**T_0**	**T_1**	**T_2**	**Mean**
DRRH3(V1)	8583.33	8850.00	9773.33	9068.89	6733.33	7583.33	7993.33	7436.66
PA 6129(V2)	8056.67	9433.33	10456.67	9315.56	5663.33	10910.00	9233.33	8602.22
PA6201(V3)	9201.67	9163.33	9416.67	9260.56	7783.33	8173.00	9236.67	8397.67
PA6444(V4)	8945.00	9013.33	9600.00	9186.11	7166.67	7166.67	7780.00	7371.11
PHB 71(V5)	9943.33	9146.67	10036.67	9708.89	8013.33	8763.33	9353.33	8710.00
BPT 5204(V6)	6876.67	7323.33	8916.67	7705.56	5596.67	6296.67	7196.67	6363.34
CO 39(V7)	5270.56	5786.67	6530.37	5862.53	4886.67	5780.00	6530.00	5732.22
HR 12(V8)	4670.28	5620.12	6278.21	5522.87	4660.00	5063.33	5953.33	5225.56
Mean	7693.44	8042.10	8876.07		6312.92	7467.04	7909.58	
	T	G	T ×G		T	G	T ×G	
SE m ±	91.829	189.729	320.819		38.65	106.87	177.411	
CD (P=0.05)	370.22	543.390	949.616		155.85	306.08	517.96	

Conclusion
Silicon solubilizer treatments showed best performance compared to control imidazole treatment (T_2) maintained higher values compared to silixol treatment (T_1) and, among the genotypes PHB 71(V_5), PA6129 (V_2) and PA6201 (V_3) was superior and HR 12 (V_8) and CO 39 (V_7) recorded lowest values in terms of biochemical parameters and yield under both control and treated conditions.

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